A COMPARISON OF THE HDM-4 WITH THE HDM-III ON A CASE STUDY IN SWAZILAND

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1. INTRODUCTION

The Highway Design and Maintenance Standards Model (HDM-III), developed under the auspices of the World Bank, has been used extensively for the economic evaluation of road projects over a period of approximately 15 years. Over time both the technical relationships and the computer technology used became outdated, and it became necessary to upgrade the Model. The Highway Development and Management Tools (HDM-4) was released early in the year 2000 as a result of this process of upgrading and extension of the HDM-III.

2. PROBLEM STATEMENT

Many road engineers are not yet familiar with the changes implemented in HDM-4, or what the implications in terms of data needs or model output are. A comparison of HDM-III and HDM-4 analyses on a number of case studies will help to provide more insight into the matter.

3. OBJECTIVE

The objective of this paper is to report on three case studies in Swaziland, consisting of the upgrading of gravel road to paved road standard, where both the HDM-III and HDM-4 program packages were used. One case study will be addressed in detail to illustrate the main differences / improvements, while for the other two case studies only a brief project overview and the final results will be provided.

4. OVERVIEW

4.1 HDM-III

The first step towards the development of fully integrated road investment appraisal models for developing countries was made by the World Bank in 1968 when a study was initiated to develop a system of evaluating the effects of construction and maintenance standards on road user costs for low volume roads. From 1973 to 1982 four large field studies were conducted to develop models predicting road deterioration and vehicle operating costs under a variety of circumstances. These were the:

- Kenya study (1) First study to develop relationships for road deterioration and road user costs
- Caribbean study (2,3): Investigated the effects of road geometry on vehicle operating costs
- India study (4): Studied particular operational problems of Indian roads in terms of narrow pavements and large proportions of non-motorised transport
- Brazil study (5): Extended the validity of the model relationships.

In 1987 a comprehensive model known as HDM-III (6), was developed by the World Bank, making use of the above research. As computer technology advanced the World Bank produced a microcomputer version of the HDM-III program known as HDM-95 with the following enhancements:

- HDM-Q incorporating the effects of traffic congestion into the HDM-program (7)
- HDM Manager providing a menu-driven front end to the HDM-III (8).
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The HDM Manager was used for the analysis of the case study.

4.1 HDM-4

4.2.1 Development background

When it was decided to commence with the development of the HDM-4 the technical relationships contained in the HDM-III were more than ten years old. Although much of the road deterioration models were still relevant, there was a need to incorporate the results of the extensive research that had been undertaken around the world in the intervening period. In the case of vehicle operating costs it was recognised that vehicle technology had improved dramatically after 1980, with the result that typical vehicle operating costs could be significantly less than those predicted by HDM-III models. It was therefore realised that there was a need to update the technical relationships to reflect the state-of-the-art. While most of the applications of the HDM-III and other related models have been in developing countries, many industrialised countries began to make use of the model. This resulted in the need for additional capabilities to be included, such as the need to model (9):

- Traffic congestion effects
- Cold climate effects
- A wider range of pavement types and structures
- Road safety
- Road works zone effects on road users
- Environmental effects, consisting of noise, energy consumption and vehicle emissions.

The development of the HDM-4 was undertaken against this background.

4.2.2 Highway management

While the focus with HDM-III was on the economic appraisal of projects, the function of the HDM-4 has been extended also to address the analysis of road management and investment strategies. Table 1 shows a number of HDM-4 applications which have been developed in order to address the information needs of the four road management functions: Planning, Programming, Preparation and Operations (9).

Table 1: Road management functions and the corresponding HDM-4 applications (9)

Management function	Common descriptions	HDM-4 Applications
Planning	Strategic analysis system Network planning system Pavement management system	HDM-4 Strategy analysis
Programming	Programme analysis system Pavement management system Budgeting system	HDM-4 Programme analysis
Preparation	Project analysis system Pavement management system Bridge management system Pavement/overlay design system Contract procurement system	HDM-4: Project analysis
Operations	Project management system Maintenance management system Equipment management system Financial management/accounting system	Not addressed by HDM-4

4.2.3 Structure of the HDM-4

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

The strategy analysis facility is used to analyse a chosen network as a whole, for preparing medium to long range planning estimates of expenditure needs for road development and conservation under different budget scenarios.

The overall structure of the HDM-4 is illustrated in Figure 1. The analysis tools discussed in the previous paragraph, Project Analysis, Programme Analysis and Strategy analysis, operate on core data objects defined in one of four data managers (9):

- HDM Configuration: Defines the default data to be used in the applications. A set of default data is provided when HDM-4 is first installed, but users should modify these to reflect local environments and circumstances.
- Road network: Defines the physical characteristics of road sections in a network or sub-network to be analysed.
- Vehicle fleet: Defines the characteristics of the vehicle fleet that operates on the road network to be analysed.
- Road works: Defines maintenance and improvement standards, together with their unit costs, which will be applied to the different road sections to be analysed.

Technical analysis within the system is undertaken using four sets of models (9):

- RD (Road Deterioration): Predicts pavement deterioration for bituminous, Portland cement concrete and unsealed roads.
- WE (Works Effects): Simulates the effects of road works on pavement condition and determines the corresponding costs.
- RUE (Road User Effects): Determines costs of vehicle operation, road accidents and travel time.
- SEE (Social and Environmental Effects): Determines the effects of vehicle emissions and energy consumption.

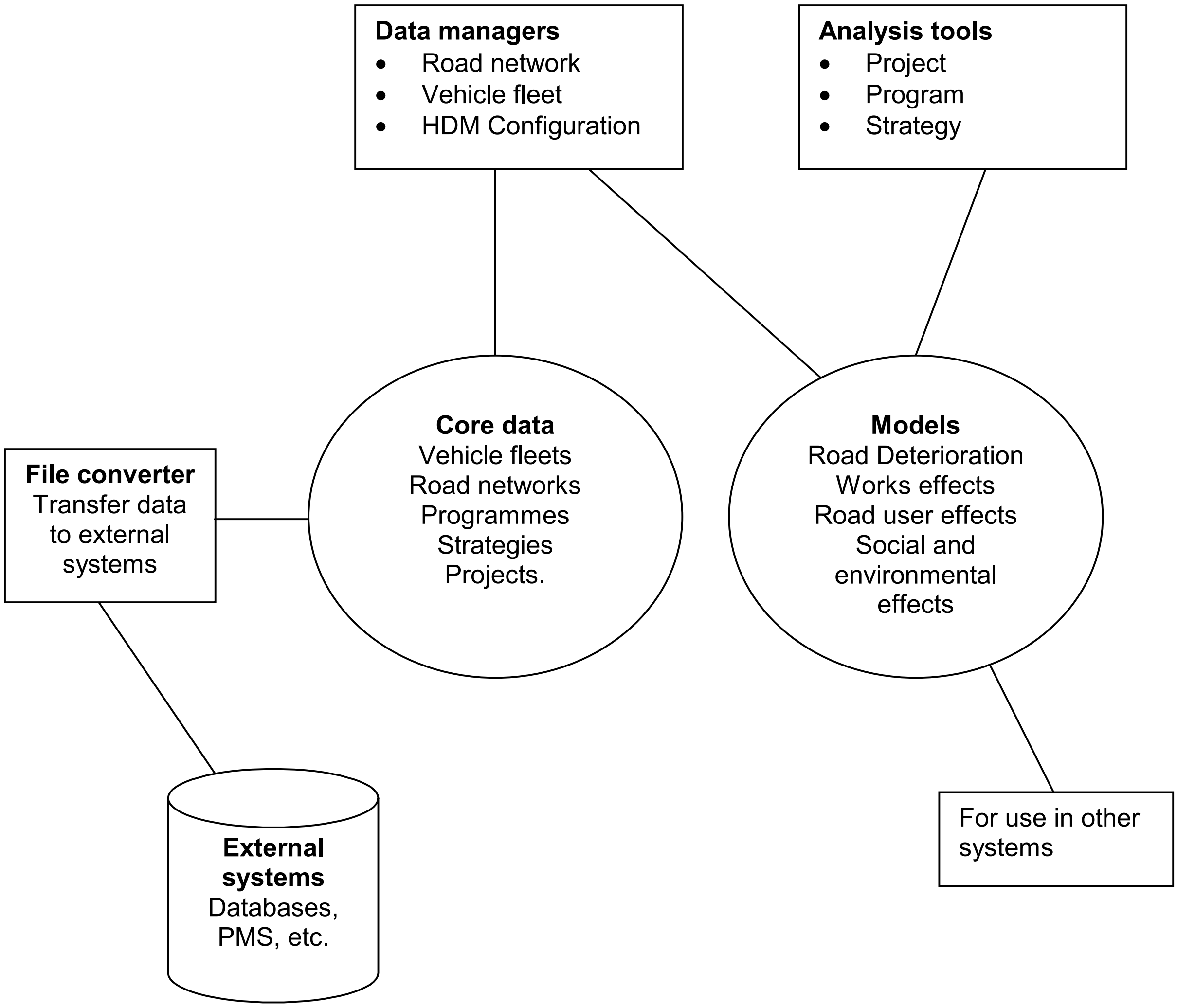

Figure 1: HDM-4 system architecture (9)

These models are detailed in the Technical Reference Manual (9).

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

- Databases: Road network information systems, pavement management systems, etc. through Import/Export of intermediate files
- Technical models: Accessed directly by external systems for research applications or other studies.

5. CASE STUDIES

5.1 Location and land-use

The case study to be addressed in detail is the MR14 route in the south-eastern part of Swaziland (Refer to Figure 2). The existing road is a gravel road stretching from Nsoko on *MR8: Big Bend to Lavumisa border post*, to Maloma. A mine producing high-quality anthracite, Maloma Colliery Limited, is situated close to Maloma and generates significant heavy traffic due to the transporting of anthracite to the railway station close to Nsoko. Apart from the mine the general land-use pattern is low density rural agriculture. Besides Nsoko and Maloma, there are two other rural settlements along the road.

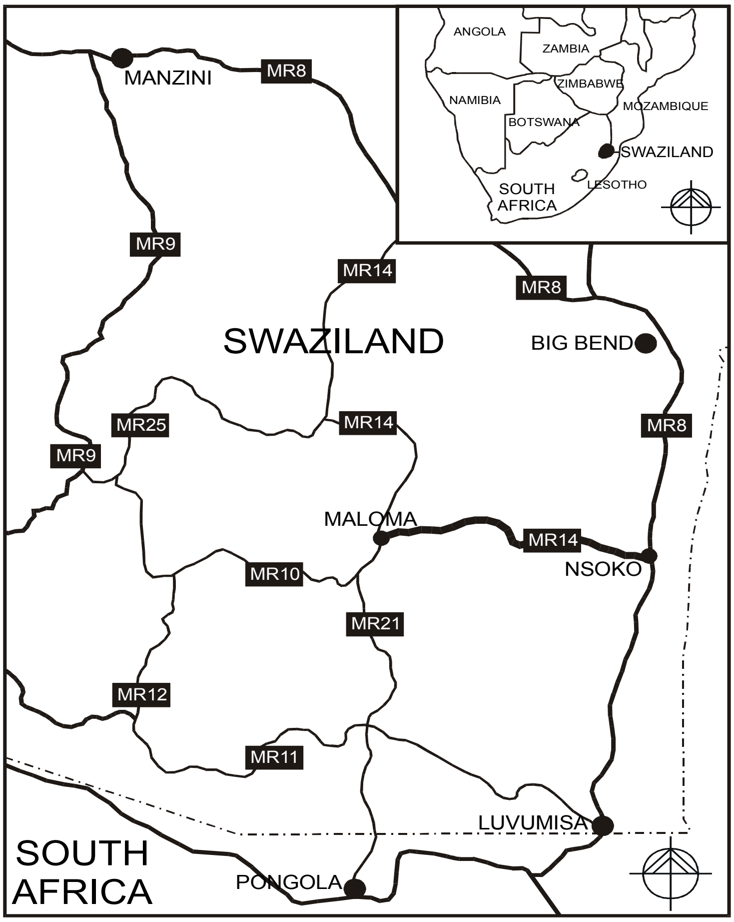

Figure 2: Locality map: MR14

The second case study is route MR20, a gravel road stretching from Bulembu on the South African border to Piggs Peak on route MR1, at total length of 20,1 km (Refer to Figure 3). This road traverses mountainous terrain and is considered to have considerable tourism potential because of the beautiful scenery along the route. The road mainly serves a mine, the Bulumbu mine, intensive forestry activity and a rural settlement. The current ADT is 212 vehicles. The motivation for considering the paving of this road is that it forms the central axis of a future tourism corridor planned for the area. For this reason a relatively high value of 1,7 times current traffic has been used to calculate generated traffic. The construction cost of the road is estimated at 2,2 million Emalangeni (E)/km, and will be determined more accurately once the design of the road has been completed. The Swaziland monetary unit, the Emalangeni (E), has the same value as the South African Rand. The road is situated in a remote, and the traffic volume is relatively low, a blading interval of 60 days has consequently been used for the analysis.

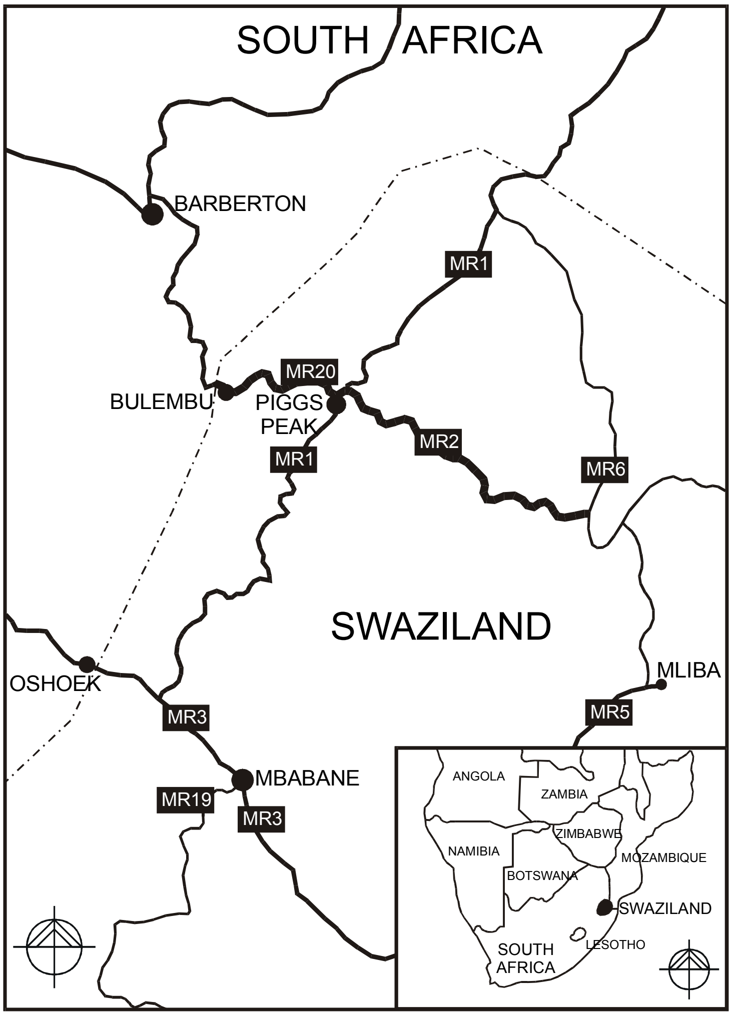

Figure 3: Locality map: MR2 and MR20

The third case study is route MR2, which is an eastward extension of route MR20 (shown on Figure 3). This gravel road is 36,9 km long, and carries an ADT of 279 vehicles. This road serves as a link road between Routes MR1 and MR6, and gives access to a saw mill and various rural communities. This road also forms part of the tourism corridor discussed above, and generated traffic has been taken as 1,25 times current ADT. The estimated construction cost is E 1,8 million/km. The cost will be determined more accurately during the design phase of the road. A blading interval of 30 days has been assumed for the analysis.

The data and analysis discussed below refer to MR14. MR20 and MR2 are referred to again in Section 7.4 (Table 8), where the economic indicators produced by HDM-III and HDM-4 are compared with one another.

5.2 Traffic

Road MR14 is 31 km long and has an undulating alignment. The average daily traffic (ADT) on the existing gravel road is 305 vehicles. Table 2 shows the composition of the traffic stream and the average vehicle occupancy figures.

Table 2: Traffic composition (MR14)

Vehicle class	Percentage	Vehicle occupancy
Cars	12,8	2,5
Light delivery vehicle	50,8	10,2
Combi-Taxi	5,9	3,2
Bus	4,6	48,0
Light truck	4,6	2,9
Medium truck	3,3	4,9
Heavy truck	17,4	1,8
Articulated truck	0,6	1,5
TOTAL	100,0	

The future traffic growth has been estimated as 6 % per year over the analysis period of 20 years. It was estimated that generated and diverted traffic after completion of the construction project will amount to 25 per cent of the traffic volume at that stage.

5.3 Maintenance and construction cost

Unit costs for maintenance were obtained from the Ministry of Public Works and Transport, Swaziland, and are shown in Table 3. Financial costs are shown because these are the values that are commonly used. As is discussed in Section 6.2.2, however, economic costs are used in the analysis.

5.4 Geometric design

The proposed road, MR14, will be a paved road and will consist of two lanes of 3,7 m each. The shoulders will each be 2,0 m wide of which 1,7 m will be paved.

5.5 Pavement design

The proposed pavement for road MR14 consists of:

- 40 mm asphalt wearing course
- 150 mm crushed stone base
- 150 mm stabilised subbase
- 150 mm selected sub-grade layer

The average in-situ CBR is 18 per cent.

5.6 Construction

Construction is planned to start in 2001, and the estimated duration is 18 months (Taken as 24 months for the purpose of the economic evaluation).

Table 3 Maintenance and construction costs

Maintenance action	Unit	Financial unit cost (Emalangeni)
Unpaved road maintenance		
Grading	Km of road bladed	395
Spot regravelling	Cubic metre	50
Gravel resurfacing	Cubic metre	42
Unpaved routine maintenance	Cost / km / year	5 000
Paved road maintenance		
Patching	Cost / square metre	139
Resealing	Cost / square metre	12
Overlay	Cost / square metre	30
Reconstruction	Cost / square metre	100
Routine maintenance	Cost / km / year	10 000
Construction		
New road construction (MR14)	Cost / km	1 370 000

5.7 Pavement deterioration

Certain work has been done in South Africa on pavement deterioration factors (10). For the HDM-III analysis a factor of 0,9 has been used for the roughness-age term, 0,8 for structural cracking progression, and 1,0 for the other deterioration factors. HDM-4 makes provision for a number of calibration factors related to surface distress, structural defects, roughness and drainage. Compared to HDM-III, HDM-4 does not use the roughness-age term as such, and a distinction is made between "all structural cracking" and "wide structural cracking". In the absence of guidelines for HDM-4 calibrations factors, a value of 1,0 was assumed for all calibration factors for purposes of the analysis.

6. MODELLING

6.1 Perspective

The application of the two models on a case study cannot provide a comprehensive comparison of the models. It is believed, however, that the comparison on a case study will contribute to an understanding of the improvements achieved.

For the HDM-III option the HDM-Manager has been used. For the HDM-4 option the first version, Version 1.0, has been used. Known problems up to 19 April 2000, as published on the HDM-4 website, were taken into account.

6.2 Data requirements and collection: HDM-III

The data requirements are not discussed in detail because of the sheer volume. The key issues are, however, highlighted.

6.2.1 Analysis period and discount rate

An analysis period of 20 years and a discount rate of 10 per cent were used.

6.2.2 Shadow pricing

For an economic feasibility analysis it is required that the project be evaluated at prices that reflect the relative scarcity of inputs and outputs. Such prices should reflect the actual economic value of inputs and outputs and are commonly known as the opportunity costs of the elements of the project. In practice, where the market prices of products or services do not reflect their scarcity value, such products or services are valued by means of shadow prices. A shadow price factor of 0,78 was used for the case study.

6.2.3 Vehicle characteristics

Vehicle characteristics such as Gross Vehicle Mass, Equivalent Standard Axles per vehicle, number of axles and number of tyres, service life, vehicle utilisation and depreciation, new vehicle and tyre prices, and fuel prices were based on data surveys done for Swaziland.

6.2.4 Value of time

The approach followed to determine the value of time is based on the Gross - output method. This method assumes that every individual contributes equally to the Gross Domestic Product (GDP) (at market prices). For a given year the value of time is therefore calculated as the GDP per capita. The value of time for Swaziland was determined as E4,41 per person per hour.

6.2.5 Savings in road accidents

HDM III does not generate the savings in accidents brought about by road improvements. For the case study accident savings were calculated separately, and were taken into account as Exogenous Benefits. For the purpose of this paper, however, accident savings have been ignored as the same values would be used for the HDM-III and HDM-4 analyses. This would not contribute to the comparison made between the models, except that the economic indicators would be improved in both cases.

6.2.6 Road maintenance strategies

For unpaved roads the following strategies were selected (in terms of the HDM-III input):

- Routine maintenance
- Grading: Scheduled strategy consisting of blading the road once in 30 days
- Regravelling when the gravel thickness falls below 50 mm.

And for paved roads:

- Routine maintenance
- Patching: Responsive strategy, that is all potholes are attended to once they have formed
- Overlay: Scheduled option – a new overlay after 10 years.

6.3 Additional data requirements: HDM-4

As was stated earlier, HDM-4 has a wider application than HDM-III. Consequently HDM-4 also requires more input data than HDM-III. The additional data needs are as follows:

6.3.1 Use of data sets

HDM-4 has a flexible approach as it makes use of the concept of data sets. These data sets are defined separately from the project being analysed, and has the benefit that the same data set could be used for more than one project. Examples of such data sets are:

- Definition of the existing road network
- Vehicle fleet characteristics
- Maintenance strategies
- Improvement strategies.

6.3.2 Road network characteristics

HDM-4 makes provision for the standardisation of datasets relating to road class, traffic flow patterns, speed flow types, climate zones, pavement types and material properties. Table 4 shows some examples.

Table 4: Standardisation of road network datasets

Characteristic	**Example of pre-defined datasets**
Road class	Primary or Trunk Secondary or Main Tertiary or local
Traffic flow pattern	Free-flow Inter-urban Seasonal
Speed flow type	Single lane road Two lane road standard Two lane road wide Four lane road
Climate zone	Sub-humid / tropical Humid / tropical Tropical semi arid
Pavement types	Unsealed Bituminous Concrete Block
Material properties	Quartzitic gravel Well-graded gravel-sands with small clay content Clays (inorganic) of high plasticity

6.3.3 Vehicle fleet

While HDM-III Manager makes provision for seven pre-determined vehicle classes, the user can define an own spectrum of vehicle classes in HDM-4. HDM-III Manager does, for example, not make provision for combi-taxi's as encountered in southern African countries. Although combi-taxi's were included in the analysis, this vehicle class was not used separately in the analysis, combi-taxi volumes were included in the light delivery vehicle class.

HDM-4 makes provision for the inclusion and analysis of non-motorised transport (animal carts, pedestrians and bicycles). Non-motorised transport was, however, not used in the case study.

With regard to tyres HDM-4 makes provision for retread options which is customary in Swaziland.

HDM-4 makes provision for the private use of all vehicle types. The influence of this was not taken into account in the case study.

6.3.4 Value of time

With regard to the value of time HDM-4 distinguishes between working time and non-working time. As the value of time has been determined as the GDP per person per working hour, this value was used for working time, while non-working time was taken as having zero economic value.

6.3.5 Road alignment and travel speed

The following additional data is required for road speed calculations:

- Number of rises and falls (apart from the rise-and-fall parameter)
- σ^{adral} : Acceleration "noise" due to driver behaviour and road alignment
- Speed limit enforcement parameter
- Speed reduction factors:
  - XNMT: Speed reduction of motorised transport due to non-motorised transport
  - XMT: Speed reduction of non-motorised transport due to motorised transport
  - Road side friction (as with HDM-III).

6.3.6 Road cross-section

The carriageway, shoulders and lanes for non-motorised transport are defined separately, and maintenance and improvement options can be applied to any one, or a combination of these.

6.3.7 Road improvement options

Probably one of the most significant improvements of HDM-4 is that it allows for a much wider range of road improvement options. The options include:

- Paving of an unpaved road (as before)
- Lane additions
- Non-motorised transport lane addition or upgrading
- Re-alignment
- Partial road widening
- Pavement reconstruction.

6.3.8 Paved road maintenance options

Paved road maintenance options have also been extended to include:

- Resurfacing
- Edge repair, patching and crack sealing
- Drainage maintenance
- Other routine maintenance

With regard to resurfacing provision has been made for a wider range of options, which include:

- Rejuvenation and fog seal
- Cape seal and cape seal with shape correction
- Surface dressing consisting of a single seal, with or without shape correction
- Surface dressing consisting of a double seal, with or without shape correction
- Slurry seal
- Overlay consisting of dense-graded, open-graded or rubberised asphalt
- Mill and replace.

6.4 Analysis

Both models have been set up and run, using the same data where possible. As discussed above, HDM-4 required more data than HDM-III.

7. MODELLING RESULTS

7.1 Deterioration

Figure 4 compares the road roughness for the base case and the upgrading option of paving the road (MR14).

From Figure 4 follows that:

- For the unpaved road option the improvement in road condition after regravelling is significantly more with the HDM-4 model than is the case with the HDM-III model (resulting in the “dips” every five years on Figure 4).
- Once a balance between road condition and blading frequency has been established again (that is some time after regravelling), the roughness results produced by the two models are similar.
- For the HDM-III model an overlay was scheduled at a 10-year interval. The model applied this maintenance action at the start of the year 13 (2012), which is in the authors’ opinion not correct. (Paved road maintenance commenced in year 4 (2003).) In the HDM-4 model a thin overlay was also specified with a time interval of 10 years. The model applied this maintenance action at the start of year 14 (2013). This approach is, in the authors’ opinion, the correct approach, as resurfacing takes place exactly 10 years after the start of paved road maintenance.
- The effect of the overlay in the case of the HDM-III is to improve the road condition (in terms of IRI) to a level better than when the road was new, which is not realistic. In the case of the HDM-4 model the road condition after the overlay is improved, but not to the same level as when the road was new, which is a more realistic approach.
- The combined effect of traffic, climate and routine maintenance acting on the road is similar for both models, as the HDM-III road deterioration models were used for HDM-4.

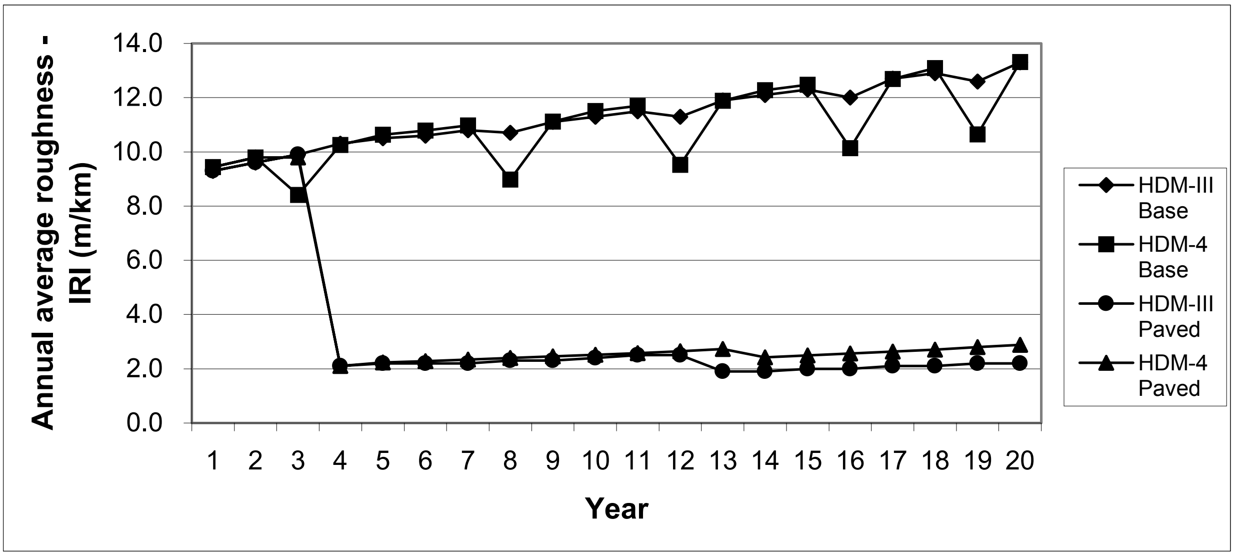

Figure 4: Comparison of roughness for the base case and the upgrading option

7.2 Road user effects

As was stated before one of the significant improvements addressed in HDM-4 was to update the model for the characteristics of modern day vehicles. In Table 5 vehicle operating costs are compared for the various vehicle types for the year 2000 (current unpaved road) and 2003 (the first year after completion of construction of the paved road). In Table 6 the annual average speeds are compared for the various vehicle types. From Tables 5 and 6 follow that:

- Vehicle operating costs (which include crew time, but exclude passenger time cost) produced by HDM-4 are for the unpaved road option considerably lower than those produced by HDM-III. The weighted average per vehicle produced by HDM-4 is E 2,84/km, compared to E 3,58/km for HDM-III, a reduction of 20,7%.
- Vehicle operating costs produced by HDM-4 for the paved road option are, however, on average only 7,5% lower than the values produced by HDM-III (weighted average per vehicle in the case of HDM-4 is E 2,09/km, and in the case of HDM-III E 2,26/km).

These results should be assessed by taking into account average speeds as shown in Table 6:

- For the unpaved road option the weighted average speed for all vehicles produced by HDM-4 is 13,0% higher than produced by HDM-III.
- For the paved road option, however, the weighted average speed of HDM-4 is 37,7% higher than that of HDM-III.

Table 5: Comparison of vehicle operating costs

Vehicle type	Vehicle operating costs (including crew-, but excluding passenger time cost) (E/km)					
	Year 2000: Unpaved road			Year 2003: Paved road		
	HDM III	**HDM-4**	**% Diff**	**HDM III**	**HDM-4**	**% Diff**
Car	2,30	1,77	-23,0	1,49	1,30	-12,8
Light del. veh. (LDV) #	2,39	1,72	-28,0	1,45	1,30	-10,3
Bus	4,89	4,59	-6,1	3,49	3,10	-11,2
Light truck	4,33	3,52	-18,7	2,65	2,46	-7,2
Medium truck	5,53	4,70	-15,0	3,37	3,37	0,0
Heavy truck	7,10	6,05	-14,8	4,58	4,46	-2,6
Articulated truck	13,39	9,52	-28,9	9,37	6,63	-29,2
Weighted average	**3,58**	**2,84**	**-20,7**	**2,26**	**2,09**	**-7,5**

 # Note that the term Pickup is being used in HDM-III for a LDV, and the term Light Goods Vehicle in HDM-4

Table 6: Comparison of annual average speeds

Vehicle type	Annual average speeds (km/h)					
	Year 2000: Unpaved road			Year 2003: Paved road		
	HDM III	**HDM-4**	**% Diff**	**HDM III**	**HDM-4**	**% Diff**
Car	65,5	65,2	-0,5	84,2	109,7	30,3
Light deliv. veh. (LDV)	58,8	65,2	10,9	78,4	109,5	39,7
Bus	51,1	51,7	1,2	68,6	74,9	9,2
Light truck	50,0	56,6	13,2	66,2	82,1	24,0
Medium truck	45,9	57,5	25,3	64,0	81,3	27,0
Heavy truck	42,0	58,4	39,0	57,1	86,8	52,0
Articulated truck	32,6	44,6	36,8	49,3	69,7	41,4
Weighted average	**55,4**	**62,6**	**13,0**	**73,8**	**101,6**	**37,7**

From the above it follows that with the relative low difference in speeds predicted by the two models for unpaved (poorer quality) roads, the vehicle operating cost difference between the models are quite significant (due to the adjustment of models for improved efficiency of modern vehicles). On paved (good quality) roads, however, the difference in speed predicted is much higher. Because of phenomena of increased vehicle operating cost with increased speed, part of the difference in costs between the outputs of the two models is "lost" because of the large increase in speed. In other words, one would expect that at the same operating speed the HDM-4 model would have shown a more significant reduction in vehicle operating cost, compared to HDM-III. This expectation was tested with the HDM-4 model. The speed limit for the paved road option was reduced from 120 km/h to 80 km/h. The weighted average speed predicted decreased from 101,6 km/h to 82,9 km/h (compared to the 73,8 km/h of HDM-III). The weighted vehicle operating cost, however, changed only slightly from E 2,09/km to E 2,08/km (compared to the E 2,84 of HDM-III). One would expect this reduction in operating cost to be more significant, and the matter warrants further investigation. (The effect on the internal rate of return of the project was to reduce it from 20,6% to 19,6%.).

7.3 Cost streams

Figure 5 compares the capital and recurrent cost streams as determined by HDM-III and HDM-4 for the base case, the existing gravel road (MR14). Figure 6 does the same for the upgrading alternative.

For the base case there is a difference in the cost of regravelling. The reason for this is that the HDM-III assumes a fixed increase in gravel thickness, 150 mm in this case, when regravelling is warranted, while HDM-4 uses an approach of restoring the thickness of the gravel wearing course to the specified thickness (200 mm in this case). The intervention criterion for the activation of regravelling is when the gravel thickness falls below 50 mm (for both models). Apart from this it appears as if gravel loss is more severe in the HDM-III model.

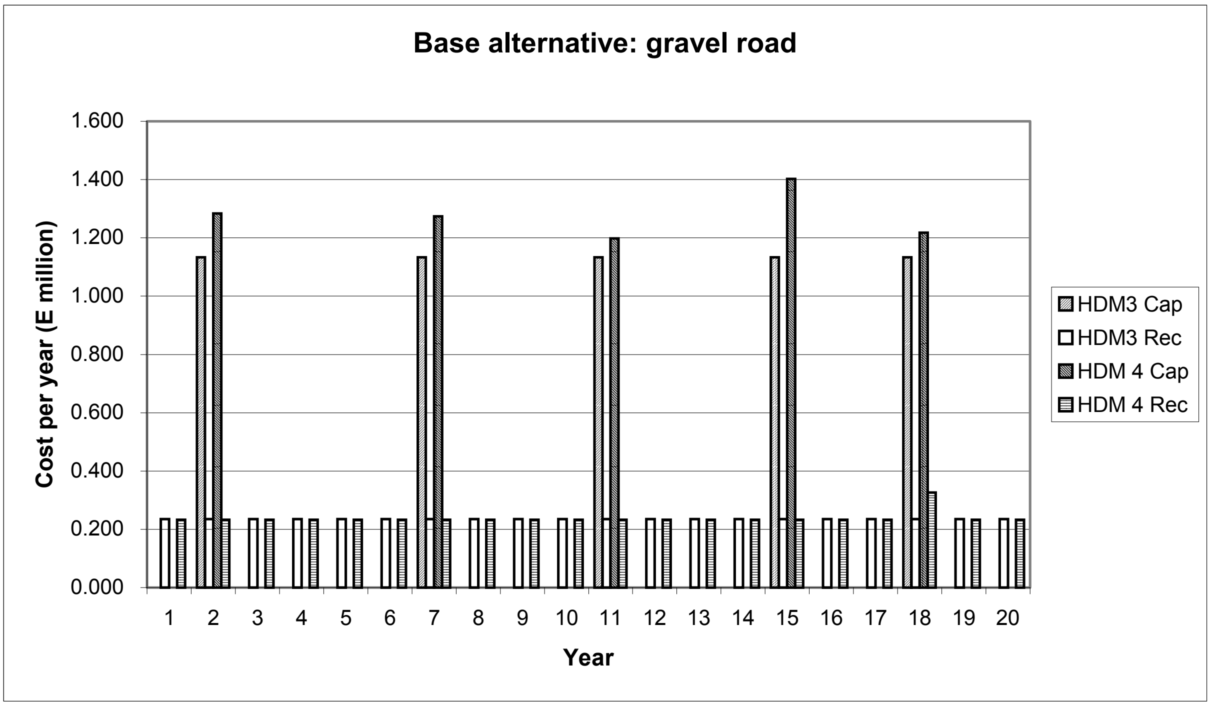

Figure 5: Comparison of capital and recurrent costs for the base case, the existing gravel road (MR14)

The construction costs and the recurrent maintenance costs are similar for both models, showing that the deterioration characteristics are similar.

With regard to routine maintenance costs it is of particular interest that where HDM-III uses a cost per year per kilometre, HDM-4 uses a cost per year for the total road project. The reason for this change is not clear, and will probably create some confusion with the use of the model.

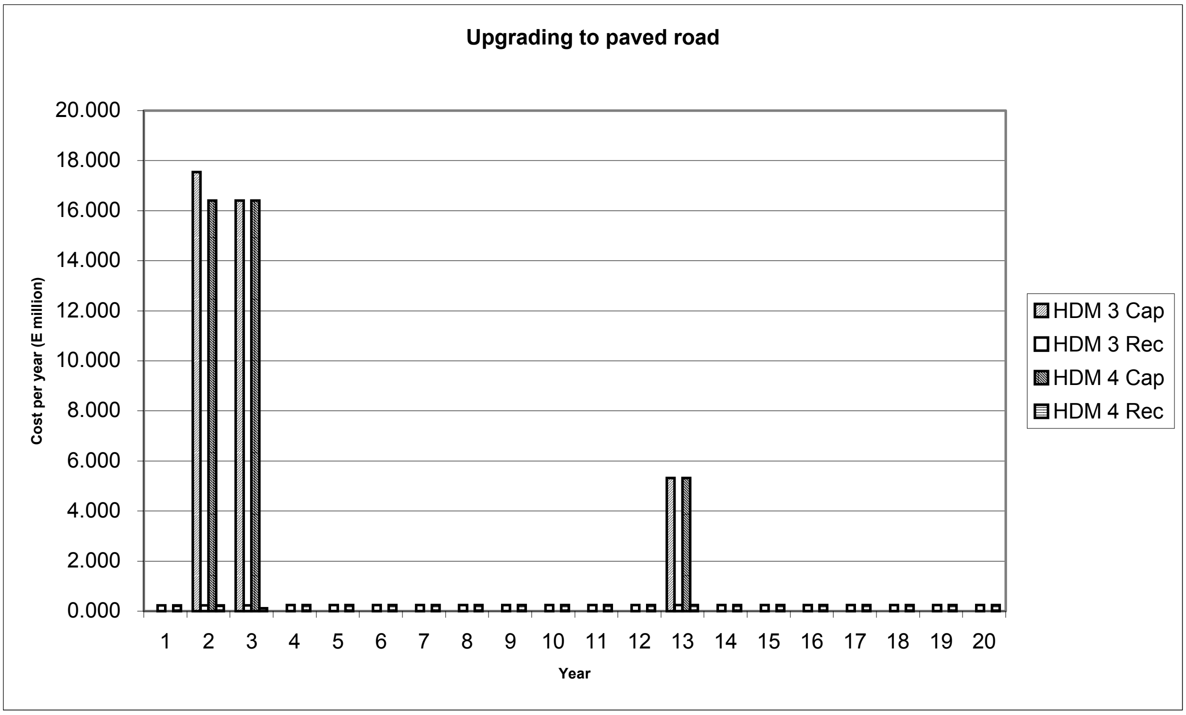

Figure 6: Comparison of the capital and recurrent costs for the upgrading alternative

Version 1,0 of HDM-4 does not make provision for the residual value of the road project at the end of the analysis period. This value has thus been taken as zero in the HDM-III model. It is well-known that this value has a minimal influence on the justification of a capital project under normal circumstances. There will be cases, however, where it will be necessary to take residual value into account, and apparently the necessary provision will be made in Version1.1 of the model for this.

7.4 Economic indicators

Table 7 compares the Present Value of costs and benefits as produced by the two models (at a 10% discount rate) for MR14. One should remember that the addition of generated traffic in the case of the construction of a paved road distorts the figures somewhat. The benefit experienced by generated traffic is taken as half of the savings of the existing traffic (expressed per vehicle). The cost and benefit components shown in the table can therefore not just simply be added to produce the total values.

The increase in road agency cost is similar for the two models, as was to be expected from the cost stream analysis. However, benefits of the project (decrease in road user cost) are much lower in HDM-4 than in HDM-III. This is mainly due to the lower vehicle operating costs resulting from the increase in vehicle efficiency from the time that the HDM-III sub-models were developed to the time when these models were re-calibrated and incorporated into HDM-4 (especially at lower speeds and poor road conditions as discussed above). More significant travel time savings are achieved with the HDM-4 models due to the higher operating speeds predicted by this model.

Table 7: Comparison of present value of costs and benefits (MR14)

Description	Present Value (E million)		Difference (%)
	HDM-III analysis	HDM-4 analysis	
Agency capital cost*			
Alt 0: Base case	2,63	2,96	+12,5%
Alt 1 Paved road construction	31,20	30,17	-3,3%
Agency recurrent cost			
Alt 0: Base case	2,20	2,20	0,0%
Alt 1: Paved road construction	2,23	2,13	-4,5%
Total increase in road agency cost	28,61	27,14	-5,1%
Vehicle operating cost			
Alt 0: Base case	197,36	167,44	-15,2%
Alt 1 Paved road construction	147,97	146,23	-1,2%
Travel time cost			
Alt 0: Base case	19,83	19,08	-3,8%
Alt 1 Paved road construction	17,45	14,68	-15,9%
Total decrease in road user cost	87,13	57,15	-34,4%
Net Present Value	58,52	30,01	-47,8%

7.5 Comparison of economic indicators for the three case studies

Table 8 compares the benefit-cost ratio (B/C), internal rate of return (IRR) and the net present value (NPV) as produced by the two models for the three case studies. These indicators are all lower for HDM-4 than for HDM-III as a result of the reduction of benefits as discussed above.

Table 8: Benefit-cost ratio, internal rate of return and net present value

Description	MR14		MR2		MR20	
	HDM-III analysis	HDM-4 analysis	HDM-III analysis	HDM-4 analysis	HDM-III analysis	HDM-4 analysis
Benefit-cost ratio	3,05	2,11	1,92	1,17	1,43	0,72
Internal rate of return	27,7%	20,6%	20,7%	12,2%	15,5%	5,6%
Net present value (E million)	58,5	30,0	36,3	6,5	11,4	-7,5

With regard to project justification the client requires a minimum IRR of 10% before taking a decision to continue with implementation. Based on the HDM-III analyses all three case study projects are justified. The justification of MR14 and MR 2 are not influenced by the HDM-4 analysis, but MR20 is no longer economically justified when analysed by HDM-4. If MR2 and MR20 are combined into one project, however, the joint B/C ratio is 0,98, and the IRR is only slightly below 10%, meaning that the combined project is justified.

8. CONCLUSIONS AND RECOMMENDATION

The most important conclusions to be drawn from the above comparison are:

- HDM-4 has been written in a modern-day, Windows-based programming style, compared to the DOS-base HDM-III. It is flexible and relatively easy to use.
- Although not used for the case study, HDM-4 offers a wide range of analysis options in that strategic and programming level analyses can be addressed over and above the normal project level analysis.
- HDM-4 has a flexible approach towards the definition of the vehicle fleet, which makes it more versatile.
- HDM-4 makes provision for a much wider range of upgrading options, pavement types, seal types and other maintenance options. The options previously offered have also been updated to better reflect modern-day terminology and practice.
- With regard to the sub-models the most important effect is the lowering of vehicle operating costs and the increase in travel speed which resulted from the fact that the models have been adjusted for the increase in the efficiency of motorised vehicles over the last 30 years.
- As a result of the last mentioned aspect HDM-4 produced lower values for the benefit-cost ratio and internal rate of return of the case studies. When compared to the justification level this reduction did not influence the economic viability of MR14 and MR2, but did result in the upgrading of MR20 no longer to be justified.

Based on the experience with HDM-4 on the case study this package can be recommended for use in southern Africa.

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A COMPARISON OF THE HDM-4 WITH THE HDM-III ON A CASE STUDY IN SWAZILAND

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