EVALUATION OF ROAD TRANSPORT INVESTMENT PROJECTS IN DEVELOPING COUNTRIES

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1. INTRODUCTION

1.1 Problem statement

Most Developing Countries have been allocating large sums of money both in absolute and relative terms, for the improvement and upgrading of their road systems. The reason for this is a widespread belief in the relationship between transport improvements and development. However it has been shown in the past, that such a relationship is not always true. Wilson (1) in this regard concluded that transport investment is no more an initiator of growth than any other form of investment or deliberate policy. Bejakovic (2) in a separate study concluded that there was no evidence of a positive relationship between the proportion of gross fixed investment in transport infrastructure and the subsequent rate of economic growth. In addition there is a serious competition for scarce resources between maintenance of existing network and investment in new alignments. Whatever policy is adopted there is still a question of what is the optimum strategy. To address these issues two models have been developed which are capable of determining life cycle costs of various investment strategies.

1.2 Computer Models

THE HIGHWAY DESIGN AND MAINTENANCE STANDARDS MODEL (HDM3) (3) is a computer model for engineering economic analyses of alternative highway design, maintenance and upgrading strategies in feasibility studies and highway sector planning. It was developed by the World Bank and is curently being employed by various governmental agencies and consultants in planning highway projects and maintenance programs in several developing countries. The ROAD TRANSPORT INVESTMENT MODEL (RTM2) (4) is also a computer model designed to aid investment decision within the roads sector in developing countries. It was developed by Transport and Road Research Laboratory in the U.K to assist engineers and planners in making decision for road investment.

1.3 The Songea-Makambako Road

The Songea-Makambako road is located in southern Tanzania as shown in figure 1. It is a 295 km two lane single carriageway road, with 6.0m carriageway width a 1.2m unpaved shoulders. Table 1 summarises the most important characteristics of the road. The road was built to standards which minimised construction costs but called for relatively high levels of maintenance. It was opened to traffic in 1983, but by 1987 it started to show cases of gradual deterioration of the base material in most sections.

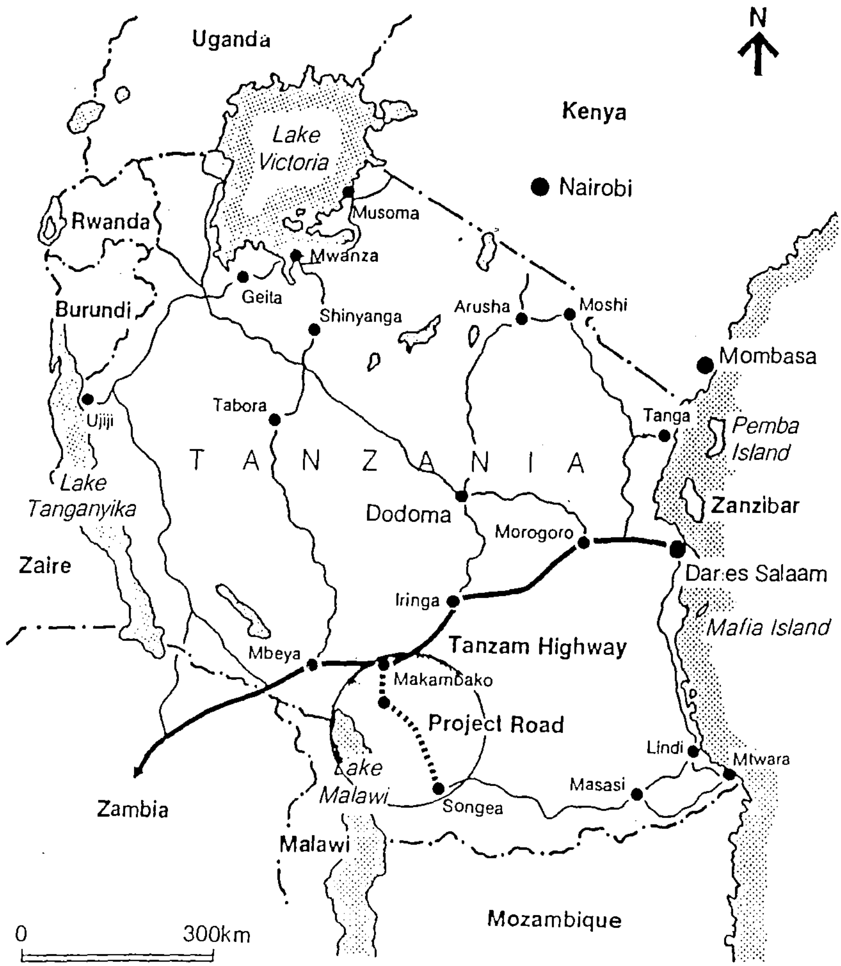

Figure 1 Location of Songea-Makambako Road Project, Tanzania

Table 1 Road characteristics of the Songea - Makambako road

Pavement layer	Makambako-Higafilo	Higafilo-Songea
Surfacing	Double seal 10mm on 19 mm chippings	Single seal. 14 mm chippings
Base	200mm thick, lime stabilised gravel CBR > 80	150mm thick, lime or cement stabilised gravel CBR > 80
Sub-base	100mm natural gravel CBR > 25	100mm natural gravel, CBR > 25
Subgrade	CBR > 10	CBR > 10

1.4 Study objective

In this study, two road links each 20 km long have been selected from the central section of the road for analysis using HDM3 and RTM2. For this purposes various parameters from these links, including enviromental conditions, alignment, pavement construction details, traffic characteristics and road maintenance options were input in both the HDM3 and RTM2 computer models for analysis. The objective of the analysis is to obtain a combination of maintenance standards (maintenance strategies) which when applied to the road results in minimum total costs to society.

2.0 INPUTS FOR ANALYSIS

2.1 Description of road links

According to HDM3 model, a link is a road segment with a given traffic volume. Segments with different traffic volumes form different links for analysis. In HDM3 model, a link can contain up to ten sections of road with different design standards and environmental conditions. All links considered in the study are analysed in a single computer run. RTM2 model analyses one road section at a time, and for a two section link two separate analysis have to be made and the results added together.

2.2 Geometric Characteristics

The details and length of each road section in the two links are shown in table 2. The width of the paved road for all sections is 6.0 m and the unpaved shoulders of 1.2 m each. The horizontal and vertical aligment details were calculated from the as-built drawings for the road and are as shown in table 2.

Table 2 Summary of links and road section characteristics

	LINK 1		LINK 2	
	Section 1	Section 2	Section 3	Section 4
Length (km)	10	10	10	10
Altitude m.a.s.l	1200	1200	850	850
Rainfall mm/year	1155	1155	1155	1155
Terrain	Mountain.	Mountain.	Flat/ rolling	Flat/ rolling
Rise+fall m/km	70.26	54.46	26.75	59.18
Curvature deg/km	196.90	75.31	62.54	83.46
Traffic ADT vpd	135	135	125	125
Roughness mm/km	2340	2400	2425	2340
Base mm	150 lime-stab.	150 lime-stab.	150 cement-stab.	150 cemet-stab
Subbase mm	100 gravel	100 gravel	100 gravel	100 gravel
C'way width m	6.0	6.0	6.0	6.0
Unpaved shoulder m	1.2	1.2	1.2	1.2
Mod. Struct. No.	2.5	2.7	3.0	4.0

2.3 Surface roughness

A pavement roughness survey was carried out in November 1987 for the entire road. A vehicle mounted Bump Integrator was used and the readings were taken at as near as possible to a constant speed of 32 Km/hr. Table 2 shows the roughness values for the links under consideration.

2.4 Pavement strength

Both HDM3 and RTIM2 models incorporate relationships for prediction of surface roughness of the road and the amount of cracking (plus patching for RTIM2). HDM3 predicts rutting, ravelling and potholing as well. All three characteristics are mainly functions of cumulative number of equivalent standard axles and strength of the pavement in terms of modified structural number (SNC). A geotechnical survey of the road was carried out, to evaluate the structural conditions of the pavement. Modified structural numbers for different pavement sections were calculated from the World Bank s HDM3 formula for cement stabilised bases:

$$SNC = 2.2 \text{ X deflection}^{(-0.63)} \quad (1)$$

2.5 Traffic

Traffic data used in the analysis was obtained from the surveys carried out every year. For purpose of analysis, seven vehicle types have been used as shown in table 3. Total traffic flows at the beginning of analysis for link 1 under medium traffic case is 135 veh/day and for link 2 is 125 veh/day. Traffic growth has been predicted at 8% per annum up to year 1992 for the medium traffic case, 12% per annum for high traffic case and 6% per annum for low traffic. Percentage growth rate beyond 1992 has been asumed to be half the initial growth for all traffic cases. In the year 1992 incremental traffic of up to 45 veh/day has been estimated from the proposed coal and iron ore development project near Madaba.

Table 3 Summary of vehicle fleet characteristics

Name	Car	Light truck 1	Light truck 2	Med. truck 1	Med. truck 2	Med truck 3	Bus
Veh.type	1	3	3	5	5	5	6
Fuel	Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Typical Veh.	Peog. 504	L/Rover	L/Rover	Isuzu 7 ton	Scania 112 single	Scania 112 artc.	Scania 65 seater
Price mill.Tsh	1.5	3.271	3.271	6.667	10.0	13.333	10.50
GVW		1.9	1.9	14	20	30	12
ESA(exp 4)	0	0	0	1.13	5.5	10.0	2.5
No. of axles	2	2	2	2	3	5	2

Table 4 shows traffic figures and growth rates used in the analysis. No "generated" traffic has been considered since there are no major route improvements involved in the analysis. Traffic axle loadings for each vehicle type used in the analysis were taken from the axle load surveys of 1985, 1986 and 1987. Table 3 shows the values of axle equivalent factors used. Financial and pretax vehicle prices (1987 prices) for typical passenger car, light goods vehicle, typical bus and trucks were obtained from Ministry of Communications and Works in Dar es Salaam. Percentage foreign exchange component of vehicle prices was estimated as 90% of untaxed price for passenger car and light goods vehicles, and 75% for commercial trucks and buses. Other prices were obtained from various sources and are shown in Table 3 in Tshs. (x 1000).

Table 4 Traffic Volumes and growth characteristics

Period	Type	Car	LGV1	LGV2	MT1	MT2	MT3	BUS
1988-1988	Fixed	1.0	26.0	26.0	51.0	15.0	10.0	6.0
1989-1991	% growth	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1992-1992	inc.growth	2.0	3.0	3.0	20.0	10.0	5.0	2.0
1993-2003	% growth	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Total traffic = 135 veh/day

2.6 Road maintenance costs

Unit costs for road maintenance operations have been estimated from the Ministry s maintenance unit. Other unit rates e.g. bituminous overlay were derived from estimates made in 1984 by Howard Humphreys and Partners for the SongeaMakambako Road Maintenance study (5) and adjusted using price indices (6) to get estimates of 1987 prices. Table 5 summarises unit maintenance costs for various maintenance operations.

Table 5 Unit Maintenance Costs (Tshillings)

Maint. Operation	Economic	Financial	Forex % (economic)
Routine per km/yr	22100	23400	37
Resealing per m2	440	480	50
Bituminous overlay/m2	1690	1860	56
Cement stab.overlay/m2	950	1050	40
Patching per m2	1300	1400	48

2.7 Foreign Exchange

The conversion factor for Tanzania shilling to US Dollars and vice versa, applicable in 1987 was 1 US $ = 84 Tsh.

3. MAINTENANCE DEFINITIONS AND STRATEGIES

The purpose of this study was to determine the optimum maintenance strategy for the two road sections. Before that can be attempted the terminologies used to describe maintenance in the two models have to be clearly defined.

3.1 Routine maintenance

HDM3: Routine maintenance includes drainage maintenance, vegetation control, shoulder maintenance, safety installations, and any item which are not modelled as affecting the riding quality of the pavement.(7)

RTIM2: Routine maintenance activities are those that are required whether the road is paved or unpaved and do not depend on traffic level. They consist of items such as grass cutting, drain clearing, recutting ditches and maintenance of culverts, bridges and road furniture.(4) Shoulder repair is treated as a periodic maintenance activity in RTIM2 model whereas HDM3 treats it as routine maintenance activity.

3.2 Preventive treatment

HDM3: Preventive treatment includes slurry seal, rejuvenation and fog seal applied to the pavement surface to preempt the onset of surface ravelling, or oxidation of binder in the exisiting surface. Slurry seal is an application of a thin layer of a cold mixture of bitumen emulsion, fine aggregate (5-10mm) and cement Fog seal is a light spray application of bitumen directly to a bituminous surface to reduce ravelling and counter oxidation of the binder. Rejuvenation is a light spray application of solvents, oils or plasticizers on to an existing surface to counter oxidation of the binder by plastisizing it.

RTIM2: No specific treatment is defined under preventive treatment in RTIM2 model. In the circumstance where slurry sealing is to be studied (using RTIM2) the best way would be to consider a slury seal in the same way as surface dressing seal.

3.3 Patching

HDM3: Patching involves cutting out and replacing with good materials or better materials than original pavement, a localised area of pavement which is severely damaged or just potholed. Severely damaged area consist of areas of wide cracks, ravelled and potholed. A wide crack is a crack which is more than 3mm in width and its edges spalling.(8) Potholing is usually a consequence associated with the spalling of wide cracking or with ravelling of thin surface treatments, although in new construction it can be caused by local defects which occur at random places. In both cases the initiation and progression of potholes are highly dependent on the mechanical disintegration properties of the base (7) A pothole is assumed to take an average depth of 50mm.

RTIM2: RTIM2 model assume that all areas where cracking exceeds 5m/sq.m. are patched to subbase level.

The HDM3 model can be used to study the consequencies of various degrees of patching or not patching at all. It is not possible to use RTIM2 model to study the consequencies of not patching or reduced amount of patching below 5m/sq.m. as this is fixed by the model. Potholing is not one of RTIM2 deterioration parameters for paved roads.

3.4 Rut depth

Rutting is defined as permanent deformation in the longitudinal direction in the form of a channelised depression especially along wheel tracks due to traffic action on the pavement structure. Rut depth is measured as a gap (in mm) under a straight edge placed across the wheel track. TRRL uses a 2.0m straight edge while the AASHO Road Test used a 1.22m (4ft) straight edge.

HDM3: From the literature available to the authors on HDM3, there is no specific mention of the length of straight edge on which the rut depth variable is based. It could simply be assumed that a 2m straight edge was used during the UNDP Brazil study, from which most of HDM3 deterioration relationships were derived.

RTIM2: According to reference (4) page 13, a 2m straight edge is the standard length used by the Overseas Unit of TRRL for rut depth measurement. The relationship between rut depths measured under the two straight edges is (9):

$$RD1 = 0.17 + 0.87RD2 \quad (2)$$

Where RD1 is the rut depth measured in mm under a 1.22m straight edge. RD2 is the rut depth measured in mm under a 2m straight edge. The relationship is only valid for roads which display significant rutting, and the correlation coefficient obtained during the Kenya study (9) is r = 0.98.

For both paved and unpaved roads, rut depth is one of HDM3 variables predicted during the analysis. RTIM2 predicts rut depths for unpaved roads only. According to reference 9 page 20, from the study in Kenya on surface dressed roads with cement stabilised bases, rutting was found to be very slight, the maximum mean rut depth recorded on any section was 8mm. Most of the readings were between 3 and 5mm regardless of the traffic that had been carried by the pavements. For this reason, RTIM2 model does not consider rutting as one of the paved road deterioration parameters.

But according to the authors' own experience on the cement/lime stabilised bases of the Songea-Makambako road, rut depths of more than 20 mm have been observed on some road sections. The absence of rut depth consideration by RTIM2 is deemed to be a weakness to the model.

3.5 Resealing

There is no difference in the two models in the meaning of resealing. Resealing is an application of alternate layers of bituminous binder and aggregates laid onto an existing bitumious surface. The two models differ in the way the user specifies trigger values for activating resealing operation during the analysis period.

3.6 Overlaying

In both models overlaying is an application a layer of bitu minous premix to an existing surfaces mainly to reduce surface roughness and strengthen the pavement structure. The two models differ in the way the user specifies trigger values for overlaying.

3.7 Pavement reconstruction

HDM3: Pavement reconstruction applies in the model to all works that require respecification of the surfacing, and base types, pavement thicknesses and strength parameters. This encompasses renewing the road structure to remedy the consequencies of prolonged neglect or where strengthening by overlay is no longer possible.

RTIM2: In the RTIM2 model, pavement reconstruction cannot be triggered off through road condition response during the analysis. The only way of analysing pavement reconstruction is to treat it as if it involves a new overlay on top of the existing surface and an allowance made for a reduction in the value of the original pavement structural number. The assessment and estimation of the reduction in structural number is a very subjective concept and would highly depend on the engineering judgement of an individual.

The aspect of estimating the reduction in the original pavement structural number when studying overlays of pavement reconstruction by RTIM2 model as described above, weakens to a certain extent the capability of RTIM2 model in handling these maintenance options.

3.8 Maintenance Strategies

A maintenance strategy or policy is a combination of maintenance standards which could be applied to the pavement in a serviceable condition or prevent it from rapid deterioration. All road sections investigated are paved, so only paved road maintenance policies have been considered. HDM3 permits formulation of several maintenance options from the following maintenance operations; (a) Routine maintenance, (b) Preventive treatment, (c) Patching, (d) Resealing, (e) Overlaying, (f) Pavement reconstruction.

Of these only resealing and overlaying can be investigated by RTIM2 model. Table 6 shows a full range of maintenance policies considered in the analysis

Table 6 Maintenance Strategies and their code names

	Routine Maint. + 0% patching	Routine maint. + 50% patching severely damaged area	Routine maint. + 100% patching potholes
None	NON0	NON1	NON2
Resealing	RSL0	RSL1	RSL2
Bituminous overlay	BTV0	BTV1	BTV2
Cement stab. overlay	CSV0	CSV1	CSV2
Pavement reconstruction	REC0	REC1	REC2
Resealing + Bit overlay	RBV0	RBV1	RBV2
Resealing + cement stab. overlay	RCV0	RCV1	RCV2
Resealing + reconstruction	RRE0	RRE1	RRE2

3.8.1 Routine maintenance

Routine maintenance has been assumed to take place in all policies except option N00 which is aimed at investigating the effect of omiting routine maintenance.

3.8.2 Patching

Three different levels of patching have been considered.
(a) Zero or no patching: Implying doing no patching at all
(b) Patching 50% of severely damaged area.
(c) Patching 100% potholes: This implies patching all potholes as soon as they are formed throughout the analysis period.

HDM3: Patching can be specified by the user in one of the following ways: In a scheduled case, by a fixed amount per year in sq.m per km. In a condition responsive case, the user can either specify the percentage damaged area or percentage of potholing areas to be patched.

RTIM2: All areas of cracking more than 5 m/square meter area assumed to be patched every year.

3.8.3 Resealing

Only surface dressing has been considered. Slurry sealing has not been considered.

HDM3: Resealing can be activated by one of the following; In a condition responsive case, the user specifies the percentage damaged area. In a scheduled case the user specifies the interval in years and the last applicable year for resealing.

RTIM2: Resealing can only be activated by specifying the number of elapsed time since construction or the last resurfacing.

3.8.4 Bituminous overlay

Hot mix asphaltic concrete 50 mm thick has been considered. Thicknesses less than this have not been considered due to practical difficulties in laying them, and thicknesses more than this have been found to be uneconomical at the existing traffic levels. It was established during preliminary analysis (HDM3) that the optimum intervention level for overlaying is between 3600-3700 mm/km roughness for the particular links being analysed.

HDM3: Overlaying can be activated in one of the following ways; In a condition responsive case, roughness trigger value is specified. In a scheduled case the user specifies the interval for overlaying in years, and the last applicable year for overlaying.

RTIM2: Overlaying is triggered by the number of cumulative standard axles that have passed over the road since construction or last overlay. The user also specifies the percentage reduction of the pavements modified structural number immediately before the overlay is applied.

3.8.5 Cement stabilised overlay

150 mm thick cement stablised gravel has been considered. Intervention level is the same as that for bituminous overlay.

3.9 Strategies considered for final investigation

From Table 6 the following maintenance policies were considered for final evaluation, after HDM3 preliminary analysis: NON0,NON1,NON2,RSL0,RSL2, BTV0, BTV2, CSV0, CSV2, RBV2 and NOO0

NON0 is routine maintenance only
NON1 is 50% patching severely damaged area + routine
NON2 is 100% pothole patching + routine
RSL0 is resealing + zero pothole patching + routine
RSL2 is resealing + 100% pothole patching + routine
BTV0 is Bituminous overlay + zero pothole patching + routine
BTV2 is Bituminous overlay + 100% pothole patching + routine
CSV0 is Cement stablised overlay + zero pothole patching + routine
CSV2 is Cement stabilised overlay + 100% pothole patching + routine
NOO0 is doing no maintenance at all.

Of the above listed maintenance policies, the following policies were also analysed using RTIM2 model: NON0, RSL2, BTV2, and CSV2.
From the preliminary analysis by HDM3 model, the following invervention levels form maintenance oiperations were derived. (a) Resealing (policies RSLQ and RSL2) specified by 40% total damaged area invervention level in HDM3 model. In RTM2 model, resealing (RSL2) scheduled to take place in year 1 or 2 of the analysis in order to match with HDM3 trends. (b) Overlaying (policies BTV0, BTV2, SCV0, and CSV2) specified by intervention level of 3600 mm/km road roughness on the Bump integrator scale for links 1 and 2.

4. RESULTS AND DISCUSSION

4.1 Results

Tables 7,8,and 9 show Net Present Values (NPV) for various maintenance strategies analysed by HDM3 model. Table 7 shows NPVs for link 1 and 2 for medium traffic case at discount rates of 6.0%, 12.5%, and 20% per annum. Table 8 shows NPVs for links 1 and 2 for low traffic case. Table 10 shows RTIM2 results for a medium traffic alternative for link 1.

4.2 Discussion

From table 7, the option of patching 50% of severly damaged area (NON1) has been found to give negative NPVs for all discount rates considered. The policy of 100% pothole patching (NON2) has been found to give positive NPVs for all three discount rates and remain positive for all traffic cases on both road links. This policy shows high internal rates (IRR) for all the traffic cases. Resealing policies show negative NPVs for light traffic cases but this turns to a positive rate for medium and heavy traffic cases.

Table 7 HDM3 Net Present Value of Maintenance Policies (Medium traffic) (Million Tshs.)

Maint. policy code	Link No.	Discount rate per annum (N=15yrs)			
		6%	12.5%	20%	Internal rate of return %
NON1	1	-0.508	-0.335	-0.227	NONE
NON2	1	0.055	0.030	0.017	115.0
RSLQ	1	0.044	0.004	-0.017	13.4
RSL2	1	0.043	0.003	-0.017	13.4
BTVQ	1	0.010	-0.011	-0.015	8.0
BTV2	1	0.020	0.007	0.003	112.0
CSVQ	1	0.053	0.016	0.002	22.6
CSV2	1	0.058	0.027	0.013	114.0
RBV2	1	N/A	N/A	N/A	N/A
NON1	2	-0.574	-0.380	-0.260	NONE
NON2	2	0.042	0.024	0.014	109.0
RSLQ	2	0.013	-0.012	-0.024	8.7
RSL2	2	0.012	-0.012	-0.025	8.6
BTVQ	2	-0.033	-0.026	-0.017	-4.9
BTV2	2	0.014	0.009	0.006	108.0
CSVQ	2	0.008	-0.002	-0.004	10.4
CSV2	2	0.042	0.024	0.014	109.0

Overlaying with bituminous premix has been found to show positive NPVs for all three discount rates for both links at medium and high traffic cases, provided 100% pothole patching preceeds the period before overlaying takes place (BTV2).

Refering to Table 7 and 8 overlaying with cement stablised gravel (CSV2) has been found to show higher NPVs than overlaying with bituminous premix (BTV2) for the traffic cases considered on both links, despite the fact that BTV2 gives a smoother finished road surface than CSV2. This is due to the difference in unit costs involved i.e. cost per square metre of 150 mm cement stabilised overlay is less than a 50 mm asphaltic concrete overlay. For high traffic case (Table 8), overlaying policies with 100% pothole patching have been found to show higher economic benefits than both resealing policy (RSL2) and the policy of 100% pothole patching (NON2). This is due to the fact that with high traffic levels, economic benefits accrue from keeping the road as smooth as possible to keep VOCs down.

Table 8 HDM3 The Net Present Value of Maintenance policies (High Traffic) (Million Tshs)

Maint. policy Code	Link No	Discount rate per annum (N=15yrs)			
					Internal rate of return %
NON2	1	0.095	0.051	0.027	136.0
RSL2	1	0.121	0.042	0.002	20.5
BTV2	1	0.124	0.053	0.022	134.0
CSV2	1	0.163	0.075	0.034	135.0
RBV2	1	0.121	0.042	0.002	20.6
NON2	2	0.080	0.044	0.024	139.0
RSL2	2	0.075	0.018	-0.012	16.2
BTV2	2	0.077	0.038	0.020	139.0
CSV2	2	0.096	0.048	0.025	139.0
RBV2	2	0.075	0.019	-0.011	16.5

The main advantage of HDM3 over RTIM2 model in the analysis of maintenance policies is that HDM3 permits formulation of a wide range of maintenance policies than RTIM2 does. In this analysis for instance, a total of 25 different maintenance policies were formulated for analysis by HDM3 model, (refer table 6) but of these, only six policies could be analysed by RTIM2 model albeit with limited flexibility. This arises because RTIM2 model cannot be used to analyse different amounts of patching, and pavement reconstruction cannot be fully simulated in the model.

Table 9 HDM3 The Net Present Value of Maintenance policies (Low Traffic) (Million Tshs)

Maint. policy code	Link No.	Discount rate per annum (N=15yrs)			
		6%	12.5%	20%	Internal rate of return %
NON2	1	0.033	0.018		90.0
RSL2	1	0.002	-0.019		6.4
BTV2	1	N/A	N/A		N/A
CSV2	1	N/A	N/A		N/A
NON2	2	0.027	0.016		86.0
RSL2	2	0.012	-0.025		2.9
BTV2	2	N\A	N\A		N/A
CSV2	2	N\A	N\A		N/A

Overall there is no great difference between the two models in the relative prioritisation of resealing and overlaying policies. Both HDM3 and RTIM2 have shown the major maintenance policies to be in the following order of economic preferences at the particular traffic levels. a) cement stabilised overlay b) Bituminous overlay c) Resealing.

Table 10 RTIM2 Net Present Values of alternatives (Medium Traffic) (Million Tshs)

	Discount rate per annum (N=15yrs)		
Policy code	6%	12.5%	20%
RSL2	0.000	-0.020	-0.032
BTV2	0.040	0.008	-0.003
CSV2	0.056	0.018	0.002

5. CONCLUSIONS AND RECOMMENDATIONS

From the discussion above, the following inferences have been made:

(a) Based on average section conditions and medium traffic conditions, the optimum maintenance strategy in terms of economic benefits to society as a whole is 100% pothole patching, but the optimum strategy switches to cement stabilised overlay at lower discount rates.

(b) At a high traffic flow situation the optimum maintenance strategy predominatly becomes cement stabilised overlay plus 100% pothole patching.

(c) Considering the bad portion of the road with the links under consideration, the proposed strategy of overlaying three portions with cement stabilised gravel have been found to be economically beneficial. It should be appreciated that the outcomes of this analysis on the bad portions of road do not necessarily represent the actual situation because the nature of the pavement problems observed on site are slightly different from the idealised deterioration patterns described in both HDM3 and RTIM2 models.

(d) It is understood that the above conclusions apply under unconstrained budgetary conditions to the maintenance authority, and the analysis involves some monetary approximations, so the results should not be treated as sacrosanct.

Both HDM3 and RTIM2 are very powerful models in the way they interrelate construction, maintenance standards and vehicle operating costs. The models can predict road conditions on a year by year basis, but the predicted year by year road conditions are not likely to fully resemble the observed actual road conditions. This can definitely be said for rutting, cracking and revelling aspects. As mentioned earlier the predicted rut depths seem to be on the lower side. HDM3 provides a facility for calibrating various deterioration progression parameters through adjustable initiation factors for the different parameters. Over a number of years the predicted deterioration values can be made to match the values observed on site through road condition surveys, in which case the model would give improved VOCs and road maintenance costs, and thus the resultant NPVs would be much more representative of the actual situation.

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