HDM-4 ANALYSIS OF MAINTENANCE ALTERNATIVES FOR THE MALAWI ROAD NETWORK

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for the TI-UP Resource Centre

CNTR 2008 08377 Support to the Ministry of Finance:
Analysis of Road and Road Maintenance Investment Priorities

April 2008

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1 INTRODUCTION

A Pavement Management System (PMS) was implemented in Malawi in 2006 by TRL. The PMS comprises two components; a centralised road database entitled Road Data Manager (RDM) and the economic analytical tool, the Highway Development and Management tool (HDM-4).

Road surveys comprising ordnance, inventory, condition, traffic counts, pavement layer thickness and strengths were conducted in 2006 and the data entered in RDM. Also in 2006 HDM-4 was configured and adapted for Malawi, and personnel from the Roads Authority (RA) were trained in the use of HDM-4. This resulted in the Malawi PMS being fully implemented in 2006.

Under a DFID funded project, commissioned through the TI-UP Framework Agreement, a visit was undertaken by TRL in March 2008 to update the Malawi Pavement Management System and then to use the PMS to examine various maintenance alternatives for managing the Malawi road network.

2 UPDATING THE PMS

Many of the RDM and HDM-4 parameters configured in 2006 are applicable for the current use of the software by the Ministry of Finance. However, parameters such as condition of the road network, traffic levels and unit costs need to be updated to reflect current Malawi conditions.

2.1 Road Condition

Condition surveys of the road network were repeated in 2007 and the data entered in RDM enabling current condition data to be available in the PMS.

2.2 Traffic

Traffic counts conducted at 59 locations in 2006 were used to assign traffic levels to all the road links on the Malawi road network in RDM. Information from traffic surveys conducted in 2007 was available for 12 of these locations. The average increase in traffic levels at these 12 locations was 7.5%.

However, it was noted that these 12 locations were all on paved sections of road. The general consensus is that increases in traffic volumes on unpaved roads are less than on paved roads. Therefore for 2007, the traffic levels on paved roads were increased by 7.5% and on unpaved roads by 2.5%.

2.3 Unit Costs

Information published by the National Statistical Office of Malawi indicates that the inflation rate in Malawi was 13.9% in 2006 and 8% in 2007. Unit costs in HDM-4 for 2006 were derived in the second half of 2006. It has been assumed that these costs rose by approximately 4% by the end of 2006 and therefore all unit costs in HDM-4 have been increased by 12% (4% in 2006 + 8% in 2007) to reflect end of 2007 costs.

2.4 Road Works Costs

The end of 2007 unit costs, in economic and financial terms, of the various works activities in HDM-4 are listed in Table 1.

Table 1
Works Activities Unit Costs (US$)

	Works activity	Unit	Economic Cost	Financial Cost
Paved	Single Reseal	m^2	4.45	6.35
	Double Reseal	m^2	5.39	7.69
	Rehab with Single Surface Dressing	km	151,300	216,150
	Rehab with Double Surface Dressing	km	170,900	244,150
	40 mm Overlay	m^2	11.85	16.92
	Miscellaneous (including drainage clearance)	km/yr	280.73	401.04
	Pothole Patching	m^2	18.14	25.92
Unpaved	Upgrade to 6.7m with a Double Surface Dressing	km	273,050	390,000
	Heavy Grading	km	1028.76	1469.66
	Light Grading	km	514.38	734.83
	Miscellaneous	km/yr	222.20	317.43
	Spot Regravelling	m^3	15.43	22.04
	Regravelling	m^3	49.92	71.31

2.5 Vehicle Fleet

Six representative vehicle types have been selected in HDM-4 to describe the vehicle fleet in Malawi. The vehicle characteristics of these six vehicle types are listed in Table 2.

Table 2
Motorised Vehicle Characteristics

Parameter	Car 4WD	Minibus	Bus	Light Goods	Medium Goods	Heavy Goods
PCSE	1	1.2	1.6	1	1.4	1.6
No. of wheels	4	4	6	4	6	14
No. of axles	2	2	2	2	2	4
Tyre type	Radial	Radial	Radial	Radial	Radial	Radial
Base no. of recaps	1.3	1.3	1.3	1.3	1.3	1.3
Retread cost (%)	15	15	15	15	15	15
Annual km	22500	75000	75000	45000	80000	100000
Working hours	450	2000	1200	1200	1500	1800
Average life (yr)	9	8	10	10	8	8
Private use (%)	50	0	0	0	0	0
Passengers	3	12	50	3	6	4
Work related trips (%)	35	10	10	25	25	25
ESALF	0	0.03	2.5	1	4.3	4.6
Operating weight (kg)	2150	3200	12600	4000	12300	40000

The economic unit costs derived in 2006 for these six vehicle types were increased by 12% with the exception of fuel. The cost of a barrel of oil has risen on the world markets by far more than 12% over this period. In Sep 2006 the cost of a barrel was approximately US$66.

By the end of 2007 the cost had risen to over US$90, an increase in the order of 36%. Therefore the current economic cost of fuel used in this study was increased by 36%. A similar increase was applied to the cost of lubricating oil.

The end of 2007 economic unit costs, in US$, associated with these vehicles are listed in Table 3.

Table 3
Motorised Vehicle Economic Unit Costs (US$)

Parameter	Car 4WD	Minibus	Bus	Light Goods	Medium Goods	Heavy Goods
New vehicle	20822	38923	85577	42822	67109	108236
Replacement tyre	110	130	258	253	400	470
Fuel / litre	0.75	0.80	0.80	0.80	0.80	0.80
Lubricating oil / litre	4.23	4.23	4.23	4.23	4.23	4.23
Maintenance labour / hr	2.17	2.17	2.17	2.17	2.17	2.17
Crew wages / hr	0	1.24	1.86	0.62	1.24	1.24
Annual overhead	308	380	1920	380	750	1446
Annual interest (%)	12	12	12	12	12	12
Passenger work time / hr	0.08	0.08	0.08	0.08	0.08	0.08
Passenger non-work time	0	0	0	0	0	0
Cargo / hr	0	0	0	0.02	0.02	0.02

2.6 Road Network

The Malawi road network has been categorised based on the type of surface, traffic levels and surface condition.

The paved road network comprises pavements that are surface dressed and those that have asphalt concrete surfacings. The unpaved road network comprises primarily earth roads. Therefore the road network was divided into three categories; surface treatment (ST), asphalt mix (AM) and earth (EA) roads.

Three traffic volume categories, High, Medium and Low, were used for paved and unpaved roads. The representative AADT values for each category were reviewed and where necessary amended from those used in 2006 to take into account the increase in traffic levels and are listed in Table 4 together with the range of AADT that is applicable to each representative AADT.

Table 4
Traffic Category

Traffic Category	AADT			
	Paved Roads		Unpaved Roads	
	Rep Value	Range	Rep Value	Range
High	1500	> 1000	200	> 100
Medium	650	250 – 1000	75	50 – 100
Low	150	< 250	25	< 50

The traffic composition for each AADT category is listed in Table 5.

Table 5
Traffic Composition

Vehicle Class	Paved Roads			Unpaved Roads		
	High	Medium	Low	High	Medium	Low
Car / 4WD	795	338	80	126	45	20
Minibus	300	97	18	8	1	1
Light Goods	75	52	15	30	10	2
Bus	60	26	7	2	1	0
Medium Goods	150	72	18	30	18	2
Heavy Goods	120	65	12	4	0	0
Total	**1500**	**650**	**150**	**200**	**75**	**25**

Three road condition categories, Good, Fair, Poor, were used for paved and unpaved roads, based on roughness (IRI) measurements. The definitions of the roughness categories for paved and unpaved roads were amended during this visit. This involved changing the RDM source code to accommodate these changes. The revised representative IRI values for each category are listed in Table 6 together with the revised range of IRI values that is applicable to each representative IRI.

Table 6
Roughness Category

IRI Category	Roughness - IRI			
	Paved Roads		Unpaved Roads	
	Rep Value	Range	Rep Value	Range
Good	2.5	< 3	6	< 7
Fair	4	3 – 5	8	7 - 10
Poor	6	> 5	12	> 10

In association with each roughness category for paved roads, values for the other HDM-4 condition parameters were assigned as listed in Table 7.

Table 7
Surface Condition for Paved Roads

Condition Category	Paved Roads					
	All Cracking (%)	Wide Cracking (%)	Ravelling (%)	Potholes (no./km)	Edge Break (m^2/km)	Rut Depth (mm)
Good	0	0	0	0	0	2
Fair	2	0	5	0	25	5
Poor	5	2	10	15	50	10

The unpaved roads are all classified as Earth roads, and therefore the gravel thickness was set to zero for all three unpaved road condition categories.

3 CURRENT CONDITION OF THE ROAD NETWORK

The road network was categorised by the three parameters, surface type, traffic and surface condition as follows:

- Pavement Types (3) – Surface Treatments (ST), Asphalt Mix (AM), Earth (EA)
- Traffic (3) – High (H), Medium (M), Low (L)
- Condition (3) – Good (G), Fair (F), Poor (P)

This produces a Network State Matrix (NSM) that comprises 27 (3 x 3 x 3) Network States (i.e. cells). The length of road currently in RDM (2007 surveys) for each cell is given in Table 8 and this length was used in the analysis of each Network State.

Table 8
Categorised Length of the Road Network in 2007 (km)

Surface Type	Traffic	Condition			Total
		Good	Fair	Poor	
Surface Dressing	High	434.5	79.7	146.4	660.6
	Medium	808.5	572.2	229.1	1,609.8
	Low	258.8	143.9	23.6	426.3
	Total	1501.8	795.8	399.1	2696.7
	%	55.7%	29.5%	14.8%	
Asphalt Concrete	High	101.3	-	-	101.3
	Medium	95.8	7.2	4.7	107.7
	Low	11.0	2.0	5.0	18.0
	Total	208.1	9.2	9.7	227.0
	%	91.7%	4.1%	4.3%	
Paved (ST & AM)	Total	1,709.9	805.0	408.8	2,923.7
	%	58.5%	27.5%	14.0%	
Earth	High	277.1	730.1	347.1	1,354.3
	Medium	441.3	809.0	331.6	1,581.9
	Low	2,267.4	4,396.6	1,687.1	8,351.1
	Total	2,985.8	5,935.7	2,365.8	11,287.3
	%	26.5%	52.5%	21.0%	
All	Total	4,695.7	6,740.8	2,774.6	14,211.0
	%	33.0%	47.5%	19.5%	

The figures in Table 8 show that the majority of the paved road network (surface dressings and asphalt concrete) is currently in Good condition (58%), 28% is in Fair condition and 14% is in Poor condition. For the entire network including the earth roads, 33% is in Good condition, 47% in Fair condition and 20% in Poor condition.

4 HDM-4 ANALYSIS

4.1 Routine Maintenance

The maintenance that is currently carried out on the road network by the Roads Authority (RA) is basically routine maintenance which comprises the following activities:

- Paved Roads – Patch potholes, grass cutting and some shoulder and drainage repairs

- Earth Roads – Light grading every 3 years on Good & Fair roads + drainage repairs
  Heavy grading every 3 years on Poor roads + drainage repairs

HDM-4 was used to analyse the effect of carrying out this routine maintenance on the road network – i.e. with no other periodic maintenance such as resealing, rehabilitation, etc. The condition of the road network in 5 years time (i.e. at the end of 2012) is summarised in the NSM shown in Table 9.

Table 9
Categorised Length of the Road Network in 2012 after Routine Maintenance (km)

Surface Type	Traffic	Condition			Total
		Good	Fair	Poor	
Surface Dressing	High	-	434.5	226.1	660.6
	Medium	808.5	-	801.3	1,609.8
	Low	258.8	-	167.5	426.3
	Total	1,067.3	434.5	1194.9	2696.7
	%	39.6%	16.1%	44.3%	
Asphalt Concrete	High	101.3	-	-	101.3
	Medium	95.8	7.2	4.7	107.7
	Low	11.0	2.0	5.0	18.0
	Total	208.1	9.2	9.7	227.0
	%	91.7%	4.1%	4.3%	
Paved (ST & AM)	Total	1,275.4	443.7	1,204.6	2,923.7
	%	43.6%	15.2%	41.2%	
Earth	High	-	-	1,354.3	1,354.3
	Medium	-	-	1,581.9	1,581.9
	Low	-	-	8,351.1	8,351.1
	Total	-	-	11,287.3	11,287.3
	%	-	-	100%	
All	Total	1,275.4	443.7	12,491.9	14,211.0
	%	9.0%	3.1%	87.9%	

The figures in Table 9 show that in a 5-year period, the proportion of the paved road network that is in Poor condition will have increased from 14% to over 40% if only routine maintenance is carried out during this period. For the entire road network, less than 10% of the roads will remain in Good condition, compared with the current value of 33%. Also 88% of the road network would be in a Poor condition, compared with the current value of 20%.

The cost of undertaking this routine maintenance was estimated to be approximately US$8.5 million per year (i.e. MWK 1.2 billion per year). It therefore appears that if no periodic maintenance, such as resealing or rehabilitation, is carried out then the maintenance budget is not being spent appropriately as MWK 1.2 billion is spent to effectively deteriorate the road network.

4.2 Periodic Maintenance

An alternative maintenance scenario was examined which investigated the effect of undertaking the following maintenance activities:

- Paved Roads
  High trafficked roads in Good & Fair condition – Reseal every 7 years if IRI > 3.5

Medium trafficked roads in Good & Fair condition – Reseal every 9 years if IRI > 3.5
Low trafficked roads in Good & Fair condition – Reseal every 10 years if IRI > 3.5
Roads in Poor condition – Rehabilitate with a double surface dressing

- Earth Roads – Grading twice a year
  High & Medium trafficked roads – Grade twice a year
  Low trafficked roads – Grade once a year

The condition of the road network in 5 years time (i.e. at the end of 2012) under this periodic maintenance strategy is summarised in Table 10.

Table 10
Categorised Length of the Road Network in 2012 after Periodic Maintenance (km)

Surface Type	Traffic	Condition			Total
		Good	Fair	Poor	
Surface Dressing	High	146.4	514.2	-	660.6
	Medium	1,037.6	572.2	-	1,609.8
	Low	282.4	143.9	-	426.3
	Total	1,466.4	1,230.3	-	2,696.7
	%	54.4%	45.6%	-	
Asphalt Concrete	High	101.3	-	-	101.3
	Medium	107.7	-	-	107.7
	Low	18.0	-	-	18.0
	Total	227.0	-	-	227.0
	%	100%	-	-	
Paved (ST & AM)	Total	1,693.4	1,230.3	0.0	2,923.7
	%	57.9%	42.1%	0.0%	
Earth	High	-	-	1,354.3	1,3754.3
	Medium	-	1,581.9	-	1,581.9
	Low	-	8,351.1	-	8,351.1
	Total	-	9,933.0	1,354.3	11,287.3
	%	-	88.0%	12.0%	
All	Total	1,693.4	11,163.3	1,354.3	14,211.0
	%	11.9%	78.6%	9.5%	

These figures show that under this maintenance strategy, none of the paved roads would be in a Poor condition after 5 years, with 58% in Good condition and 42% in Fair condition. Grading the medium trafficked earth roads twice a year and the low trafficked roads once a year, rather than once every 3 years, is effective in maintaining these earth roads in Fair condition, but is not effective on the high trafficked roads.

The cost of this periodic maintenance was estimated to be approximately US$ 230 million over the 5-year period (i.e. US$ 46 million per year; MWK 6.4 billion per year). The cost of rehabilitating the paved roads in Poor condition in 2007 is approximately US$100 million over the 5 years. Excluding this rehabilitation cost reduces the annual maintenance budget to US$ 26 million (i.e. MWK 3.6 billion per year).

4.3 Alternative Maintenance of Low Trafficked Earth Roads

The maintenance strategy of low trafficked earth roads in the above analysis was to grade them once a year. A further analysis was conducted to examine the effect of grading these roads twice a year, as carried out on the high and medium trafficked earth roads.

Grading the 8,351.1 km of low trafficked earth roads twice a year improved their condition after 5 years to Good from the Fair condition achieved with grading once a year. The overall effect on the state of the network is to increase the percentage of the entire road network that is in Good condition from 12% (see Table 10) to 70% as shown in Table 11.

Table 11
Categorised Length of the Road Network in 2012 – Grading all Earth Roads 2/year (km)

Surface Type	Traffic	Condition			Total
		Good	Fair	Poor	
Surface Dressing	High	146.4	514.2	-	660.6
	Medium	1,037.6	572.2	-	1,609.8
	Low	282.4	143.9	-	426.3
	Total	1,466.4	1,230.3	-	2,696.7
	%	54.4%	45.6%	-	
Asphalt Concrete	High	101.3	-	-	101.3
	Medium	107.7	-	-	107.7
	Low	18.0	-	-	18.0
	Total	227.0	-	-	227.0
	%	100%	-	-	
Earth	High	-	-	1,354.3	1,3754.3
	Medium	-	1,581.9	-	1,581.9
	Low	8,351.1	-	-	8,351.1
	Total	8,351.1	1,581.9	1,354.3	11,287.3
	%	74%	14.0%	12.0%	
All	Total	10,044.5	2,812.2	1,354.3	14,211.0
	%	70.7%	19.8%	9.5%	

The cost of grading the low trafficked earth roads twice a year rather than once a year increases the maintenance budget by US$6 million per year (i.e. MWK 0.85 billion per year).

4.4 Economic Analysis

The HDM-4 analysis described above examined the cost implications of a range of maintenance scenarios and their effect on the condition of the road network after a 5-year period. The next stage of the analysis was to examine the economic justification of carrying out these maintenance activities.

HDM-4 analyses were conducted on the maintenance scenarios described in Sections 4.2 and 4.3; i.e. resealing every 7, 9 or 10 years on high, medium and low trafficked paved roads respectively, and grading all earth roads twice a year, or the low trafficked earth roads once a year. These maintenance scenarios were compared with a 'base' alternative of the current routine maintenance regime; i.e. patching potholes, etc on paved roads and grading every 3 years on earth roads.

The analyses were conducted over a 20-year period using a discount rate of 12%. Traffic growth rates of 7.5% and 2.5% were used for paved and earth roads respectively.

The main outputs from an HDM-4 economic analysis that should be considered are Net Present Value (NPV), the Internal Rate of Return (IRR) and the Net Present Value/Investment Cost ratio (NPV/C).

NPV is defined as follows:

$$NPV = (B_1-C_1)/(1+r) + (B_2-C_2)/(1+r)^2 + \ldots\ldots(B_n-C_n)/(1+r)^n$$

where

B_1, B_2, ……B_n are the benefits in year 1, 2, ……n
C_1, C_2, …..C_n are the costs in year 1, 2, …..n
r is the discount rate
n is the analysis period

A positive NPV indicates that the project is economically viable. The larger the NPV, the better the project. NPV can be used to choose between mutually exclusive projects.

To calculate the IRR, the NPV equation needs to be solved for r such that NPV=0. If the IRR is above the discount rate then the project is economically viable. The higher the IRR the better the project.

NPV/C is mainly used to rank projects when there is a budget constraint. The higher the ratio the better the project. Projects are ranked in descending order of NPV/C and the highest ranked projects are accepted until the budget is exhausted. NPV/C is an important economic indicator when undertaking either Programme or Strategy analysis in HDM-4 with budget constraints. The HDM-4 analysis carried out in this study was Project analysis which does not consider budget constraints. Hence NPV/C is not an economic indicator that is relevant to this analysis.

The values for the economic indicators NPV and IRR from the analysis are listed in Table 12. These figures indicate that on the high and medium trafficked paved roads, the resealing / overlaying maintenance scenarios are strongly viable with high IRR values significantly higher than the 12% used in the analyses. However, on the low trafficked paved roads, resealing / overlaying at 10-year intervals is barely justifiable.

Grading the earth roads twice a year (or once a year on low trafficked roads) is highly justifiable compared with grading every 3 years with extremely high NPV and IRR values for all categories of road. For the high and medium trafficked roads, no solution was obtained for IRR. The reason for this is that no solution can be obtained for the criteria NPV=0 as illustrated in the figure below.

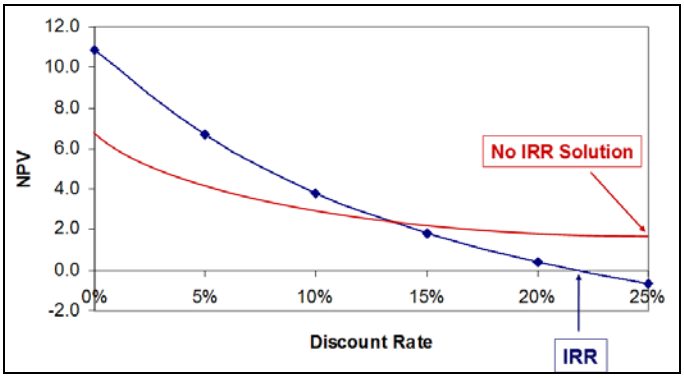

Table 12
Economic Indicators from the HDM-4 Analysis

Surface	Category	Maintenance Scenario	Length (km)	NPV (US$m)	IRR (%)
ST	High-Good	Reseal every 7 years	434.5	355.5	107.9
	High-Fair	Reseal every 7 years	79.7	85.9	75.3
	High-Poor	Reseal every 7 years	146.4	126.8	103.0
	Medium-Good	Reseal every 9 years	808.5	208.7	54.0
	Medium-Fair	Reseal every 9 years	572.2	194.6	49.8
	Medium-Poor	Reseal every 9 years	229.1	52.3	74.2
	Low-Good	Reseal every 10 years	258.8	-1.1	7.6
	Low-Fair	Reseal every 10 years	143.9	0.8	14.0
	Low-Poor	Reseal every 10 years	23.6	0.2	15.1
AM	High-Good	Overlay every 7 years	101.3	57.8	55.1
	High-Fair	Overlay every 7 years	-	-	-
	High-Poor	Overlay every 7 years	-	-	-
	Medium-Good	Overlay every 9 years	95.8	10.3	28.0
	Medium-Fair	Overlay every 9 years	7.2	1.7	29.0
	Medium-Poor	Overlay every 9 years	4.7	1.7	38.5
	Low-Good	Overlay every 10 years	11.0	-0.4	-5.5
	Low-Fair	Overlay every 10 years	2.0	-0.06	6.7
	Low-Poor	Overlay every 10 years	5.0	-0.02	11.4
EA	High-Good	Grade twice a year	277.1	21.9	n/s
	High-Fair	Grade twice a year	730.1	58.9	n/s
	High-Poor	Grade twice a year	347.1	25.0	n/s
	Medium-Good	Grade twice a year	441.3	14.3	n/s
	Medium-Fair	Grade twice a year	809.0	27.4	n/s
	Medium-Poor	Grade twice a year	331.6	9.8	n/s
	Low-Good	Grade twice a year	2267.4	4.5	25.7
	Low-Fair	Grade twice a year	4396.6	10.7	29.8
	Low-Poor	Grade twice a year	1687.1	4.0	82.6
	Low-Good	Grade once a year	2267.4	6.8	57.5
	Low-Fair	Grade once a year	4396.6	14.5	62.6
	Low-Poor	Grade once a year	1687.1	6.3	73.9

n/s – no solution

4.5 Sealing Earth Roads

HDM-4 was used to examine the economic viability of upgrading (i.e. sealing) earth roads. Two alternatives were used as the 'base case' in this analysis:

- Alternative 1 – current maintenance strategy of grading once every 3 years

- Alternative 2 – grading twice a year

The cost of upgrading a 6-metre wide earth road to a 6.7 metre wide road sealed with a double surface dressing used in the analysis was MWK 390,000 per km. Options of using less expensive 'low cost seals' were also examined in the analysis.

- Option 1 – 50% of the above cost (i.e. MWK 195,000 per km)
- Option 1 – 25% of the above cost (i.e. MWK 97,500 per km)

A discount rate of 12% was used in this analysis and the results are summarised in Table 13.

Table 13
Optimum Traffic Levels for Upgrading Earth Roads

Cost of Seal (MWK / km)	Grading every 3 years	Grading twice a year
390,000	250 ADT	350 ADT
195,000	150 ADT	225 ADT
97,500	100 ADT	150 ADT

These results show that it is economically viable to seal earth roads carrying traffic in excess of 250 vehicles per day if the current routine maintenance practice of grading once every three years continues. The threshold for sealing earth roads under this maintenance practice drops to 100 vehicles per day if low cost sealing is used.

If grading twice a year is carried out then the threshold for sealing earth roads rises to 350 and 150 vehicles a day for these two types of sealing costs.

4.6 Sealing the High Trafficked Earth Roads

The analysis described in Section 4.5 showed that it is economically viable to seal earth roads that have traffic levels in excess of 250 vehicles per day. The earth roads in RDM with an ADT > 250 are listed in Table 14.

Each of these roads were analysed in HDM-4 to examine the economic benefits of sealing the individual lengths of road. The analyses were conducted over a 20-year period using a discount rate of 12%. Traffic growth rates of 7.5% were used.

Two 'base' alternatives were used in the analyses:

i) current maintenance of grading once every 3 years
ii) grading twice a year

The sealing alternative was to seal the road in 2008 and then to reseal every 10 years provided the roughness (IRI) was > 3.5. Three different costs for the seal were used – Full cost (US$ 390,000 / km), 50% cost (US$ 195,000 / km) and 25% cost (US$ 97,500 /km).

The economic indicators from this analysis are shown in Table 15 for the base alternative of grading every 3 years and in Table 16 for the base alternative of grading twice a year.

Table 14
Earth Roads with ADT > 250

District	Road	Link	Start Location	End Location	Length (km)
Lilongwe	S125	11482	Bunda :Junction S125/ College Access Rd	Mitundu: Junction S125/Market Access	7.2
		11492	Mitundu: Junction S125/Market Access	Start Diamphwi Bridge	22.1
Mangochi	S129	15191	Start Unga River Bridge	Mwanjati: Start at Box Culvert	22.4
		15192	Makanjira: Junction S129/T377	Start Unga Bridge	38.0
Chikwawa	S136	22031	Changoima: Junction S136/D379	Start of Mwanza River Bank	18.9
		22032	Start of Mwanza River Bank	Start Phwadzi River Drift	12.1
		22061	Start Phwadzi River Drift	Chikwawa: Junction M001/S136	34.5
Chiradzulu	S149	20090	Losa: Junction M4/S149	Chonde: Junction M2/S149	11.8
Thyolo	T418	23041	Didi: Junction at Trading Centre	Thunga: Junction M002/T418	23.7
Blantyre	D328	19307	Nsomba Junction M1/D328	Madziababgo Junction M1/D328	22.2
Chikwawa	M1	22120	Ngabu: Junction M001/T424	Start Lalanje Bridge	17.1
		22130	Goma: Junction M001/T424	Ngabu: Junction M001/T424	6.9
		22180	Nchalo: T/off to Sugar Factory	Goma: Junctiom M001/T424	16.7
Chiradzulu	T411	20052	Chinkankheni: Junction S146/T411	Nguludi: Junction M4/T411	17.4
Nsanje	M1	24042	Start Lalanje Bridge	Bangula: Junction M1/S151	14.1
		24050	Bangula: Junction M1/S151	Lundu: Junction M1/T425	41.7
Dedza	M10	13361	Njolo: Junction M005/M010	Kapiri: Junction M010/S127	15.4
Karonga	M26	2062	Mwesha bridge	Karonga roundabout	13.2
		2080	Lufira Bridge	North Rukuru Bridge	34.7
Mangochi	M10	15250	Chintulo Junction M10/T381	Kuchilipa Junction M10/T379	7.0
		15251	Phanga Trading Centre - Bus Stop LHS	Namwiri River	2.8
		15252	Mpanka at Namwiri RIver	Chitntulo JUnction M10/T381	7.8
		15260	Kuchilipa Junction T379/M10	Mangoma Junction S128/M10	17.0
Ntcheu	M10	14172	Phanga: Access to School (Dimba School)	Kangona: Start of Namwili River Culvert (Armco)	2.9
Dedza	S127	13341	Chifambe: Junction S127/S138	Kabulika: Junction M005/S127	12.6

Table 15
Economic Indicators for Sealing Earth Roads that are Graded every 3 years

				Full Cost		50% Cost		25% Cost	
District	**Road**	**Link**	**Length (km)**	**NPV (US$m)**	**IRR (%)**	**NPV (US$m)**	**IRR (%)**	**NPV (US$m)**	**IRR (%)**
Lilongwe	S125	11482	7.2	0.8	16.4	1.7	29.3	2.2	51.6
		11492	22.1	2.4	16.5	5.4	29.5	6.8	51.8
Mangochi	S129	15191	60.4	6.8	16.7	15.0	29.7	19.0	52.4
		15192							
Chikwawa	S136	22031	61.4	9.0	17.6	17.9	31.3	22.3	55.2
		22032							
		22061							
Chiradzulu	S149	20090	11.8	1.2	16.4	2.8	29.3	3.6	51.6
Thyolo	T418	23041	23.7	2.7	16.7	5.9	29.9	7.5	52.7
Blantyre	D328	19307	22.2	14.9	37.4	17.6	66.7	18.9	122.6
Chikwawa	M1	22120	17.1	5.1	26.6	6.9	45.9	7.8	84.9
		22130	6.9	1.0	24.8	1.4	43.8	1.6	79.1
		22180	16.7	2.8	25.8	3.8	45.7	4.4	82.9
Chiradzulu	T411	20052	17.4	7.7	36.6	9.2	65.5	10.0	120.9
Nsanje	M1	24042	14.1	5.9	40.6	6.9	73.1	7.4	135.7
		24050	41.7	35.8	41.4	41.4	74.6	44.2	138.5
Dedza	M10	13361	15.4	11.6	38.2	13.7	68.4	14.7	126.3
Karonga	M26	2062	13.2	6.4	29.7	8.2	52.8	9.1	96.3
		2080	34.7	22.1	34.5	26.8	61.5	29.1	113.1
Mangochi	M10	15250	17.6	5.1	23.1	7.5	40.6	8.7	72.3
		15251							
		15252							
		15260	17.0	5.4	24.0	7.7	42.2	8.8	75.4
Ntcheu	M10	14172	2.9	0.8	23.1	1.2	40.8	1.4	73.0
Dedza	S127	13341	12.6	1.6	24.8	2.2	43.3	2.5	77.2

Table 16
Economic Indicators for Sealing Earth Roads that are Graded twice a year

				Full Cost		50% Cost		25% Cost	
District	**Road**	**Link**	**Length (km)**	**NPV (US$m)**	**IRR (%)**	**NPV (US$m)**	**IRR (%)**	**NPV (US$m)**	**IRR (%)**
Lilongwe	S125	11482	7.2	0.1	12.7	1.1	22.5	1.5	37.9
		11492	22.1	0.5	12.9	3.3	22.8	4.8	38.3
Mangochi	S129	15191	60.4	1.4	13.0	9.4	22.9	13.3	38.5
		15192							
Chikwawa	S136	22031	61.4	2.9	13.9	11.5	24.2	15.8	40.7
		22032							
		22061							
Chiradzulu	S149	20090	11.8	0.2	12.7	1.7	22.5	2.5	37.7
Thyolo	T418	23041	23.7	0.6	13.0	3.7	23.0	5.2	38.6
Blantyre	D328	19307	22.2	10.5	29.3	13.1	49.6	14.5	85.0
Chikwawa	M1	22120	17.1	3.3	21.3	5.0	36.1	5.9	61.4
		22130	6.9	0.6	19.8	1.0	33.6	1.2	56.9
		22180	16.7	1.9	21.1	2.9	35.9	3.4	61.1
Chiradzulu	T411	20052	17.4	5.7	29.5	7.1	50.1	7.9	86.4
Nsanje	M1	24042	14.1	4.4	32.4	5.3	55.2	5.8	95.3
		24050	41.7	26.7	33.1	32.2	56.4	34.9	97.4
Dedza	M10	13361	15.4	8.4	30.3	10.4	51.5	11.4	88.7
Karonga	M26	2062	13.2	4.2	23.5	6.0	39.9	6.8	68.2
		2080	34.7	15.6	27.4	22.2	46.5	22.4	79.9
Mangochi	M10	15250	17.6	2.7	17.9	5.0	30.8	6.2	52.6
		15251							
		15252							
		15260	17.0	3.1	18.9	5.3	32.5	6.5	55.6
Ntcheu	M10	14172	2.9	0.4	17.8	0.8	30.8	1.0	52.7
Dedza	S127	13341	12.6	0.9	19.5	1.5	33.3	1.8	56.7

The economic indicators listed in Table 15 show that it is highly desirable from an economic perspective to seal these high trafficked roads when compared with the current policy of grading them every 3 years. The IRR values from the analysis of sealing with the 'full cost' option are in excess of 16%, rising to over 50% if a low cost seal (25% cost) is used.

Sealing these roads is still economically viable when compared with the base alternative of grading twice a year as shown in Table 16. The IRR vales are in excess of 12% for the 'full cost' option, rising to over 40% in most cases for the low cost seal option.

5 SUMMARY

i) Carrying out routine maintenance as currently undertaken by the RA costs the agency approximately MWK 1.2 billion per annum. This maintenance budget is not being spent appropriately as the road network effectively deteriorates rapidly under this strategy (88% of the road network will be in Poor condition in 5 years time compared with the current value of 20%).

ii) Undertaking a maintenance strategy which includes resealing paved roads in good or fair condition, rehabilitating paved roads in poor condition and grading the earth roads twice a year would cost approximately MWK 6.4 billion per annum. The effect of this maintenance would be to significantly improve the condition of the paved road network (no paved roads in Poor condition after 5 years). If the cost of rehabilitating the paved roads in Poor condition is excluded, the cost of maintaining the rest of the network reduces to approximately US$26 million a year which equates to MWK 3.6 million per year.

iii) Grading the medium trafficked earth roads twice a year and the low trafficked roads once a year maintains them in a Fair condition, but grading the high trafficked roads is ineffective as they deteriorate to a poor condition in less than 5 years.

iv) Increasing the grading frequency of the low trafficked earth roads from once a year to twice a year increases the maintenance budget by US$6 million per year (i.e. MWK 0.85 billion per year). However the effect of this additional maintenance is to increase the percentage of the road network in Good condition from 12% to 70%.

v) The cost of rehabilitating the current paved Poor roads would cost approximately US$100 million (MWK 14 billion). However, if the current routine maintenance strategy is continued for the next 5 years then the cost of rehabilitating the paved Poor roads in 2012 would cost approximately US$295 million (MKW 41 billion) – i.e. a three fold increase.

vi) Sealing earth roads is economically viable at traffic levels of 250 vehicles a day under the current grading policy. Using low cost seals reduces the threshold for sealing to 100 vehicles a day.

vii) The Internal Rates of Return for sealing the high trafficked earth roads (ADT > 250) were in excess of 16% for the option of using the 'full cost' seal which includes widening the roads to 6.7 metres. The IRRs for the low cost seal option are in excess of 40%. These values show that sealing these earth roads is economically highly viable.

6 RECOMMENDATIONS

The current use of the maintenance budget to carry out 'routine' maintenance of the road network needs to be re-evaluated. Without the use of donor funding to undertake rehabilitation works on the paved road network, the paved road network will rapidly deteriorate under the current maintenance policy (40% of the paved road network will be in Poor condition within five years compared with the current value of 14%).

Sealing earth roads is not currently considered as a maintenance / improvement option. The HDM-4 analysis indicates that sealing earth roads carrying traffic levels in excess of 250 vehicles per day is economically highly viable. Using low cost seals rather than widening these roads to 6.7m and surfacing them with a double surface dressing is economically viable at lower traffic levels and should be considered as an option on roads carrying traffic in excess of 100 vehicles per day.

The findings of this analysis were presented to the Minister of Finance. His concerns were focussed on issues related to employment. As such, maintenance of roads using labour-based techniques should be considered, primarily for maintenance (grading) of earth roads and sealing them with low cost seals.

TRL are currently carrying out demonstration trials of low cost sealing in neighbouring African countries (Ethiopia, Mozambique) with plans to undertake further trials in Namibia, Zambia and Kenya. Consideration should be given to possibly extending the trials to Malawi.

The data stored in RDM and used in this analysis is collected from relatively unsophisticated surveys. The quality of the data could be improved by carrying out more detailed surveys. For example, rather than a qualitative ranking of sections of road (codes of 1 to 4 are used to rank the roads as Good to Bad), a detailed condition survey could be conducted on a proportion (say 10%) of the paved road network (< 3000 km). This could take the form of recording the amount of cracking and rutting over a 100 metre length of road at 1 km intervals.