OPTIMUM STRATEGIC MANAGEMENT SYSTEM FOR LESOTHO ROADS NETWORK THROUGH RONET MODEL

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Abstract

The paper presents the application of World Bank's Model RONET to optimize strategic management system for Lesotho roads network.The Lesotho road network condition deteriorated considerably during the 2000s due to under-financing of operations and maintenance. In recent years, as the financial situation in Lesotho has improved, financing for the road sector has gradually increased, focusing on the most hazardous and highly trafficked parts of the road network. However, the overall budget allocated to the sector remains inadequate to maintain the entire district road network in a stable condition. This research is going to present the application of World Bank's model Road Network Evaluation Tool (RONET) to strategic network level analysis of the Lesotho road network. The goals of the presented study are to obtain the optimum maintenance and rehabilitation strategy and related budget, estimate the impact of different funding levels on the future quality and estimate the economic consequences of budget constraints.

The application of RONET model will lead to an optimal maintenance and rehabilitation strategy with a good balance between rehabilitation, periodic and recurrent maintenance. The implementation of optimal maintenance and rehabilitation strategy would cause major improvement compared to current condition of the network. Implementation of higher than optimal maintenance and rehabilitation leads to substantially higher roads directorate costs and consequently lower net benefits, while the implementation of the lower than optimal maintenance and rehabilitation standards would lead to considerably worse network condition for slightly lower agency costs. This means that even minor budget constraints would result in considerably higher total road transport costs in the country's economy.

Keywords: road network, strategic level pavement management, RONET

1. INTRODUCTION

The total length of the road network in Lesotho is about 5,859 km (Sentle M. Mpuru., 2010). The road network, motorways, main and regional roads, is managed by the Road Directorate. The Lesotho road network condition deteriorated considerably during the 2000s due to under-financing of operations and maintenance.

In recent years, as the financial situation in Lesotho has improved, financing for the road sector has gradually increased, focusing on the most hazardous and highly trafficked parts of the road network. However, the overall budget allocated to the sector remains inadequate to maintain the entire district road network in a stable condition. This research is going to present the application of World Bank's model Road Network Evaluation Tools (RONET) to strategic network level analysis of the Lesotho road network.

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2. CURRENT CONDITION OF THE COUNTRY ROAD NETWORK

It is imperative for Lesotho to have an efficient transport system, which ensures cost effective access to economic opportunities, internal and external markets and basic services. The country's mountainous terrain and landlocked situation creates an immense challenge to construct and maintain all weather roads to an adequate level. Hence, a reliable road network has been a lifeline to residents in the highlands and lowlands for centuries. This fact remains an increasingly significant priority for the Government as well as visitors to the country and the citizens. The Road networks as defined by the road networks information of the Lesotho Roads Management System- LRMS is as follows: (Fig 1)

- 1515 km are paved;
- 3,078 km are Unpaved roads
- 1149 km as Earth roads
- 117 km tracks.

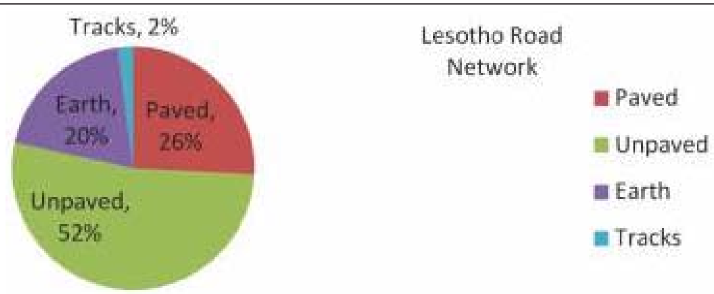

Figure 1: Network Consistency

Using the available data that is stored in a road database, analyzed state road network is length of 5,859 km. The structure of the network is the following: 26% of the paved roads, 52% of the unpaved, 20% of the Earth and 2% of Tracks roads.

The Lesotho Roads network is divided into two maintenance types, the Equipment Based Roads & the Labor Based Roads. As the maintenance types indicate, the former is maintained predominantly with equipment based methods and the latter by means of Labour based methods. Fig 2 represents the length of roads under equipment base maintenance. The north region and the central region have a longer length of roads than the south region while Fig 3 represents the length of roads under labor base maintenance. The north region and the south region have a longer length of roads than the central region.

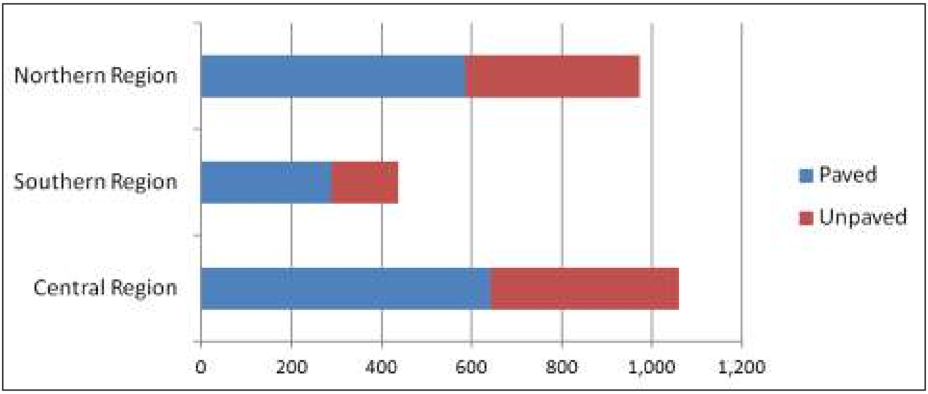

Fig 2: Roads Length (Km) by Pavement type with region (Equipment Based Maintenance) [Sentle M. Mpuru, 2012]

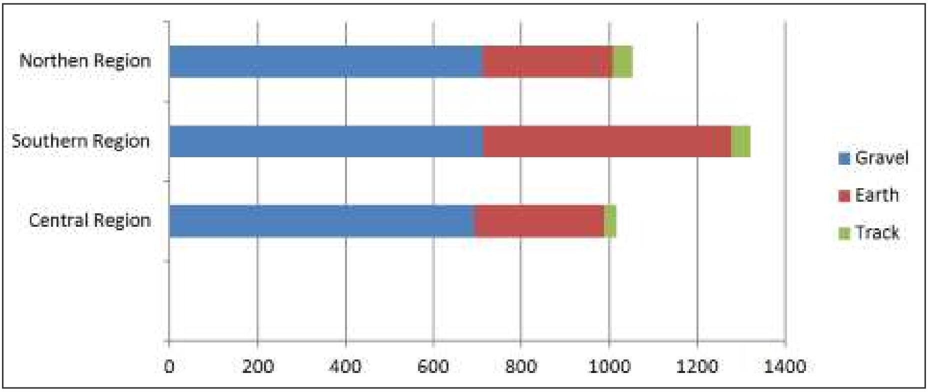

Fig 3: Roads Length (Km) by pavement type with region (Labor Based Maintenance) [Sentle M. Mpuru, 2012].

According to the road traffic surveys performed in 2012 Annual Average Daily Traffic (AADT) on the regional paved roads ranges between 0 and 5,000 vehicles per day (vpd), with very small percentage of network, in particular Central region, having AADT above 5,000 vpd. Figure 4 presents the road network split by traffic level for paved roads in accordance regions.

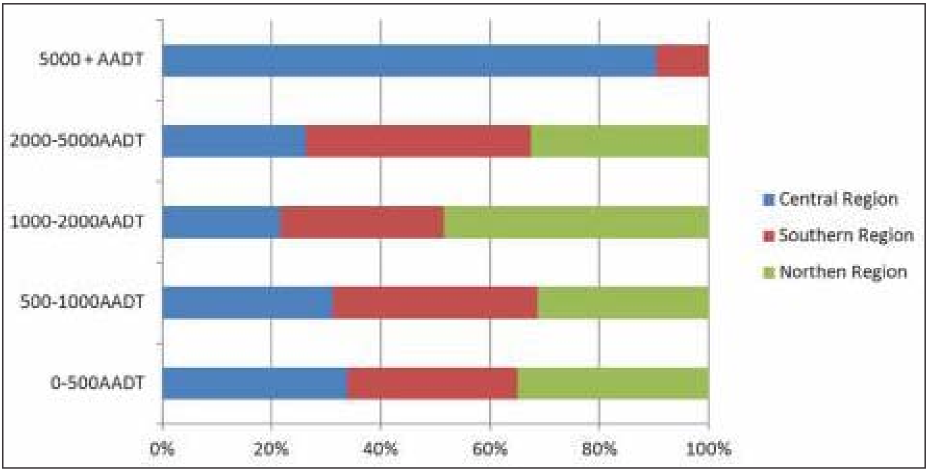

Fig 4: Traffic distribution of paved roads per region [Sentle M. Mpuru, 2012]

Traffic information is expressed as the Annual Average Daily Traffic (AADT), travelling on a road link in the road network. Further, the product of the ADT on a road link and its length represents the daily vehicle kilometers travelled on that link on a day. Summarized for the road network, they represent the total distance travelled by vehicles on the road network on a daily or yearly basis. In total 941 million vehicles–kilometers are travelled each year on the equipment based paved road network and the Equipment Based unpaved roads (Sentle M. Mpuru, 2012).However 53% of the total traffic occurs on the central region roads network. In addition, traffic levels are also related to road condition: 45% of the traffic on the roads in very good condition, opposite to only 5% of the traffic on the roads in very poor condition.

Overall, the Lesotho road network is currently in fair condition with an average roughness IRI = 3.9 m/km. About 50% of the network is in fair or worse condition.

3. DESCRIPTION OF THE RONET MODEL

The Road Network Evaluation Tools (RONET) model is being developed for the Sub-Saharan Africa Transport Policy Program1 (SSATP) by the Energy, Transport and Water Department, Transport Anchor (ETWTR), of the World Bank to assist decision makers to accomplish the following:

- Monitor the current condition of the road network
- Plan allocation of resources
- Assess the consequences of macro-policies on the road network
- Evaluate road user charges revenues

RONET is a tool for assessing the performance of road maintenance and rehabilitation policies and the importance of the road sector to the economy. This in turn demonstrates to stakeholders the importance of continued support for road maintenance initiatives. It assesses the current network condition and traffic, computes the asset value of the network and road network monitoring indicators. It uses country-specific relationships between maintenance spending and road condition, and between road condition and road user costs, to assess the performance over time of the network under different road works standards. It determines, for example, the minimum cost for sustaining the network in its current condition. It also estimates the savings or the costs to the economy to be obtained from maintaining the network at different levels of road condition. It further determines the proper allocation of expenditures among recurrent maintenance, periodic maintenance, and rehabilitation road works. Finally it determines the "funding gap," defined as the difference between current maintenance spending and required maintenance spending (to maintain the network at a given level of road condition), and the effect of under spending on increased transport costs.

4. CONFIGURATION OF RONET FOR LOCAL CONDITIONS

The RONET uses a simplified road deterioration model for paved roads [1] that calculates increment in pavement roughness as a function of traffic loading expressed as annual number of equivalent standard axles (ESAL), pavement modified structural number, sub grade bearing capacity, pavement age, and environmental coefficient that involves impact of local climate conditions (mean monthly precipitation and temperature regime) on pavement deterioration.

RONET defines five default treatments that should be applied depending on the road condition, which means that one maintenance treatment is applicable only to the road in a certain condition. The intensity and cost of maintenance treatment can be adjusted in the program. Maintenance treatments should be used in the study of Lesotho road network.

Country-specific road user costs are established by specific Road User Costs - Roughness correlation for each vehicle category:

Road User Unit Costs (\$/vehicle-km) = $a_0 + a_1 * IRI + a_2 * IRI^2 + a_3 * IRI^3$

Table 1: Applicability of Roads Maintenance Treatments

	IRI Range (m/km)	Maintenance Treatment	Routine Maintenance Cost($/Km)
Very Good	<3.0	Routine Maintenance(RM)	4000- 8000
Good	3.0-4.0	RM+Preventive Maintenance	5000- 7500
Fair	4.0-6.0	RM+Overlay50mm	5500-7000
Poor	6.0-8.0	RM+Overlay80mm	2500-4500
Very Poor	>8.0	RM+Reconstruction	3500-5000

Table 2: Maintenance Treatments with Associated Unit Costs

Maintenance Treatment	Periodic Maintenance Treatment Cost($/Km)
Routine Maintenance(RM)	23000-35000
RM+Preventive Maintenance	200,000-250,000
RM+Overlay50mm	300,000-350,000
RM+Overlay80mm	500,000-600,000
RM+Reconstruction	1,200,000-1,300,000

RUCKS (Road User Costs Knowledge System) model (Gryp Van Der., 2011) is used for computing coefficients a0, a1, a2, a3. Inputs are based on local prices, and local specific vehicle fleet characteristics, as well as on the geometrical and topographical features of the state road network. The horizontal curvature and rise and fall are used to define the terrain type.

Characteristics of representative vehicles for each vehicle category used in RUCKS model were based on the data used for development of road database. The structure of the traffic flow is weighted for all road sections that have predefined traffic level (Cirilovic Jelena et al, 2011).

A consensus has been growing among highway administrators, economists and engineers, in developed and developing countries alike, on using the principle of total transport cost minimization as a basis for determining road construction and maintenance policies. It has long been known that of the three main components of total life-cycle costs of a roadway, which also include those of road construction n and maintenance, the road user costs of vehicle operation (including ownership) and travel time are by far the largest and can amount to more than 90 percent for two-lane highways serving a few thousand vehicle per day or more.

Therefore, it is important to quantify empirically, as accurately as practicable, how road user costs are affected by road characteristics, including geometric standards, which reflect the amount of capital investment in the road, and surface standards, which reflect both initial capital and subsequent maintenance expenditures.

The variables that affect the cost of operating a vehicle on a given route may be divided into three broad groups:

Road attributes, which comprise the relevant geometric and surfacing characteristics of the route, e.g., vertical and horizontal alignments, road width, and surface profile irregularity or 'roughness'; Vehicle attributes, which comprise the relevant physical and operating characteristics of the vehicle, e.g., the weight, payload, engine power, suspension design, and number of hours and kilometers operated per year;

Regional factors, which comprise the relevant economic, social, technological and institutional characteristics of the region, e.g., the region-wide speed limit, fuel prices, relative prices of new vehicle, parts and labor,, stage of technological development, drive training and driving attitudes, such as lane discipline, and general attitude of vehicles drivers toward safety.

The approach to estimate road user costs is to model on country or region-specific basis physical components of vehicle operating costs, including principally speed, fuel consumption, lubricants consumption, tire wear, maintenance parts and labor, and depreciation and interest. Vehicle operating costs are computed simply by multiplying the predicted quantities of physical resources consumed with their relative prices. Travel costs are computed multiplying the travel time per unit distance (the inverse of vehicle speed) by the value of time. This physical-component approach yields models which, if correctly specified in form, are more easily transferable to new countries, since the most direct effects of prices have been remove (Archondo-Callao., 2009).

Table 3 & 4shows the collected vehicle fleet economic unit costs and basic characteristics from 44 HDM-4 applications worldwide to obtain an order of magnitude of current unit road user costs in Africa expressed in 2005 USD per vehicle –km.The vehicle fleet economic unit costs & basic characteristics vary by country. Therefore and effort was done to obtain average vehicle fleet economic unit costs and basic characteristics for regional average like Africa. With this input data, typical economic unit road user costs were computed, using worlds banks HDM-4 Road user costs model (version 1.00) for paved roads on a flat terrain with different roughness levels and the typical road user costs composition for paved road in good condition with roughness equal to 2.0 IRI , m/km.

Table 3: Presents the Africa region average vehicle fleet economic unit costs and basic characteristics

Description	Motor Cycle	Medium Car	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	Medium Bus	Large Bus
Economic Unit Costs								
New vehicle Cost ($/vehicles)	1,900	20,000	19,000	70,000	119,000	133,000	40,000	65,000
New Tire Cost ($/tire)	20.00	65.00	90.00	275.00	290.00	290.00	110.00	215.00
Fuel Cost ($/litre)	0.39	0.39	0.38	0.38	0.38	0.38	0.38	0.38
Lubricant Cost ($/litre)	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
Maintenance Labor Cost ($/hour)	1.18	3.68	4.78	4.78	5.37	5.82	5.41	5.41
Crew Cost ($/hour)	0.40	0.52	1.07	2.00	3.67	3.67	1.88	1.88
Overhead ($/year)	26	69	138	138	280	280	177	208
Interest Rate (%)	12	12	12	12	12	12	12	12
Working Passenger Time ($/hour)	0.60	0.60	0.38	0.38	0.38	0.38	0.38	0.38
Non-working Passenger Times ($/hour)	0.20	0.20	0.11	0.11	0.11	0.11	0.11	0.11
Cargo Delay ($/hour)	0.00	0.00	0.11	0.11	0.11	0.11	0.00	0.00
Basic Characteristics								
Kilometers Driven per Year (km)	15000	24000	59000	67000	69000	65000	90000	103000
Hours Driven per Year (hr)	700	880	1500	2200	2300	2400	2800	2700
Service Life (years)	9	9	9	9	10	9	6	10
Percent Private Use (%)	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Number of Passengers (#)	1.0	3.0	1.0	1.0	1.0	1.0	30.0	42.0
Work-related Passenger-Trips (%)	75.0	75.0	0.0	0.0	0.0	0.0	75.0	75.0
Gross Vehicle Weight (tons)	0.3	1.6	4.6	13.9	28.2	36.5	5.0	11.9

(Source: Archondo-Callao., 2009)

Table 4: Presents the Africa region average economic unit road user costs and typical road Costs composition

Road User Costs per Roughness Level for Flat Terrain (US$ per vehicle-km)								
Roughness(IRI)	**Motor Cycle**	**Medium Car**	**Light Truck**	**Medium Truck**	**Heavy Truck**	**Articulated Truck**	**Medium Bus**	**Large Bus**
2	0.042	0.201	0.195	0.459	0.788	0.968	0.351	0.501
4	0.043	0.207	0.205	0.487	0.839	1.022	0.367	0.527
6	0.045	0.217	0.223	0.541	0.932	1.106	0.401	0.577
8	0.046	0.232	0.240	0.594	1.022	1.207	0.446	0.646
10	0.049	0.251	0.260	0.652	1.125	1.327	0.502	0.734
12	0.053	0.273	0.282	0.712	1.236	1.453	0.562	0.830
14	0.057	0.295	0.304	0.773	1.348	1.582	0.623	0.927
16	0.061	0.318	0.328	0.835	1.462	1.710	0.685	1.025
Road User Costs Composition for Flat Terrain and Roughness 2.0 IRI(US$ per vehicle-km)								
	Motor Cycle	**Medium Car**	**Light Truck**	**Medium Truck**	**Heavy Truck**	**Articulated Truck**	**Medium Bus**	**Large Bus**
Road User Costs	0.042	0.201	0.195	0.459	0.788	0.968	0.351	0.501
Vehicle Operating Costs	0.037	0.187	0.193	0.456	0.786	0.965	0.252	0.349
Fuel	0.018	0.043	0.059	0.093	0.181	0.248	0.073	0.109
Lubricants	0.001	0.002	0.004	0.005	0.009	0.010	0.005	0.007
Tire	0.001	0.003	0.006	0.016	0.027	0.051	0.008	0.017
Maintenance Parts	0.002	0.039	0.032	0.154	0.276	0.319	0.034	0.076
Maintenance Labor	0.002	0.009	0.042	0.048	0.069	0.077	0.041	0.048
Crew Time	0.000	0.000	0.012	0.022	0.042	0.039	0.020	0.022
Depreciation	0.012	0.078	0.030	0.096	0.143	0.186	0.062	0.052
Interest	0.002	0.013	0.008	0.021	0.036	0.035	0.009	0.017
Overhead	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
Value of Time Costs	0.005	0.014	0.002	0.002	0.003	0.002	0.099	0.152
Passenger Time	0.005	0.014	0.001	0.001	0.001	0.001	0.099	0.152
Cargo Time	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000

(Source: Archondo-Callao., 2009)

5. ROAD MAINTENANCE STANDARDS

RONET defines seven default maintenance standards that are based on different trigger levels for each maintenance treatment. The “Very High” standard represents a scenario with a high level of periodic maintenance and rehabilitation works. The “High”, “Medium”, “Low” and “Very Low” standards represent scenarios of reduced levels of road works expenditures. The “Do Minimum” standard represents a scenario where only reconstruction is applied at a very high road roughness, while no capital road works are applied over the evaluation period.

The maintenance standards for paved roads with trigger levels for treatment application applied in this study (Cirilovic et al, 2011) are presented in the table 5:

Table 5: The maintenance standards for paved roads

Scenario		Roughness Range and Required Maintenance Work				
		IRI<=4.0 Overlay	4.0<IRI<=6.0 Overlay	6.0<IRI<=8.0 Strengthening	8.0<IRI<=10.0 Reconstruction	10<IRI Reconstruction
Code	Name	Roughness Threshold (IRI)(m/km)				
A	Very High Standard	3.00	4.00	6.00	8.00	10.00
B	High Standard	3.25	4.50	6.50	8.50	10.50
C	Medium Standard	3.50	5.00	7.00	9.00	11.00
D	Low Standard	3.75	5.50	7.50	9.50	11.50
E	Very Low Standard	4.00	6.00	8.00	10.00	12.00
F	Do Minimum	99.00	99.00	99.00	99.00	14.00
G	Do Nothing	99.00	99.00	99.00	99.00	99.00

The routine maintenance costs presented in Table 1 are adopted for the "Very High Standard." These values were gradually reduced for lower maintenance standards, down to zero for the "Do Nothing" standard.

6. NETWORK-LEVEL MAINTENANCE STRATEGIES USING RONET

For each road class, defined by road condition, surface type and traffic level, RONET was used to evaluate all maintenance standards. Optimal standard is defined as the standard that leads to the lowest society costs and highest Net Present Value (NPV). Total society costs are the sum of road agency costs and road user's costs. The 'Optimal' strategy at network level consists of optimal strategies for each road class. The program also evaluates two higher ('Optimal + 1 and 'Optimal' + 2) and the three lower ('Optimal – 1, 'Optimal' – 2 and 'Optimal – 3) strategies that consist of application of higher and lower maintenance standards compared to the optimal one for each road class.

The base maintenance strategy, used for the calculation of benefits, is the 'Do minimum' strategy that consists of the application of pavement reconstruction at a relatively high roughness level. In addition the program evaluates the 'Do nothing' strategy that consists of no maintenance works (Papshane, 2012).

The obtained annual budgets for maintenance of Lesotho road network range up to $310million. For paved roads, it was found that the "Optimal" strategy consists typically of the application of all five maintenance standards. For unpaved roads, the optimal maintenance standard in all cases is "Very high" standard. However, the unpaved roads make up a small proportion of the network with substantially cheaper maintenance treatments, so this has a relatively small impact on the overall strategy.

The required annual maintenance and rehabilitation budget for the "Optimal" scenario is about to $83.3 million per year, which represents annual requirements of about $14,130 per kilometre. The economic internal rate of return for the optimal strategy is 60.0 %, as calculated by RONET.

7. CONCLUSIONS

The paper presented the application of World Bank's model RONET to a strategic network level analysis of the Lesotho road network. The current state of the network is fair, with considerable variation in road condition between different road classes.

Application of the RONET model to the prevailing conditions on the Lesotho network led to an optimal M&R strategy with a good balance between rehabilitation, periodic and recurrent maintenance. The corresponding ("optimal") budget for the Lesotho road network was found to be $153 million over the 20-year analysis period. The implementation of the "Optimal" M&R strategy would cause considerable improvement compared to the current condition of the state network. Implementation of higher M&R standards would lead to substantially higher road agency costs and consequently lower net benefits, while the implementation of lower M&R standards would lead to considerably worse network condition for approximately the same or slightly lower agency costs. This means that even slight budget constraints (i.e., budget below the "optimal" level) would result in substantially worse network condition and much higher total road transport costs. It is anticipated that practical applications of the study described in this paper can assist road agencies in transition and developing countries to make a convincing case to obtain maintenance and rehabilitation budgets that are close to the "optimal" level.

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