PAVEMENT MANAGEMENT ANALYSIS USING RONET: CASE OF THE FREE STATE PROVINCE

By

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ABSTRACT

Currently, more than 40% of roads in the Free State are in very poor condition as a result of underfunding, lack of technical capacity, lack of maintenance, increased vehicle tyre pressure, increased traffic volumes, and more. Moreover, it was discovered that local municipalities do not have a tool to strategize their maintenance expenditure. This research study was undertaken in an attempt to address this challenge, and with the intention that RONET be introduced to the Free State road network at some stage. This would be done in an effort to improve the conditions of this road network by addressing maintenance and rehabilitation backlogs. The study was limited to roads in the Free State province as the data was available to the researcher.

This research study presents the application of the World Bank's model, the Road Network Evaluation Tools (RONET), to perform a strategic network level analysis of the road network of the Free State province. As already mentioned, the condition of this network deteriorated considerably during the early 2000s due to under-financing of operations and maintenance, increased vehicle tyre pressure, increased traffic volumes, etc. In recent years, financing for the road sector has gradually increased, focusing on the dangerous and highly trafficked sections of the road network. However, the overall budget for the road sector remains inadequate to maintain the entire road network in a stable condition (Free State Department of Roads, 2002).

The primary goals of RONET are to design and obtain an 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 the RONET model will lead to an optimal maintenance and rehabilitation strategy with a good balance between rehabilitation, periodic and recurrent maintenance. The implementation of an optimal maintenance and rehabilitation strategy would cause major improvement compared to the current condition of the network. Implementation of higher than optimal maintenance and rehabilitation strategies would lead to higher costs and subsequently lower net benefits, while implementation of lower than optimal maintenance and rehabilitation standards would lead to considerably worse network conditions for slightly lower agency costs. In other words, even minor budget constraints would result in considerably higher total road transport costs, impacting on the province's economy. The undertaking of appropriate road maintenance of even a small road network is difficult without some form of road maintenance management plan, hence the study to

investigate RONET in an attempt to enable road authorities to formulate a feasible business plan to curb the maintenance and rehabilitation backlog.

Decision makers can use the Road Network Evaluation Tools model to appreciate the current state of the network, determine its relevant importance to the economy and compute a set of monitoring indicators to assess the performance of the road network. RONET assesses the performance of the road network, over time, under different road maintenance standards. It determines, for instance, the minimum cost of sustaining the network in its current condition and estimates the savings or the costs to the economy for maintaining the network at different levels of service. RONET further determines the allocation of expenditure among routine maintenance, periodic maintenance and rehabilitation road works. Moreover, it determines the optimal maintenance standard for each road class (highest Net Present Value) and compares it with the current (budget constraints) and other maintenance standards. Lastly, it determines the "funding gap", which is defined as the difference between current maintenance spending and required maintenance spending (to maintain the network at a given level of service), and the effect of under-spending on increased transport costs. The new Road User Revenues module estimates the level of road user charges required (e.g. fuel levy.)

The application of RONET will lead to an optimal Maintenance and Rehabilitation (M & R) strategy with a good balance between rehabilitation, periodic and routine maintenance. Implementation of the "Optimal" maintenance and rehabilitation strategy will result in an improvement to the current condition of the network. Implementing RONET will alleviate the backlog and bad conditions of the Free State road network, which was caused by the lack and/or shortage of experienced technical staff in government.

RONET will also be used to assess the current characteristics of the road network and its future performance depending on different levels of network funding. The future performance of the road network under different funding levels will also be simulated.

List of Acronyms and Abbreviations

AADT	Average Annual Daily Traffic
CSIR	Council for Scientific and Industrial Research
DoT	National Department of Transport
dTIMS	Deighton Transport Infrastructure Management System
EPWP	Expanded Public Works Programme
ESA	Equivalent Standard Axles
GDP	Gross Domestic Product
HDM	Highway Development and Management
IRI	International Roughness Index
Km	Kilometer
KZN	KwaZulu-Natal Province
NPV	Net Present Value
PAM	Performance Assessment Model
PMS	Pavement Management System
PPP's	Public-Private Partnerships
RAFU	Road Agency Formulation Unit
RAI	Rural Access Indicator
RED	Road Economic Decision Model
RM	Road Maintenance
RMI	Road Management Initiative
RMMS	Road Maintenance Management System
ROCKS	Road Cost Knowledge System
RONET	Road Network Evaluation Tools
RUC	Road User Charges Model
RUCKS	Road User Cost Knowledge System
SANRAL	South African National Road Agency Limited
SARF	South African Road Federation
SSATP	Sub-Saharan Africa Transport Policy Program
ST	Surface Treatment
USD	United States Dollar
VDoT	Virginia Department of Transport, USA
VOC	Vehicle Operating Costs

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CHAPTER 1: INTRODUCTION

1.1 Background

The condition of the road network is perhaps the only municipal and provincial service that impacts on all residents regardless of their financial standing. If appropriate routine and periodic maintenance are correctly and timely applied to a road, the road will give an acceptable level of service until such time that the structural design loading is reached. Many roads actually exceed this point significantly before requiring major structural repairs. If roads are not adequately maintained they will fail prematurely. The allocation of routine and periodic road maintenance funding is habitually insufficient to address actual needs and preserve the road network in an acceptable condition. The consequence of under-funding is an expanding backlog of maintenance and an exponentially increasing budget deficit (Maree et al., 2012).

The American Association of State Highway and Transport Officials, 2001 stated that there is a strong need to have a system for management and maintenance of surfaced roads. Engineers globally invested funding in developing a system that could solve the problem at hand, until the Pavement Management System (PMS) was adopted as an effective solution to pavement management in the 1950s (The American Association of State Highway and Transport Officials, 2001).

Before the development of the Pavement Management System, countries typically established yearly road maintenance budgets that emphasized maintenance improvements on a worse-case first basis, or in response to citizen complaints and political priorities. This approach worked satisfactorily for most communities as long as sufficient funding was available. However, while funding sources dried up and maintenance budgets remained the same or decreased, the need for improvements increased due to greater traffic volumes, aging of pavements and inflated material cost (Mapikitla, 2012).

Instead of providing preventative maintenance at an early stage, authorities often wait until much more expensive reconstruction is needed to reach a satisfactory and safe road condition. Unfortunately, the short span of extra service years, during the delay of maintenance, is purchased at a very high price in terms of increased upgrade costs. This is one reason why a decision-making tool, such as RONET, is needed in order to curb the maintenance and rehabilitation backlog to orderly prioritize the repair of roads.

Instead of preparing a typical one-year maintenance budget, RONET allows road authorities to prepare a series of budgets, known in the Free State as the Medium Term Expenditure Framework. RONET assesses the performance over time of the road network under different road maintenance standards. It determines, for example, the minimum cost of sustaining the network in its current condition and estimates the savings or the cost to the economy of maintaining the network at different levels of service**.** RONET determines the allocation of expenditure among recurrent maintenance, periodic maintenance, and rehabilitation road works. The model allows for the prioritization of routine and periodic maintenance as well as rehabilitation projects based on cost and condition ratings and other factors, such as traffic. It further can be used for selecting and ranking projects for the upcoming budget year, as well as for long term financial planning.

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, calculates the network asset value 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 cost to the economy from maintaining the network at different levels of road condition. It further determines the proper allocation of expenditure 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.

1.2 Free State Road Network

The Free State is centrally situated in South Africa and is surrounded by six of the nine provinces in the country, as well as by the Mountain Kingdom of Lesotho. Major national roads traverse the province, of which the N1, N3, N5, N6 and N8 are the most important. Since 2003 the roads administrative regions of the Free State have changed from six regions (Kroonstad, Winburg, Heilbron, Bethlehem, Bloemfontein-East and Bloemfontein-West) to five regions (Lejweleputswa, Fezile Dabi, Thabo Mofutsanyane, Xhariep and Motheo).

The borders of the new regions do not correspond with those of the former regions and the historical data on the condition of the road network in the regions can thus not be transferred directly to the new regions (Heyns and Viktor, 2011).The former regions were incorporated into the new regions as follows:

Xhariep district: Consists of most of the old Bloemfontein-West region as well as the southern part of the old Bloemfontein-East region. The northern part of the Bloemfontein-East region is now incorporated into Lejweleputswa. The historical data of the Bloemfontein-West region is used for the Xhariep region.

Motheo district: Consists of mostly the northern part of the Bloemfontein-East region (higher traffic volume roads) as well as the eastern part of the old Winburg region. The historical data of the Bloemfontein-East region is used for the Motheo region (Heyns and Viktor, 2011).

Lejweleputswa district: Consists mostly of the old Winburg region as well as the western part of the Kroonstad and the northern part of the Bloemfontein-West regions. The historical data of the Winburg region is used for the Lejweleputswa region.

Fezile Dabi district: Consists mostly of the Heilbron region as well as the northern part of the Kroonstad region. The historical data of the Heilbron region is used for the Northern Free State region. Sasolburg, Kroonstad, Parys, Heilbron and Vredefort form part of this region.

Thabo Mofutsanyane district: Consists mostly of the Bethlehem region and eastern part of the Winburg region. The historical data of the Bethlehem region is used for the Thabo Mofutsanyane region (Heyns and Viktor, 2011).

The province comprises five district municipal areas. The size of the different district municipal areas, as well as the population sizes of these districts are presented in Table 1.1.

Table 1.1: Size and population per district (Lehohla, 2011)

DISTRICT	SIZE OF DISTRICT (KM^2)	%	POPULATION SIZE	%
Xhariep	34 132	26%	135 273	5%
Motheo	15 950	12%	728 259	27%
Lejweleputswa	34 686	27%	657 012	24%
Thabo Mofutsanyane	21 273	16%	725 933	27%
Fezile Dabi	23 423	16%	460 324	17%
AVERAGE	25 893	18%	541 360	20%
TOTAL	**129 464 km^2**	**100**	**2 706 765**	**100**

Table 1.2: Road length per district municipality (Heyns and Viktor, 2011)

DISTRICT	Length of surfaced roads (km)	%	Length of gravel roads (km)	%
Xhariep	788	12.4%	4900	22.6%
Motheo	723	11.4%	2441	11.2%
Lejweleputswa	1809	28.5%	4718	21.7%
Thabo Mofutsanyana	1560	24.6%	5676	26.1%
Fezile Dabi	1463	23.1%	3976	18.3%
Average	1269	20%	4342	20%
TOTAL	**6343**	**100%**	**21711**	**100%**

These figures indicate that 78% of the population is evenly distributed between three districts, with Xhariep having the smallest population representing only 5% of the entire province. The Motheo region is the most urbanized and densely populated area with 52 people per km², while Thabo Mofutsanyana has the most people (52%) still living in rural areas. However, the majority of the rural population of Thabo Mofutsanyana resides within the Maluti-a-Phofung area, which is regarded as being peri-urban in nature.

Lejweleputswa, Thabo Mofutsanyana and Fezile Dabi have more than the average number of surfaced roads and Xhariep and Motheo have less than the average number of surfaced roads. Xhariep, Lejweleputswa and Thabo Mofutsanyana have more than the average number of gravel roads and Motheo and Fezile Dabi have less than the average number of gravel roads. Motheo is a relatively small district and would therefore have less roads (gravel and surface). Xhariep is an area with relatively less rainfall than the northern regions and would therefore have less intensive farming activities, which would require a less dense road network. The three northern and north eastern districts have a high intensity of rainfall areas as well as mining areas, which would require a denser road network.

From 1998, the length of the paved network remained relatively constant at 7222 km, which at that stage included approximately 879 kilometers of proposed national routes that were maintained by the Provincial Government. These roads were taken over by SANRAL in 2003 and were then not to be part of the Provincial network (Free State Roads Department, 2011). The figure below gives an indication of the condition of the Free State province road network in 2011.

Figure 1.1: Condition of the Free State road network (Free State Roads Department, 2011**)**

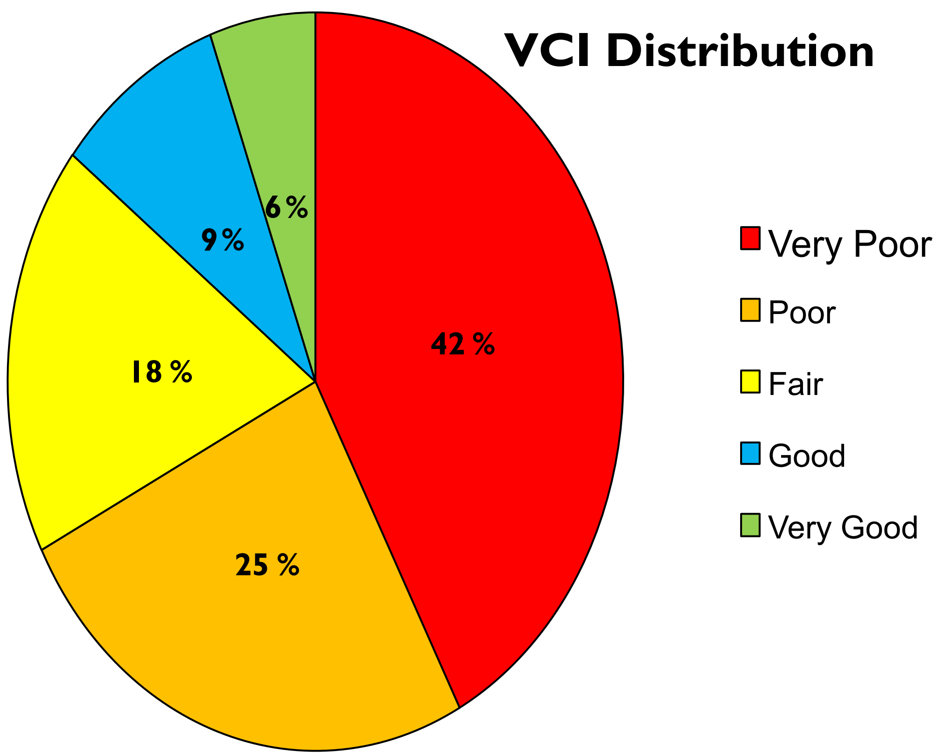
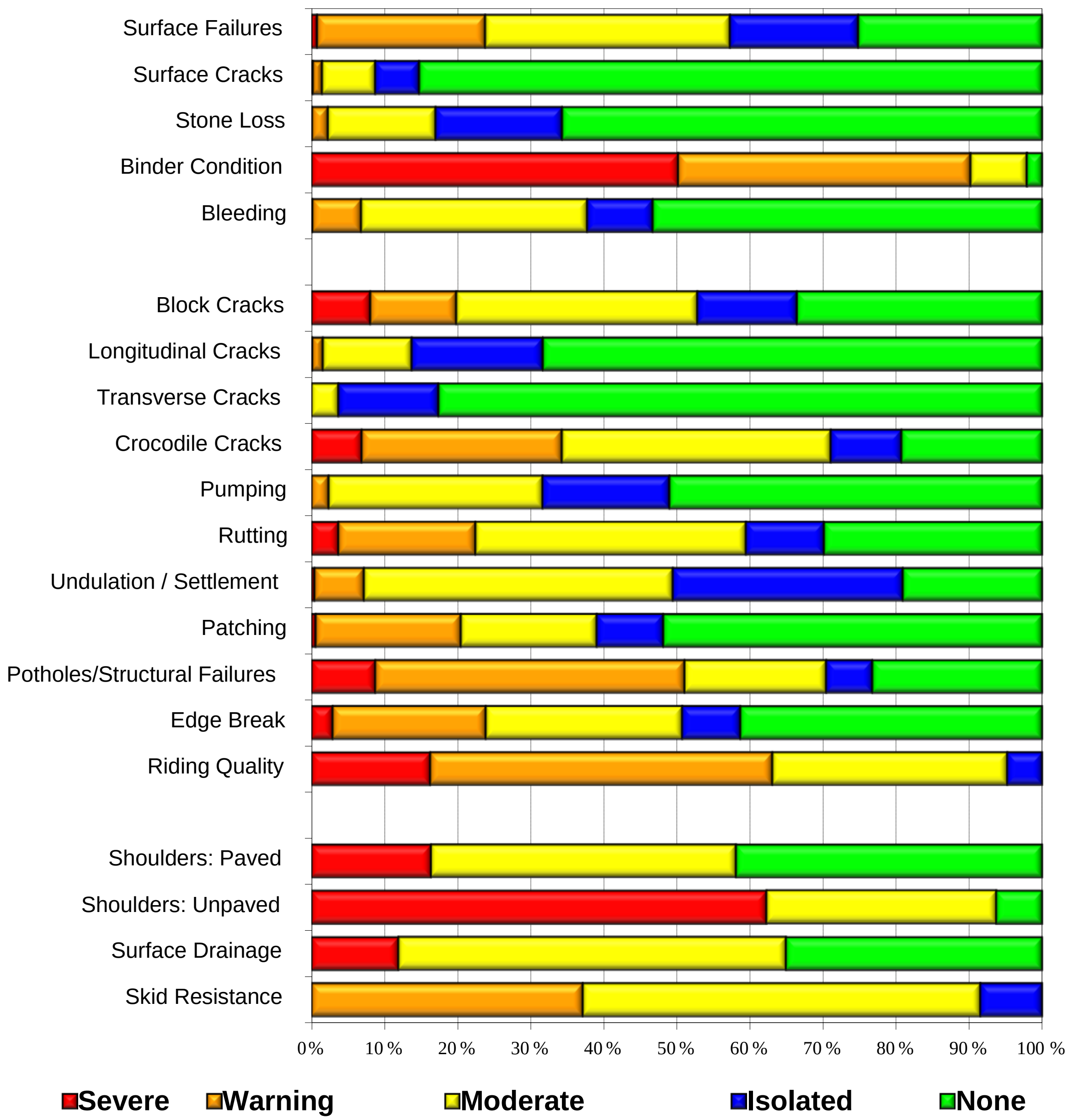


Table 1.3 Calculation of Visual Condition Index for paved obtained from Technical Recommendations for Highways 22 (TRH 22, 1994)

Condition category	***VCI***	***General description***
Very good	> 85	The road segment appears very good and the ride is comfortable. No potholes, cracks or unevenness are visible. Newly built roads or roads recently reconstructed typically fall into this category.
Good	70 – 85	The road segment appears good and no discomfort is experienced. Very few cracks and unevenness are visible and only isolated patches. A new road normally deteriorates to this category within three years.
Fair	50 – 70	The road segment still appears to be in good condition but closer examination will show cracks, potholes and unevenness. Road users will experience slight discomfort. These roads should be considered for resealing.
Poor	30 – 50	The road segment appears in poor condition. Potholes, cracks, unevenness and patchwork commonly occur, indicating structural failure. The ride is becoming uncomfortable and rehabilitation of these roads should be considered.
Very poor	< 30	The road segment looks bad and the ride is uncomfortable. Severe potholes, cracks, structural failures and unevenness occur regularly and extensively. These roads should be reconstructed soon.

Calculation of Visual Condition Index (VCI) for every paved road segment according to the **TRH22** guidelines and weights of the various distresses. The VCI ranges from 0 to 100, with 0 indicating a very poor pavement, and 100 indicating a very good pavement.

Figure 1.2: TMH9 Distress Analysis (TMH 9, 1992)



1.3 Problem Statement

1.3.1 Current trends in the Free State province

Currently, in the Free State, there is no specific software, such as HDM-4 or RONET, being used to draft a business plan for short, medium and long term periods. Instead, to determine the road maintenance budget (for both maintenance and rehabilitation) necessary for the next 25 years an algorithm that simulates the expected behavior of the road network with different budget levels has been developed. This algorithm is not a true optimization procedure but rather a heuristic method that has been developed based on experience of the behavior of the road network (Heyns and Viktor, 2011).

In order to formulate the algorithm the following assumptions are made with regard to the behavior of the road network as well as the expenditure of the available budget (Heyns and Viktor, 2011).

Figure 1.3: Predicted road network condition calculated on current funding levels (Heyns and Viktor, 2011)

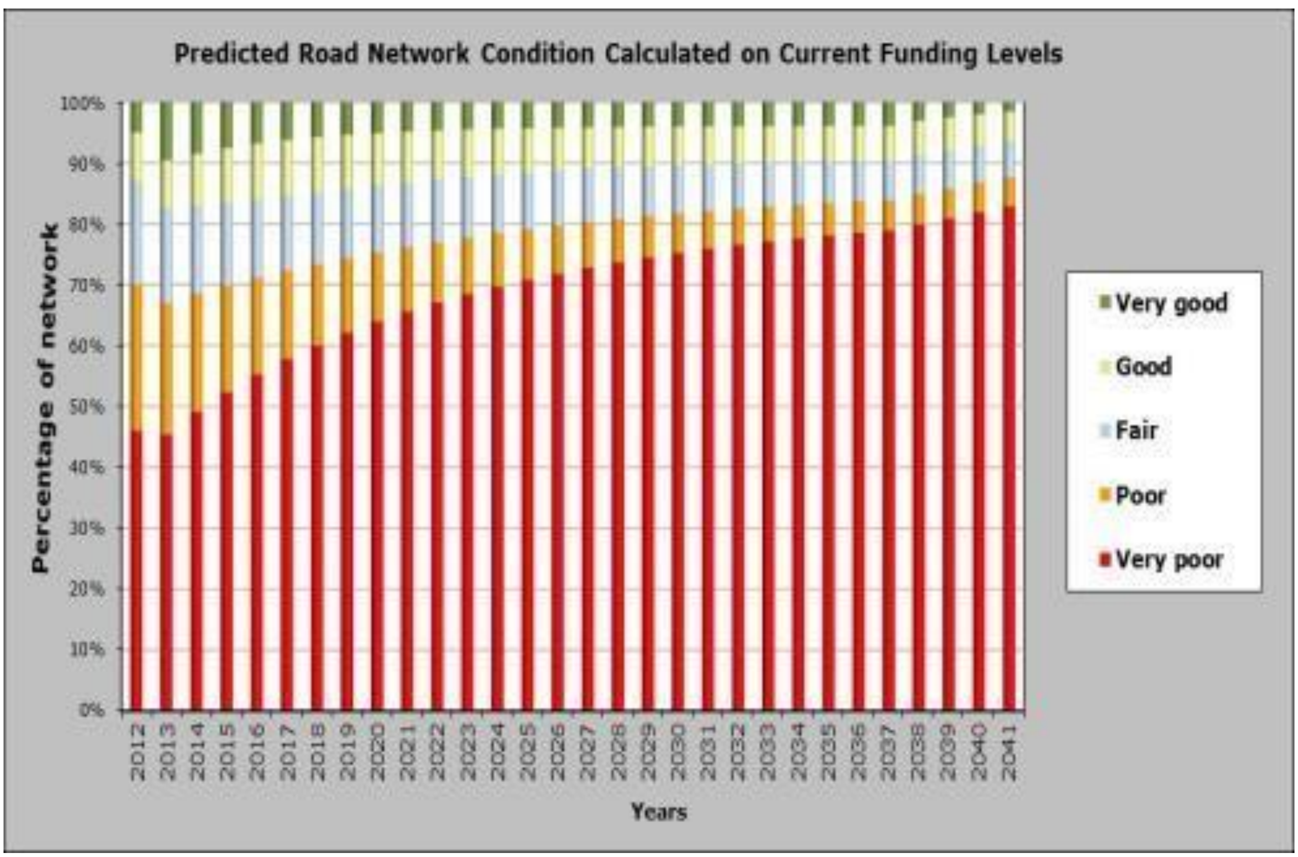


Figure 1.4: Road condition based on historic and predicted funding levels

(Heyns and Viktor, 2011)

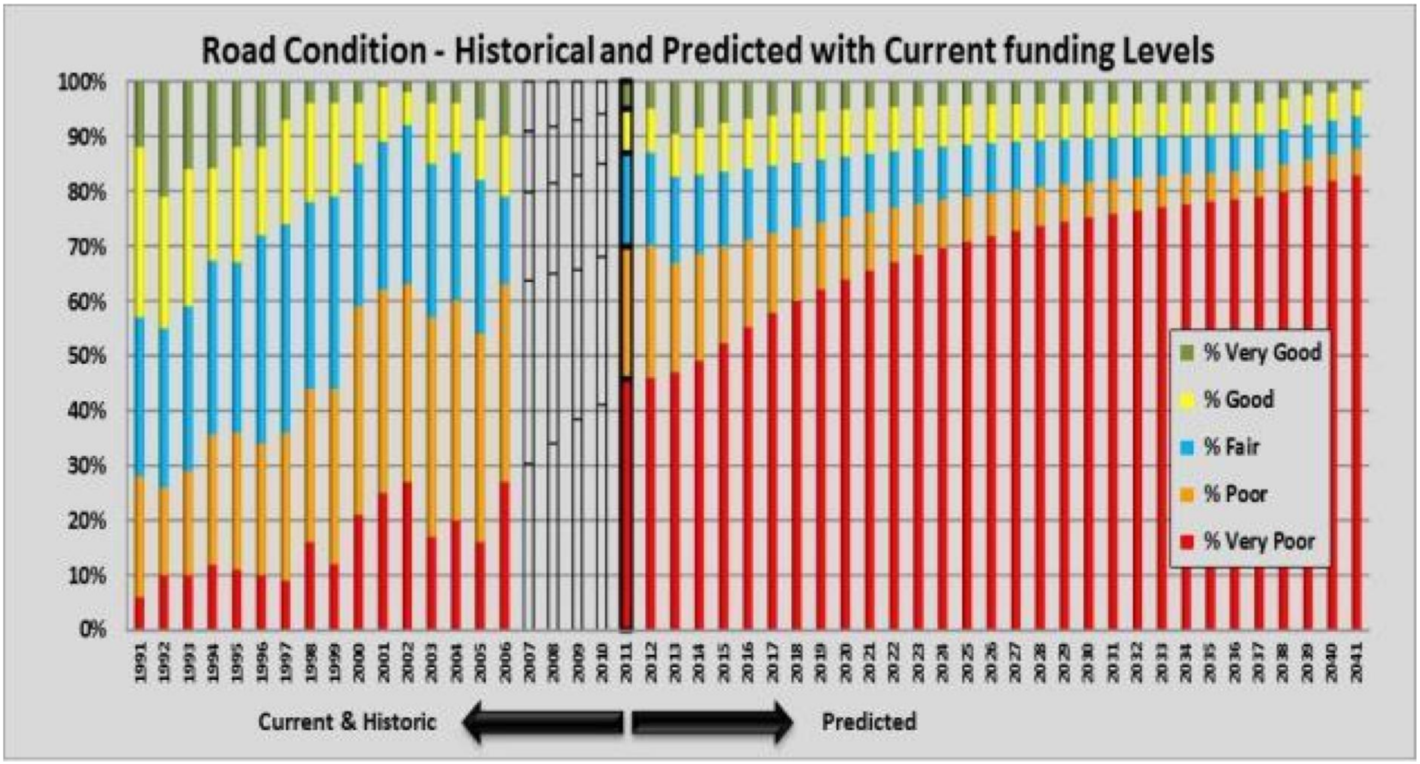


Figure 1.5: Predicted road network condition calculated with 100% more budget

(Heyns and Viktor, 2011)

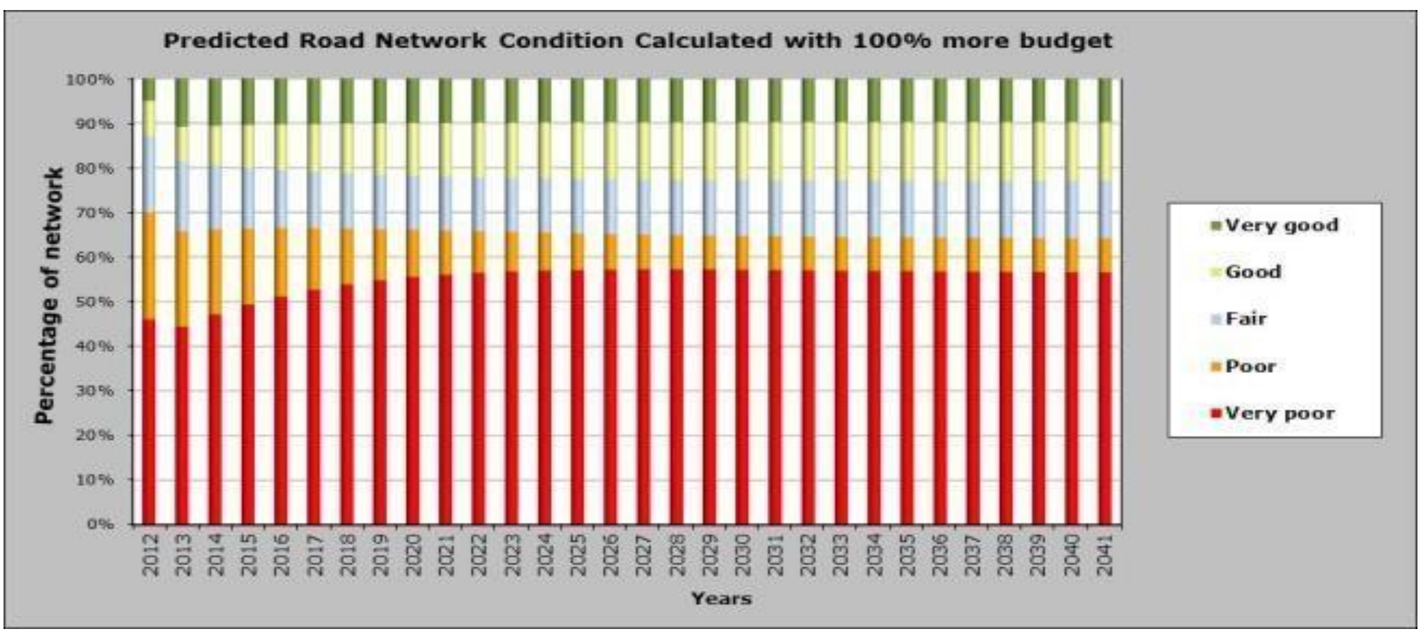
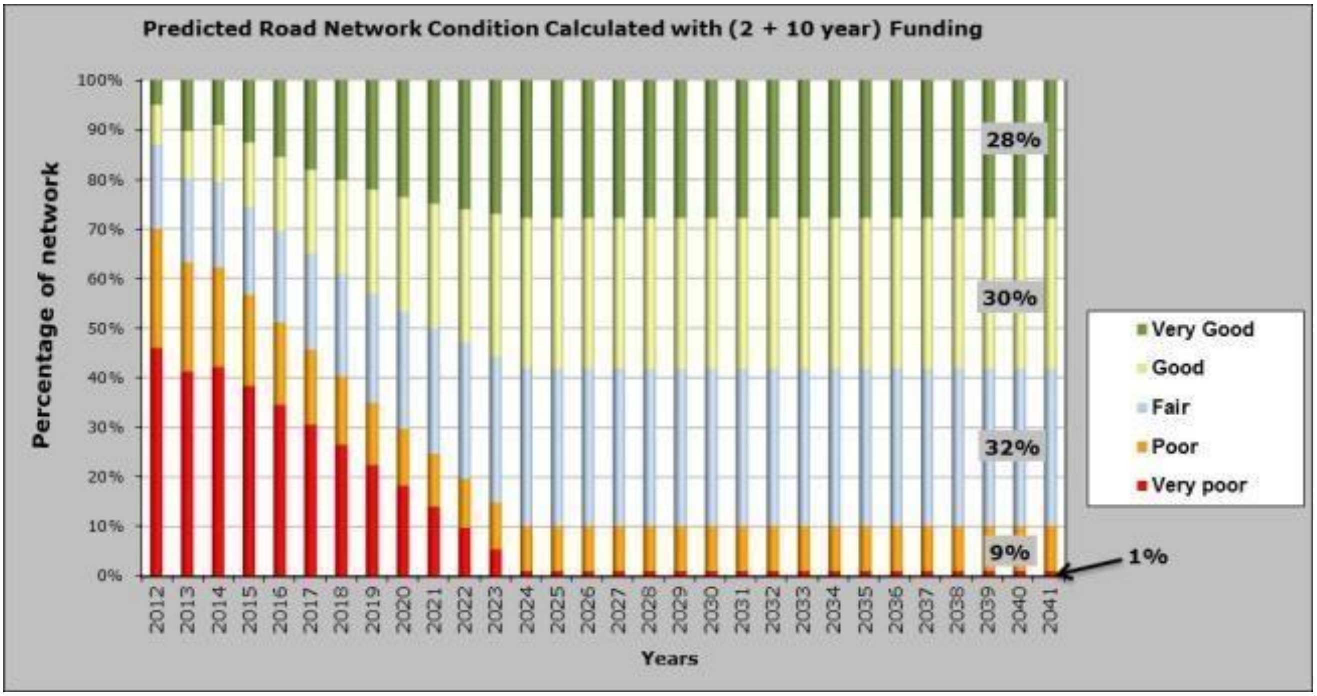


Figure 1.6: Predicted road network condition calculated with (2 + 10 year) funding (Heyns and Viktor, 2011)



One such assumption is that the deterioration rate of the roads from one condition category to the next is not linear but simulates the traditional condition curve of a road.

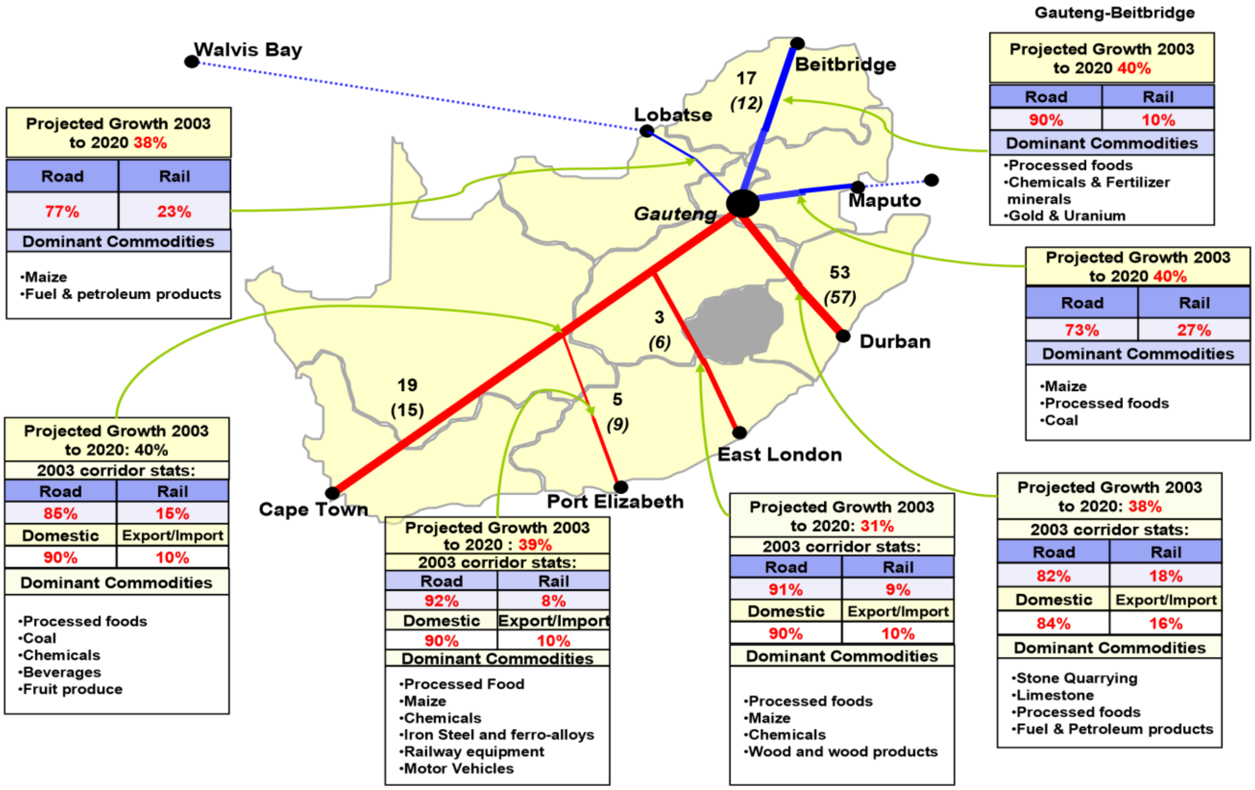
The percentage of the budget allocated to roads in each condition category is based on the assumption that rehabilitation work are more concentrated on the roads in the very poor condition category and reseal work are more concentrated on the roads in the poor and fair condition categories. The unit costs are based on the same unit costs as used in the CAPEX spreadsheet (Heyns and Victor, 2011). The unit costs are average costs and not linked to level of roads or traffic volumes.

Roads that are rehabilitated move to the very good category due to the major improvement in condition. Roads that are resealed only move to the good category as the pavement is not strengthened enough to justify movement to the very good category.
Based on the major assumptions listed above and the built-in heuristic model that has been developed, three possible scenarios of expenditure were analyzed.

Scenario one follows the current budget and expenditure for the next 25 years. Current values are used. It is assumed that budget increase will be affected to take inflation into account. **Picture 1.1: Free State Province Map** (Google map, 2014)

Picture 1.2: The extent at which the Free State network is utilized

(Free State RAMP, 2014)



From Figure 1.2 it can be seen that the Free State province is situated in the center of the Republic of South Africa and is bordered by Gauteng, North West, Mpumalanga, Eastern Cape, Northern Cape and KwaZulu-Natal provinces as well as the Mountain Kingdom of Lesotho. This suggests that the majority of cargo, grains, fuel, vegetables, passengers, etc. that are transported in the country is transported via the Free State. As a result the road network in this province is under constant heavy loads and as such it must be maintained regularly as it plays a big role in the economy of the country. The safety of the road users must be ensured as well.

Figure 1.7: Free State road network Visual Condition Index in 2014

(van Wyk, Phume, Sekhaolela and Mosianedi, 2014)

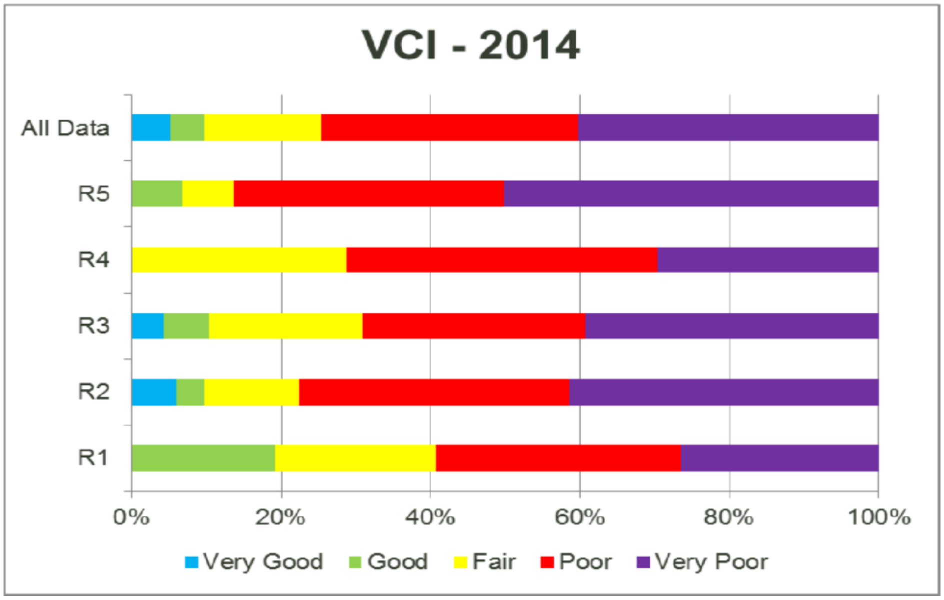
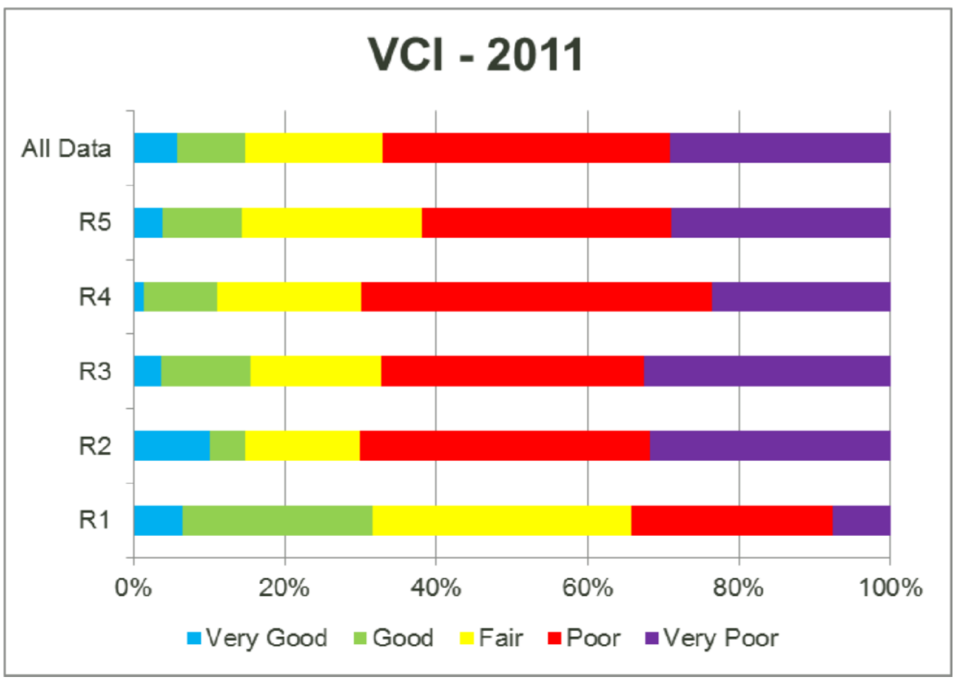


Figure 1.8: Free State road network Visual Condition Index in 2011

(van Wyk et al, 2014)



A comparison of the 'All Data' horizontal bar of the two graphs indicates a deterioration of the paved network with an increase of the % poor and very poor roads from 67% to 75% respectively (Free State Province Road Asset Management Systems, 2014). It should, however, be kept in mind that the 2014 data only represents approximately 76% of the total paved network. However, it is expected that the rest of the paved network, consisting of the S and T-prefixed roads, will typically be in worse condition. It can therefore be concluded that the paved network has deteriorated between 2011 and 2014. However, it must be stated that the two visual assessments under comparison here were done according to different assessment approaches. The 2011 and 2014 visual assessments were done on the road according to the TMH9 prescribed approach.

"Good", "Fair", and *"Poo*r" and *"Very Poor"*. The *"Very Poor"* category describes roads with functional and/or structural distress over the full extent of the road. Due to the poor condition of the road network the department not only classified the very poor roads as *"very poor"* but also assessed the very poor roads into an additional category, namely "non-trafficable". The "non-trafficable" roads are roads where a driver cannot drive on the road without having to negotiate potholes/undulations without reducing speed to a standstill, and/or, in some cases, even has to drive on the shoulder of the road to avoid accidents and/or dangerous conditions. Of concern is that 6% (400km) of the road network was assessed as being in the below very poor condition.

1.3.2. Funding

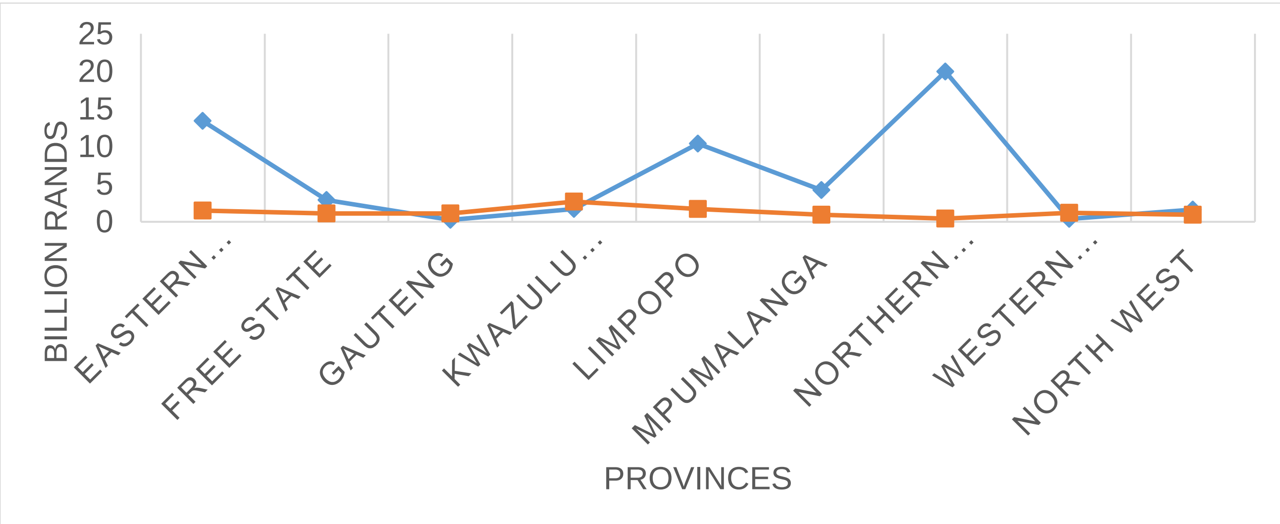
1.3.2.1 Actual funds allocated to provinces versus actual needs of provinces

(National Department of Transport, 2011)

Current technical guidelines provide for five classes of road conditions, i.e. *"Very Good"*, In 2008 the South African Council for Scientific and Industrial Research discovered that the funds that the National Treasury allocated to departments of roads in different provinces for road maintenance and rehabilitation were considerably below what the provinces needed at that time. In the Free State, for instance, the province needed R2.9 billion and was allocated R1.1 billion only; the Eastern Cape Province received R1.5 billion instead of R13.5 billion. The report further indicated that the Limpopo province needed R10.4 billion and only received R1.7 billion, whereas Mpumalanga received R0.94 billion instead of the

R4.2 billion required. The Northern Cape and North West provinces received R0.419 billion and R0.923 billion respectively, instead of R20 billion and R1.6 billion that they needed respectively. In total the provinces were in need of R52.5 billion and received R6.582 billion (10.6%). The only provinces that received more than what they needed were Gauteng, KwaZulu-Natal and the Western Cape.

Figure 1.9: Needed budget vs Allocated budget (National Department of Transport, 2011)



1.3.3. Capacity

One of the factors that contribute immensely to the deterioration of the South African road network is the lack of capacity in the form of technical staff employed in roads and transport departments (based on 2006 Survey of five provinces). Vacancy rate statistics indicated then that on average each department had 11 senior engineers, three younger engineers and two candidate engineers. While the Western Cape, Gauteng and KZN were relatively well resourced with senior engineers, subjective evidence shows a change on the down side for these provinces.

The Department of Roads and Transport in the Free State shows from the eight construction engineers that are needed, only one is employed and from the 20 construction technicians that are needed, only four are employed. Of the four maintenance engineers that are needed, only one is employed and of the five technicians required, only one is available. Furthermore, it shows that of the four design engineers required, only one is employed. There are no design technicians currently employed although the province requires the services of 10 design technicians. It also shows that the province is in need of nine planning engineers but only one is available, and seven planning technicians are employed instead of the 20 needed. In total, the province needs 25 engineers but currently only four are employed. The same goes for the 55 technicians that are needed, of which only nine are currently employed. These numbers show the actual number of engineers and technicians that are currently employed within the South African government compared to the number of skilled persons actually needed.

For instance, in 2010, the Free State provincial government was forced to deal with its deteriorating road network after the province received claims worth R68.5 million from motorists for pothole damage over a two-year period. Secondly, the Free State has 6370 km of surfaced roads and 22179 km of gravel roads. As a result of budget shortfalls and a lack of experienced and skilled managers, the majority of these roads are in a poor state and require urgent rehabilitation (Ndebele, 2012).

Although 23 contracts were issued in the Free State for maintenance and repair work on a design, construct and finance basis, the delivery of these services to the people did not materialize due to the fact that most of these projects were subsequently abandoned as a result of non-payment of contractors. The National Treasury has asked SANRAL for intervention in order to ascertain whether the contracts were priced at the right level, and to determine whether the province may have overpaid some of the contractors (Ndebele, 2012).

Therefore, since there is a shortage of engineers and technicians in the province, RONET will be introduced to curb the maintenance and rehabilitation problems since it does not rely on specialists to run the model, its outputs are not limited and it does not require any external manipulation as compared to HDM4 (Highway Development and Management 4, 2015).

1.3.4 HDM Calibration

One of the most important elements for an efficient pavement management system is the deterioration forecasting modeling. The HDM-4 (Highway Development and Management 4) model, developed by the World Bank, is used in more than 100 countries globally. However, many users often encounter challenges related to calibration limitations, and question the reliability of their results due to the extremely large number of parameters and difficulty in the calibration procedure of deterioration models in the HDM-4 (Daeseok, Koboyashi and Myunsik, 2012). The current calibration method is based on the Network-based approach which was introduced by the HDM-4 developer and has several limitations in describing the exact deterioration progress, and practical application. In fact, many HDM-4 users often give up implementation due to these reasons (Daeseok et al, 2012*).*

Although the HDM-4 model is popularly used and is a powerful software for better road investment, many users have encountered challenges in handling and calibrating the HDM-4 model because of its extremely large number of parameters and various functions. In order to implement the HDM-4 model, various procedures to calibrate road networks, vehicle fleets, economic indices, environmental factors, deterioration models, and unit cost are required for matching local conditions. Among others, a calibration procedure for deterioration models is one of the most important requirements for successful implementation (Daeseok et al., 2012).

Most countries and case studies have expressed positive opinions about their implementation of the HDM-4 model. Nonetheless, they often point out problems related to the calibration limitation, and question the reliability of their results. Due to the limitation of the calibration data, the first level of calibration is usually performed under a Network-based approach, which can be applied by a desk study with simple data (Bennett and Paterson, 2000).

1.3.5 Justification

The main objective of the study is to introduce a decision support tool, the Road Network Evaluation Tools model (RONET), for road network maintenance. This tool will assist road authorities in efficient decision-making, provide feedback as to the consequences of these decisions, ensure consistency of decisions made at strategic level and improve the effectiveness of all decisions in terms of efficiency of results.

1.4 Research aims

The aims of this research study are to:

1. Assess the current characteristics of road networks and their future performance depending on different levels of interventions to the networks;
2. Estimate the impact of different funding levels on the future quality;
3. Estimate the consequences of budget constraints; and
4. Encourage road authorities in South Africa, especially at provincial and municipal levels, to apply RONET in order to determine the future needs of their road network and to plan accordingly in terms of budgeting.

1.5 Research Objectives

To achieve the aims of this research, the following specific objectives need to be considered:

1. To evaluate the efficiency of RONET compared to that of other software such as dTims and HDM-4;
2. To calculate increment in pavement roughness; and
3. To determine the meaningfulness of the study and to reach a conclusion.

CHAPTER 2: LITERATURE REVIEW

2.1 The importance of road maintenance

2.1.1. Importance of maintenance in relation to road purpose

Almost all roads are paid for through public funds for the benefit of the users, whether they be industry, public services or general public. The service to these users is enhanced through well-structured and well-considered maintenance that is designed to keep the roadway safe and working efficiently. In addition, the maintenance operations must be planned to meet the wide-ranging environmental requirements and the reasonable expectations of those living near to, or otherwise affected by, the roadway and its maintenance and/or operation (O'Flaherty, 2002).

2.1.2. Types of road maintenance

There are three main types of rural road maintenance systems, namely routine, periodic and emergency maintenance. Routine maintenance comprises a range of small scale and simple activities - usually carried out at least once a year - but usually widely dispersed. Typical activities include roadside verge clearing and cutting back encroaching vegetation, cleaning of silted ditches and culverts, patching and pothole repair, and light grading/reshaping of unsealed surfaces. This maintenance may be done by skilled/unskilled labor, or labor-based methods supported by light equipment. Conventional or community contracting may be appropriate. These regular operations are good opportunities to identify periodic maintenance needs (O'Flaherty, 2002).

Periodic maintenance occurs less frequently - usually after a number of years only. Works can include re-gravelling, resurfacing, resealing and structure repair. It is normally a large scale project and usually requires standard or specialist equipment and skilled resources. Pavement strengthening overlays and pavement re-construction are normally not considered to be 'maintenance' and are often funded separately under 'development' or 'capital' budgets (Cox, 1987). Occasionally urgent, unplanned maintenance works may also be required - sometimes known as Emergency Maintenance - for example, because of particularly severe weather conditions, floods, unexpected deterioration, or damage caused by vehicles (Odoki and Kerali, 2000).

2.1.3. The importance of timely road maintenance

Timely road maintenance is important because it sustains the quality and safety of the road in a condition close to the original design, and minimizes road user costs. It is also cheaper to regularly maintain a road in whole life cost terms, than to endure an ongoing cycle of un-managed deterioration and reconstruction. The impact of inadequate maintenance can immediately be felt with regard to the safety of the road and by vehicle performance. The World Bank's note on "Why road maintenance is important and how to get it done" gives a helpful overview of the arguments for timely road maintenance and advice on good practice (Free State Public Works, 2002).

If left unchecked, minor maintenance problems tend to become more serious and more expensive to repair. The South African National Road Agency Ltd. (SANRAL, 2004) estimates that repair costs can rise to six times maintenance costs after three years of neglect, and up to 18 times after five years of neglect. However, securing the necessary funding for maintenance can be quite challenging (SANRAL, 2004)

Road maintenance is an essential activity for a number of reasons. Firstly, various Acts of Parliament place legal obligations on road authorities to maintain their roads in a safe condition, and to ensure that maintenance operations are carried out safely. Secondly, the roads are very often the 'vehicle' for carrying the apparatus of Statutory Undertakers, e.g. electricity, gas and water, and work on the provision and maintenance of this equipment is also controlled by statute. Thirdly, well-maintained roads support national and local economies by ensuring that freight can move efficiently and safely and businesses next to the roads can grow. Fourthly, the way of life in developed countries now depends on the availability of the road network, e.g. the vast majority of trips to schools, shops, hospitals and leisure activities are made via the road network (Alive2Green, 2015)

2.2. Maintenance Management Systems

Efficient and effective maintenance management is most simply expressed as doing the right thing at the right time in the right place. Keeping in mind that a typical road network represents the largest in-place asset component of the national publicly-financed infrastructure, it is necessary and correct to manage and, importantly, to be seen to manage the asset as efficiently and effectively as possible. A structured approach to this task with the assistance of an appropriate management system should meet both of these objectives (Mapikitla, 2011).

2.2.1 Development of Pavement Management Systems

To this end, management tools take the form of pavement management (rather than maintenance) systems, to ensure that care of all the issues that influence the safety and performance of the modern road is considered. Roads vary enormously, from high capacity, high standard motorways to modest local roads; each type, however, fulfils an important function and must be accorded an appropriate consideration. Thus, any management system used to support these requirements must be flexible enough to meet the needs of all road classes (Cirilovic, Quiroz and Mlandenovic, 2011).

2.2.2 Fundamentals of Pavement Management Systems

Pavement management systems (PMS) are most effective if they fulfill a number of essential requirements in relation to the roads and road network to which they are applied. Firstly, a pavement management system can be a powerful tool when used in predictive mode to persuade governments and other decision-makers of the need for a sustained programme of investment. Secondly, a well-structured system will assist in the prioritization of maintenance works across a road network, and between roads of different types and categories. Finally, a pavement management system can assist the engineer in identifying the most appropriate treatment on selected sections of the road network through the use of economic analysis, predictive models and time series information (Miquel and Condron, 1991).

2.2.3 Pavement Management Analysis in South Africa

In South Africa (SA), many roads were constructed more than fifty years ago and have since been subjected to unanticipated increases in the weights and the numbers of the vehicles using them (National Department of Transport, 1998). These increases have occurred during a time when governments at all levels have faced, and currently are facing, escalating demands on their financial resources (McQueen, 2001). It is not surprising that the emphasis today is to plan and budget for the maintenance and rehabilitation of these roads. This can be attained by using modern management and engineering techniques (McQueen, 2001). The need for a PMS in South Africa was identified by the South African Roads Board (SARB) through the South African Roads Agency Limited (SANRAL) (National Department of Transport, 1996). SANRAL, as mandated by the SARB, developed a PMS plan of which the aim was to provide PMS Managers with guidelines regarding the requirements of the PMS. Guided by the PMS plan, various road maintenance authorities (local, metropolitan and provincial) agreed to develop and manage their PMS. The above statement applies to the Free State province road network as well, since all the provincial road departments in the country together with SANRAL are funded by one source, namely the National Treasury. The funding is called the Provincial Road Maintenance Grant (PRMG).

2.2.4 Planning and funding of road maintenance

Road maintenance costs can vary significantly depending particularly on:

- the type of road, surface and construction quality;
- how much it is used, particularly by heavy vehicles,
- organizational, logistical arrangements,
- technology choice for each operation,
- type and cost of works, equipment and transport used,
- local labour and materials costs, and
- the quality and timeliness of current and previous maintenance (SANRAL, 2004).

It is, therefore, important to consider the cost of maintenance when planning a route or investment in part of that route, setting appropriate standards and specifications for the road and the approach to contracting and procurement. On lower category roads the involvement of the local community or stakeholders can substantially reduce the operational and overhead costs. At the initial planning stages the 'whole life costs' of the road should be considered as an integral part of the design process. In other words, not just the short-run capital costs of the initial construction, but also the long term costs of its maintenance must be taken into consideration. A realistic assessment of the capability and likelihood of timely road maintenance will be a major influence on the effectiveness of the construction investment. The document *Priorities in Improving Road Maintenance Overseas: a check-list for project assessment* is a useful guideline to support assessment of maintenance capability (Cox, 1987).

Problems frequently arise because these road maintenance costs have either been under-estimated, or insufficient financial provision has been made in this regard. The World Bank's Road Costs Knowledge System (ROCKS) provides a source of knowledge on the cost of road maintenance and rehabilitation for different types of road, drawn from different regions. Maintenance can be achieved at lower cost using innovative local-resource-based approaches (South African Road Federation, 2011).

It can also be difficult to argue the case for maintenance funding against other priorities. The Norwegian Public Roads Administration published a useful note on how to sell the message "Road maintenance is necessary to" decision makers (Cirilovic et al., 2011). The World Road Association's publication *Save Your Country's Roads* is a short briefing for decision-makers to mobilize support for maintenance initiatives and funding. It is available in a number of languages. Some of the financing reforms discussed in the funding section attempt to address the problems of insufficient or cyclical funding through, for example, the establishment of dedicated road funds (Local Authority Associates, 1989).

2.3. Funding for roads in South Africa

The South African National Department of Transport (NDoT, 2009) recommends that the choice among various transport funding methods should be based on a number of parameters including equitability, efficiency, adequacy and ease of administration. This is fundamental, although it is rare to find any source of funding that fulfils all the criteria at the same time. The main sources of road (construction and maintenance) funds that are common in many countries include fuel levy, motor vehicle licenses and road tolling, among others. In other countries, such as South Africa, funds in the form of conditional and other grants are transferred from the National Treasury to the road agency. The Provincial Department of Transport also provides funding in the form of municipal infrastructure grants (NDoT, 2009).

Despite various innovative efforts, private sector participation in transportation capital and operational investment remain limited. Research shows that while transitional countries are expected to spend at least 5% of their GDP on road infrastructure, most developing countries are currently spending only about 2% (Metschies and Rausch, 1991; Gwilliam and Shalizi, 1996; Kuang and Shladover, 2006; This scenario indicates that road systems are generally underfunded. The NDoT (2009) reports that in South Africa, the National Treasury transfers over 95% of provincial revenue requirements for the construction and maintenance of road infrastructure (Mbara, Nyarirangwe and Mukwashi, 2010).

Given the limitations associated with the funding sources, most governments are pursuing the option of involving the private sector through different forms of public-private partnerships (PPPs). Forces driving the different forms of partnerships include the associated acceleration of infrastructure provision, faster implementation, reduced whole life cost, better risk allocation, better incentives to perform, improved quality of services, generation of additional revenues, and enhanced public management. The most common of such partnerships include service contracts, management contracts, leases, concessions and divestiture (full-scale privatization). These options exhibit different levels of public and private sector involvement and responsibilities (Mbara et al., 2010).

2.4 Global road maintenance standards

This study undertook the survey of road maintenance by contract in a number of countries which included the following countries where contract maintenance had been a well-established practice for several years, such as Belgium, Brazil, France, Kenya, Malaysia and the United Kingdom, and countries where the transition to contract maintenance was relatively recent, such as Algeria, Canada, Chile and Pakistan (Cirilovic et al., 2011).

2.4.1 Local Funding and Financing Tools Used by Localities in Virginia (USA)

One of the common local funding financing mechanisms for transport projects in Virginia (United States of America) before 2008 was bonds, where general obligation bonds are usually repaid from the locality's general fund, and revenue bonds are repaid from a project-related source, such as tolls. Before the recession, a study showed how VDOT could financially encourage projects that were funded primarily by local bonds, however, VDOT could not afford to contribute to these costs without cutting funds elsewhere (Virginia Department of Transport, 2006).

One other funding mechanism that was common in Virginia was termed Business, Professional, Occupational and License (BPOL) taxes, which are taxes that are based on gross annual income generated by businesses, professions, trades and occupations. Some localities' category of "general fund" may include income from BPOL tax. One of the financing methods in Virginia was referred to as Community Development Authorities (CDAs) that provided an administrative body whose primary function was to provide funding authority for a local transportation district.

General funds are primarily supported by property taxes in most localities and are the "default" local funding source for transportation projects if no other arrangement is available. However, they are also the default funding source for many other competing needs such as schools, fire stations and the police.

Impact fees are intended to recover the costs that are incurred as a result of the new growth, such as upgrading of existing roads or the construction of new roads.

Local transportation districts differ in form, but the common purpose is to collect additional taxes from a specific geographic area in order to finance transportation improvements that benefit the area. One of the financing tools was "Personal property taxes on vehicles" where vehicles owners are charged annually. Virginia localities are authorized to place a tax on the value of motor vehicles, but only a small percentage of the tax remains truly a locally derived funding source. Pro-rata reimbursement provisions in the subdivision ordinance provide for payments or reimbursements from one developer to another when land is subdivided. The payment is based on the subdivision's share of off-site road improvements that another developer paid for or constructed. Public-private partnerships (PPP's*)* are enabled under Virginia's Public-Private Transportation Act of 1995 (PPTA) and can lead to the use of local funds in lieu of federal funds. Comprehensive development agreements are a type of P3 in which a private company designs, builds, finances, operates, and maintains a facility for a period of time. The Virginia Resources Authority (VRA) provides financing for infrastructure, including roads, to Virginia localities at below-market interest rates (Ohlms, 2014).

2.4.2 Contract types worldwide

'Unit price' contracting is by far the most widely used method for obtaining road maintenance services. Most countries develop contracts with a clearly defined estimate of quantities, but allow some flexibility for payment of work quantities significantly beyond those originally estimated. Moreover, all countries surveyed have procedures to provide for the inclusion of additional work items that are not initially included in the contracts (Miquel et al., 1991). Variations of conventional 'unit price' contracts were used in some instances, for example, Belgium and France prepare long lists of work items to the agency with unit costs in close do-operation with local contractor's federations. For a given project, the contract documents identify estimated quantities for a reduced number of these items. The established costs for these items are used to arrive at an overall project cost, or at cost for generic groups of related work items. Bidders offer percentages above or below the estimated costs for the total contract costs in France, and for each generic group in Belgium. The selection of the successful bidder is based on the overall lowest price. Payment is based on actual quantities and established prices are adjusted by the contractor's percentage increase or decrease. During execution of the contract, established quantities for specific work items may vary, or new work items not previously quantified may be added, at the pre-established unit price. This is also changed by the increase or decrease offered by the winning bidder (Alive2green, 2012).

British Columbia makes exclusive use of lump sum contracts for road maintenance specific areas, defining clearly the work to be performed and maintenance standards to be achieved. However, these contracts provide some flexibility in the quantities to be executed for certain work items that may exceed the quantities forecasted when the lump sum contracts were estimated, particularly work items needed for emergency works. For this purpose the lump sum contract shows quantities of those items for which unit prices are established during negotiations. Adjustments are made to the lump sum payments based on actual work performed on these items as compared to the estimated quantities. These unit prices contribute about 10 percent of the typical contract. Lump sum contracts are seldom used for road maintenance in other countries (Odoki et al., 2000). The countries surveyed that initially used 'cost plus' contracts for maintenance works have ceased to do so as these type of contracts do not enhance productivity.

In the execution of routine maintenance and minor emergency works, Kenya has contracted *length men*, usually former construction workers who use simple hand tools, to maintain 1.5 to 2.0 km of road close to their homes, working three days on days of their choice (Miquel et al*.,* 1991).

2.4.3 Funding for roads in Zimbabwe

The gradual deterioration of the Zimbabwean road network has largely been associated with lack of funding for maintenance and rehabilitation. According to Gumbie and Kudenga (2009), a World Bank mission pointed out that whereas the total road maintenance funding requirement in 2005 was about US$160 million, only US$10 million, (6%) of the requirement, was provided. In 2009, the estimated funding requirement for road maintenance amounted to about US$225 million compared to a budget provision of US$13 million, which was less than 6% of the total required amount. The road rehabilitation requirements were estimated at about $1.3 billion, compared to a budget allocation of $8 million, a mere 0.6% of the total need. Consequently, the quality of the road network has continued to deteriorate. Ultimately, the Zimbabwean government had to introduce a tolling system as a last resort to generate more funding for roads, however, the Zimbabwean public was not at all satisfied with this arrangement (Mbara et al., 2014).

Going forward, more funding is required to keep the Zimbabwean road network at an acceptable quality. To date, the road network has deteriorated to the extent that the public is being seriously inconvenienced, while the normal functioning of businesses has also been severely affected. There is general consensus among local communities, the public and private institutions that the vital national grid has deteriorated beyond any acceptable minimal standard socially, economically and environmentally. There has, thus, been much interest and anxiety in relation to the new road management approach that the Zimbabwean government has introduced. This strategy is founded on the application of the user-pay principle to accrue funding for maintenance and construction of road infrastructure (Mbara et al., 2014).

2.4.4 Contract provisions

Algeria, Belgium, Brazil, British, Columbia, Chile, Kenya, Malaysia and Pakistan use standard contract documents that may be different for minor and major maintenance works. In France and the United Kingdom each sub-division or local road maintenance division uses its own contract documents. Sometimes, several different formats are used for different types of work, however, these standards vary with local road administration in general (O'Flaherty, 2002).

Routine and periodic maintenance operations are sometimes contracted separately. This practice is used mostly in Chile, Kenya and Pakistan, and is applied differently in other countries to more complex periodic activities, such as pavement or bridge repair work. In Algeria and Brazil, maintenance for specific contracts road sections (on average 244 km length in Brazil) combine execution of routine and minor periodic maintenance (Cox, 1987). Some countries, including the United Kingdom and Malaysia, combine both periodic and routine maintenance activities in contracts that provide maintenance for all roads within geographic areas.

British Columbia uses this method exclusively: contractors additionally are responsible for managing the maintenance and operations programmes, including performing routine patrols and inspections to identify needs, set priorities, schedule the work and maintain public relations (O'Flaherty, 2009). All countries surveyed have prepared technical specifications for maintenance works. Overall, specifications are comparable to those used for construction works. In all cases, they are more demanding than the requirements set for execution of maintenance by the in-house units (O'Flaherty, 2002).

2.4.5 Road funding and spending in Africa

Road expenditure in Africa is relatively high, with an average of about 1.8 percent of the African countries' GDP. Based on the AICD Fiscal Costs Survey (Briceno-G. C., Smith. K., Voster. V., 2008) it is possible to estimate the percentage of national income allocated to the roads sector, when all budget and extra-budgetary channels (such as Road Funds) are taken into account. On average, the sample countries devote 1.8 percent of the gross domestic product (GDP) to the roads sector. This is within the range of expenditure found in other countries around the world, although below the levels found in a number of fast growing countries that made intensive efforts to upgrade transport infrastructure. (Gwillian, Foster, Archondo – Callao, Briceno-Garmendia, Nogales and Sethi, 2008)

Industrialized countries annually invest around 1 percent of the GDP on their road systems. The USA has been investing about 1 percent of the GDP on roads over the last 25 years. Most European national governments invest no more than 2 percent of the GDP on all transport infrastructure, although in some countries there are additional expenditure by regional and urban authorities from their own resources. These are countries with already well-developed infrastructure and GDP growth rates of 2-3 percent (Gwilliam et al., 2008). Roads expenditure as a percentage of GDP varies from less than 1 percent of the GDP in South Africa to almost 4 percent in Malawi. The highest income shares are found in the poorest countries. Although the level of effort is considered relative to the scale of the country's economy the absolute values remain small, at around US$7 per capita per year for the low-income countries and US$22 per capita per year for the middle income countries.

This variation can mostly be explained in terms of underlying economic, geographic, and institutional influences. The same aggregate information about road expenditure can also be normalized per kilometer of the main road network. The main network is defined as those roads managed by the central government, which in most countries comprises the primary plus secondary network, but in a few cases are limited to the primary network only. On average, sample countries spend just over US$9,000 per kilometer of the main road network. However, spending levels in low-income countries (LICs) are more than 50 percent higher per kilometer than spending levels in the middle-income countries (MICs), with resource-rich LICs spending slightly more than aid-dependent ones. Landlocked countries and islands spend substantially more per kilometer than what is spent by coastal nations, which may be attributed to higher costs of importing materials and services. Countries with rolling and humid terrains that tend to accelerate road deterioration show somewhat higher levels of spending than countries with flat and arid terrains.

The institutional framework also seems to matter. Countries with road agencies seem to spend substantially less than those without, whether or not they have road funds. Perhaps surprisingly, those with low fuel levies actually spend substantially more than those with no fuel levies or high fuel levies (Gwillian et al., 2008).

CHAPTER 3: RONET

3.1 Network-level maintenance strategies using RONET

The Road Network Evaluation Tools (RONET) model is being developed for the Sub-Saharan Africa Transport Policy Program (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; and
- Evaluate revenue from road user charges (Archondo-Callao, Ellevset, Benmaamar, Luyimbazi, Brocke, Antasio-Bugunhe, Lwiza, Larsen, Tenga and Nogales, 2009).

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, calculates 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 (Archondo - Callao et al., 2009).

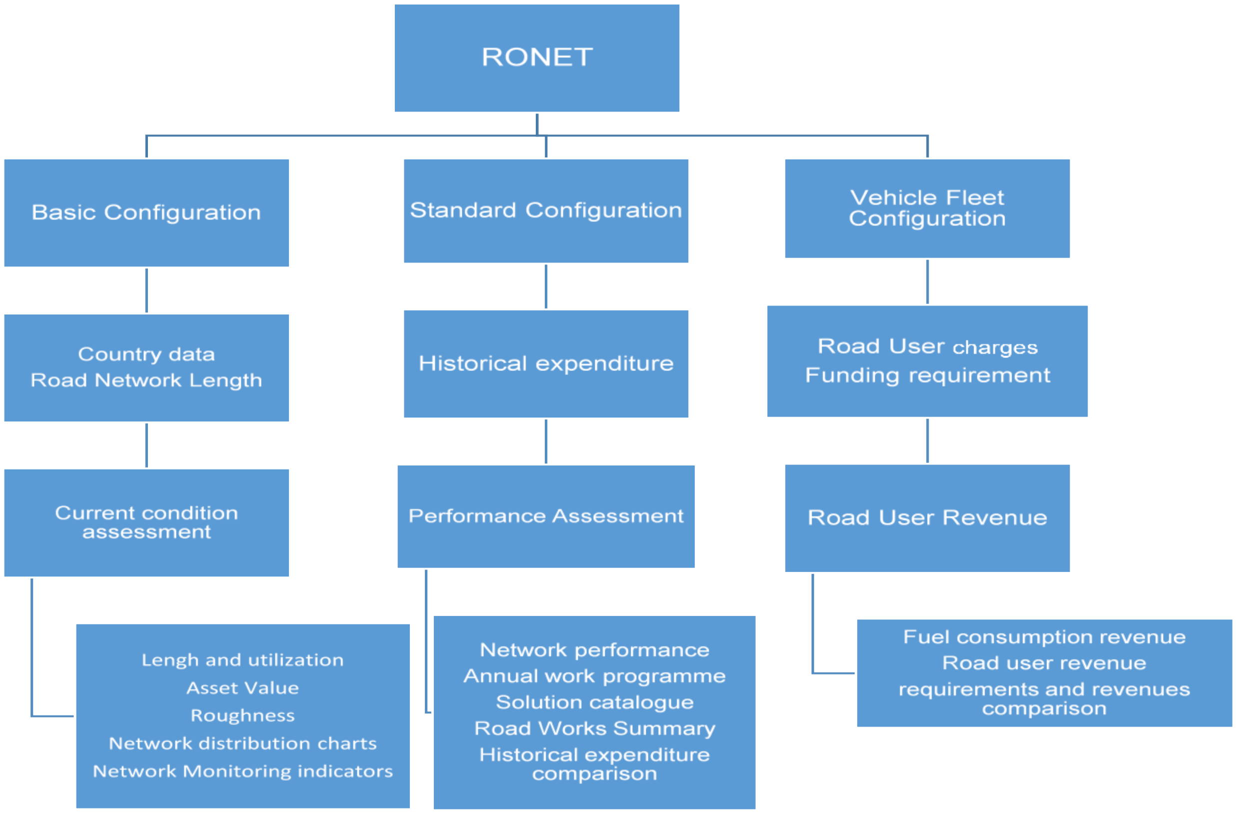
It determines, for example, the minimum cost for sustaining the network in its current condition. It also estimates the savings or the costs to the economy to be obtained from maintaining the network at different levels of road condition. It further determines the proper allocation of expenditure among recurrent maintenance, periodic maintenance, and rehabilitation road works. Finally, it also 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 (Archondo - Callao et al., 2009).

3.2 Description of RONET

The model is developed from the same principles underlying the accepted economic evaluation model, the Highway Development and Management Model (HDM-4), adopting simplified road user cost relationships and simplified road deterioration equations derived from HDM-4 research. HDM-4 is an economic evaluation module of a Pavement Management System (PMS) that can perform a strategic evaluation of a network, evaluating a series of road classes similar to what is being done in RONET. HDM-4 has comprehensive road deterioration and road user cost relationships, has great flexibility on the way of defining the maintenance, rehabilitation or improvement standards to be evaluated, and performs budget constraint optimization (Archondo-Callao, 2009).

However, HDM-4 has the following negative attributes: it has many input data requirements, it requires an HDM-4 specialist to run the model, its output is limited and it requires external manipulation. For example, very few of the RONET outputs are provided automatically by HDM-4. However, most of the RONET outputs can be obtained from HDM-4 run after processing the HDM-4 inputs and outputs in Excel or Access. The following are the negative attributes of RONET: it uses simplified road deterioration and road user costs relationships, it has a restricted way of defining the standards, it cannot evaluate improvement standards, and lacks a budget constraint optimization module (Archondo Callao, 2009).

Figure 3.1: RONET flow chart



3.3 Road Cost Knowledge System (ROCKS)

Road agencies, construction companies, consulting engineers, as well as funders, need road cost information for planning, construction and management of roads, however, this information is often collected in an unstructured and unsystematic way. This is the reason why the World Bank initiated the development of a simple system called the Road Cost Knowledge System (ROCKS) to enable them to assess cost differences among regions, road works types and road works characteristics (Archondo Callao, Bhandari and Nogales 2002).

This system can be used to gather and disseminate unit costs of road works, which can, among others, be used to:

- Monitor road cost variations at different stages, from estimation to contracting and implementation;
- Evaluate road cost variations over time;
- Compare road costs among regions, under different financing institutions, using different procurement methods;
- Differentiate between terrain types, climatic conditions, regions and construction technologies; and
- Establish consistency in estimation of investment costs and benefits (Archondo-Callao et al., 2002).

3.4 ROCKS Framework

The ROCKS framework is based on five key concepts that characterize the system and provide the foundation to achieve its objectives and intended outputs.

▪ The first concept seeks to systematically classify the different road work types and predominant work activities in order to organize and match them with typical civil works contracts. The road works have been classified into two categories, namely Maintenance and Upgrade.

▪ The second concept defines a shared concept of unit cost as the fundamental cost element, and depending on the type of work, suggests to use either $/km or $/m2.

Table 3.1: Unit cost per length and area as per ROCKS (Archondo-Callao et al., 2002)

UNIT COST PER LENGTH & UNIT COST PER AREA	
It includes all civil works costs:	It does not include other agency costs:
Mobilization – Pavement - Drainage Major Structures - Line markings Contingencies Taxes	Design Land Acquisition Resettlement Supervision

- The third concept establishes a minimum set of data requirements that are generally available in any country and that allow the system to work.

Table 3.2: Minimum and mandatory data set (ROCKS) (Archondo-Callao et al., 2002)

MINIMUM AND MANDATORY DATA SET
Record
Country (from valid list)
Project or Source Name
Cost Date
Cost Source (Section or Program)
Cost Type (Estimate, Contract or Actual)
Currency Code (from valid list)
US$ Exchange Rate
Work Description
Work Type (from valid list)
Total Cost per Kilometer ($/km) and/or
Total Cost per Carriageway Area ($/m2)
Number of Lanes

- The fourth concept seeks to add flexibility to the system by defining a set of highly recommended data and a series of optional data that allow the users to select the levels of detail or criteria to be used and adapt the system to their needs and the data available.

Table 3.3: ROCKS recommended data set (Archondo-Callao, 2002)

HIGHLY RECOMMENDED DATA SET
Work Predominant Activity (from valid list)
Length (km)
Duration (months)
Total Cost (M$)
Pavement Width (m)
Terrain Type (from valid list)
Climate Type (from valid list)
Pavement Type (from valid list)
Surface Class (from valid list)
Surface Type (from valid list)

- The fifth concept suggests that the data be collected on any currency and reference date, but to convert all data to a single currency and single reference year to allow for data comparisons.

Table 3.4: Predominant work activity for preservation works (Archondo-Callao, 2002)

Predominant Work Activity for Preservation Works

Work Category	Work Class	Work Type	Predominant Work Activity	Recommended Unit Cost	Alternative Unit Cost
Preservation	Routine	Routine Maintenance	Routine Maintenance 1L Road Routine Maintenance Unsealed 2L Highway Routine Maintenance Block 2L Highway Routine Maintenance Bituminous 2L Highway Routine Maintenance Concrete 2L Highway Routine Maintenance Bituminous > 2L Highway Routine Maintenance Concrete > 2L Highway Routine Maintenance Bituminous Expressway Routine Maintenance Concrete Expressway	$/km-year	
	Periodic	Grading	Light Grading Heavy Grading	$/km	
		Gravel Resurfacing	Regravelling	$/m2	$/km
		Concrete Pavement Preventive Treatment	Concrete Pavement Preventive Treatment	$/m2	$/km
		Bituminous Pavement Preventive Treatment	Fog Seal Rejuvenation	$/m2	$/km
		Unsealed Preventive Treatment	Unsealed Preventive Treatment	$/m2	$/km
		Surface Treatment Resurfacing	Slurry Seal or Cape Seal Single Surface Treatment Double Surface Treatment Triple Surface Treatment	$/m2	$/km
		Asphalt Mix Resurfacing	Asphalt Overlay < 40 mm Asphalt Overlay 40 to 59 mm	$/m2	$/km
	Rehabilitation	Strengthening	Asphalt Overlay 60 to 79 mm Asphalt Overlay 80 to 99 mm Asphalt Overlay > 99 mm Mill and Replace Bonded Concrete Overlay Unbounded Concrete Overlay	$/m2	$/km
		Concrete Pavement Restoration	Concrete Slab Replacement Concrete Slab Repair Concrete Diamond Grinding	$/m2	$/km
		Reconstruction	Reconstruction Unsealed Reconstruction Block Reconstruction Bituminous Reconstruction Concrete	$/m2	$/km

Number of Lanes
1L - One Lane 4L - Four Lane
2L - Two Lane 6L - Six Lane

Date: 09/09/02

Table 3.5: Predominant work activity for development works (Archondo-Callao, 2002)

Predominant Work Activity for Development Works

Work Category	Work Class	Work Type	Predominant Work Activity	Recommended Unit Cost
Development	Improvement	Partial Widening	Partial Widening to Unsealed 2L Partial Widening to Block 2L Partial Widening to Bituminous 2L Partial Widening to Concrete 2L	$/km
		Partial Widening and Reconstruction	Partial Widening to Unsealed 2L and Reconstruction Partial Widening to Block 2L and Reconstruction Partial Widening to Bituminous 2L and Reconstruction Partial Widening to Concrete 2L and Reconstruction	$/km
		Widening	Widening Adding Bituminous 1L Widening Adding Bituminous 2L Widening Adding Bituminous 4L Widening Adding Concrete 1L Widening Adding Concrete 2L Widening Adding Concrete 4L	$/km
		Widening and Reconstruction	Widening Adding Bituminous 1L and Reconstruction Widening Adding Bituminous 2L and Reconstruction Widening Adding Bituminous 4L and Reconstruction Widening Adding Concrete 1L and Reconstruction Widening Adding Concrete 2L and Reconstruction Widening Adding Concrete 4L and Reconstruction	$/km
		Upgrading	Upgrading Unsealed to Unsealed 2L Highway Upgrading Unsealed to Block 2L Highway Upgrading Unsealed to Bituminous 2L Highway Upgrading Unsealed to Concrete 2L Highway Upgrading Block to Bituminous 2L Highway Upgrading Block to Concrete 2L Highway	$/km
	New Construction	New 1L Road	New Unsealed 1L Road New Block 1L Road New Bituminous 1L Road New Concrete 1L Road	$/km
		New 2L Highway	New Unsealed 2L Highway New Block 2L Highway New Bituminous 2L Highway New Concrete 2L Highway	$/km
		New 4L Highway	New Bituminous 4L Highway New Concrete 4L Highway	$/km
		New 6L Highway	New Bituminous 6L Highway New Concrete 6L Highway	$/km
		New 4L Expressway	New Bituminous 4L Expressway New Concrete 4L Expressway	$/km
		New 6L Expressway	New Bituminous 6L Expressway New Concrete 6L Expressway	$/km

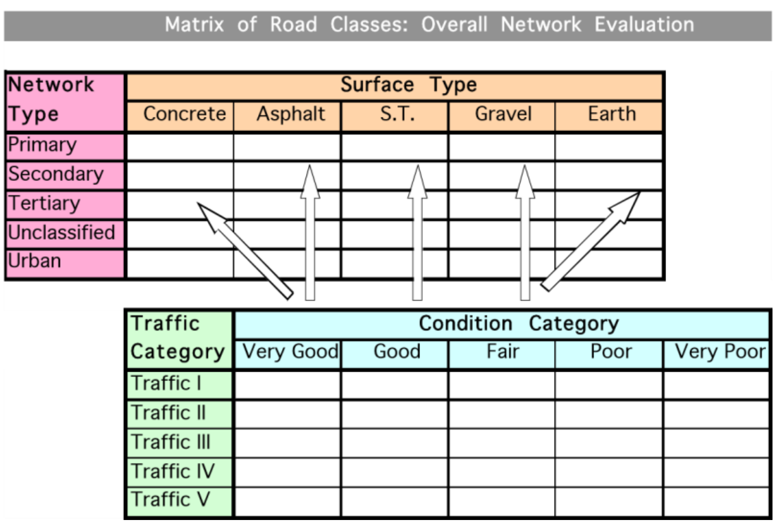
Number of Lanes
1L - One Lane   4L - Four Lane
2L - Two Lane   6L - Six Lane

Date: 09.09.02

3.5. RONET Model

The Road Network Evaluation Tools (RONET) model is a tool for assessing the performance of maintenance and rehabilitation policies, and the importance of the road sector for the economy to demonstrate to stakeholders the importance of continued support for road maintenance activities. The RONET road network length can cover the entire road network system of the country (roads, highways, streets, avenues and so forth), or a partial road network, for instance the road network of a specific province in a country, or the road network managed by the main road agency, i.e. SANRAL in the case of South Africa. The road network is represented by the road classes that are a function of (i) five network types, (ii) five surface types, (iii) five traffic categories, and (iv) five condition categories, which total a maximum of 625 road classes (Archondo-Callao et al., 2009).

Table 3.6: The representative road classes in RONET (Archondo-Callao et al. 2002)



Each surface type is subdivided into five possible traffic categories (Traffic I, Traffic II, Traffic III, Traffic IV and Traffic V). The table below presents the RONET default assignment of traffic levels to each traffic category per surface type.

Table 3.7: Illustration of the representation of different road classes as per RONET

(Archondo-Callao et al., 2009)

RONET default assignment of traffic levels							
Surface Type	Traffic Category	Traffic Level	Average Annual Daily Traffic (AADT)			Illustrative Standards	
			Minimum (veh/day)	Maximum (veh/day)	Average (veh/day)	Geometry Standard	Pavement Standard
Earth	Traffic I	T1	0	10	5	1-lane warranted	Formation not warranted
	Traffic II	T2	10	30	20	1-lane warranted	Formation warranted
	Traffic III	T3	30	100	65	2-lane warranted	Gravel warranted
	Traffic IV	T4	100	300	200	2-lane warranted	Gravel warranted
	Traffic V	T5	300	1,000	650	2-lane warranted	Paved Surface warranted
Gravel	Traffic I	T2	10	30	20	1-lane warranted	Formation warranted
	Traffic II	T3	30	100	65	2-lane warranted	Gravel warranted
	Traffic III	T4	100	300	200	2-lane warranted	Gravel warranted
	Traffic IV	T5	300	1,000	650	2-lane warranted	Paved Surface warranted
	Traffic V	T6	1,000	3,000	2,000	2-lane warranted	Paved Surface warranted
Paved	Traffic I	T4	100	300	200	2-lane warranted	Gravel warranted
	Traffic II	T5	300	1,000	650	2-lane warranted	Paved Surface warranted
	Traffic III	T6	1,000	3,000	2,000	2-lane warranted	Paved Surface warranted
	Traffic IV	T7	3,000	10,000	6,500	2-lane warranted	Paved Surface warranted
	Traffic V	T8	10,000	30,000	20,000	4-lane warranted	Paved Surface warranted

Each network type, road type and traffic category are subdivided into five possible road condition categories defined as a function of the engineering assessment of the capital road works, i.e. periodic maintenance and rehabilitation works needed to bring a road to a very good condition. Routine maintenance road works must be performed on all roads every year, therefore are not taken into consideration in the definition of the road condition classes. The road condition classes are defined as follows:

Very good: These are the roads that do not require any capital road work.

Good: These are the roads that are free of defects but require minor maintenance works, such as preventative treatment, crack sealing and grading.

Fair: These roads have defects and weakened structural resistance and require periodic maintenance, but without the need to demolish the existing pavement.

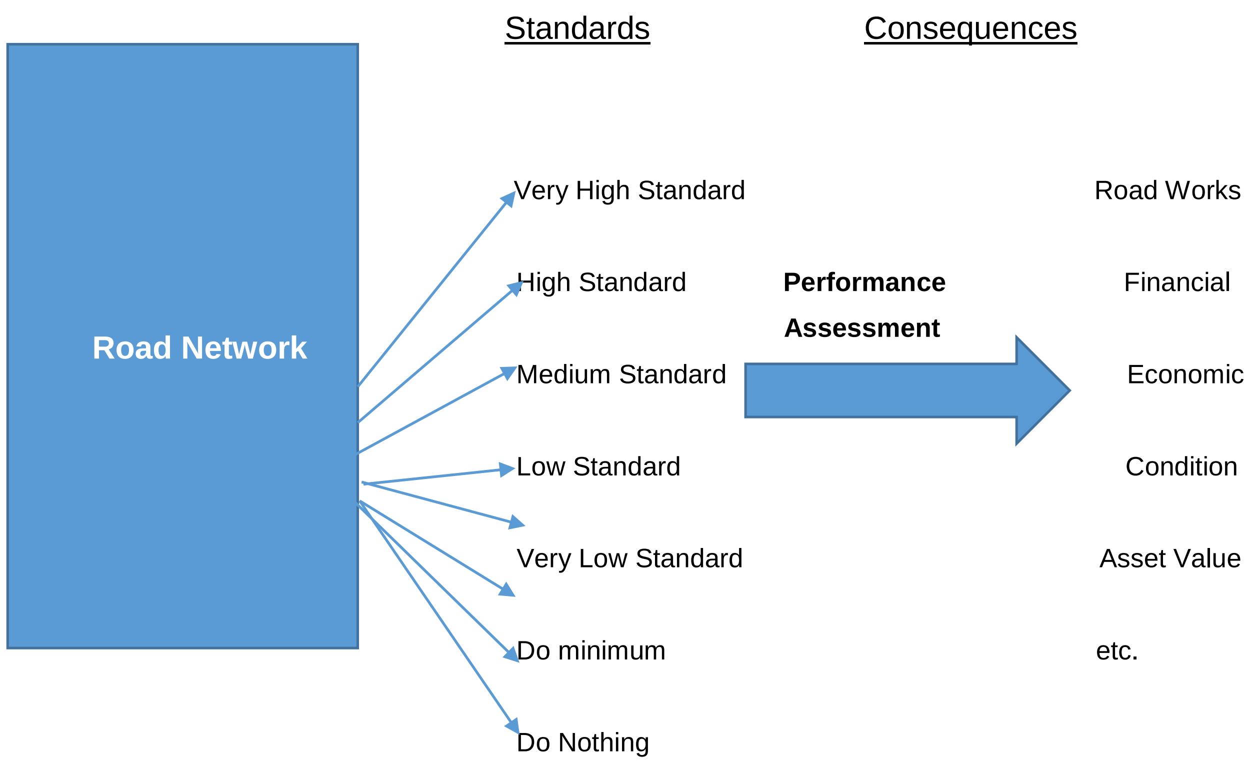
Poor: Roads in this condition require rehabilitation (strengthening or light rehabilitation).

Very poor: These are the roads that require full reconstruction, the same as constructing new roads.

RONET has a module that calculates the network monitoring indicators based on the current condition of the network and a module that does a performance assessment of the network under different road agency standards. The objective of these modules is to assess the consequences of applying different road works standards that represent different levels of road works expenditures over time. The consequences are presented on the road works requirements, financial cost, road condition, and asset value. Figure 3.2 below illustrates the process.

Figure 3.2: Consequences of applying different road works standards

(Archondo-Callao et al., 2009)



This module evaluates the performance of the network under different road works standards over a twenty year evaluation period. The user defined road works standards are the following:

- Very High Standard
- High Standard
- Medium Standard
- Low Standard
- Very Low Standard
- Do Minimum
- Do Nothing
- Custom Standard
- Optimal Standard

The *very high* standard represents a scenario without budget constraints but with a high level of periodic maintenance and rehabilitation works. The *high, medium, low* and *very low* standards represent scenarios of decreasing levels of road works expenditures. The *do minimum* standard represents a scenario where the only capital road work applied over the evaluation period is reconstruction at a very high roughness. The *do nothing* standard represents a scenario where no capital road works are applied over the evaluation period.

In all these cases, the defined is applied to all road network types. On the *custom* standard, one defines the standard (Very High, Medium, Low, Very Low, Do Minimum or Do Nothing) to apply to each road network type. On the *optimal* standard RONET evaluates each road class and identifies for each road class the standard that maximizes the society benefits Net Present Value, at a given discount rate (Archodo - Callao et al., 2009).

CHAPTER 4: METHODOLOGY

4.1. Data Collection

For the RONET model to run and give reliable outputs it has to be populated with the following data with regard to the local conditions:

Land area in square kilometers*:* A country's total area, excluding areas under inland bodies of water and some coastal waterways. In other words, the total area of a country must be known, however, the coastal area, as well as inland areas permanently covered by water, such as rivers, must be subtracted.

Total population (million persons): The mid-year estimates of all residents regardless of their legal status or citizenship. In other words, the total number of people residing in a specific country must be known. In the case of South Africa this information can be obtained from Statistics South Africa as they are responsible for conducting a census in SA every four years.

Rural population (million persons): The total number of people living in rural areas will have to be made available. Once again, in South Africa this information can be obtained from Statistics South Africa.

GDP at current prices ($ billion): The gross domestic product at current prices, that is the sum of the gross value added by all resident producers in the economy, plus any product taxes and minus any subsidies not included in the value of the products. This is the most important information because it will give the decision makers direction as to whether or not the country has the financial ability to carry out the maintenance and rehabilitation.

Vehicle fleet (vehicles): The total number of motor vehicles in use at the given year in the country. This information is also important because it provides RONET with data on how many vehicles are registered in a country and as a result, RONET can predict the rate at which the network is going to deteriorate. With this information available road authorities can plan their maintenance and rehabilitation schedules accordingly.

Total road network length (km): The total road network length of the country must be known as it informs RONET how much the road sector needs, based on the unit cost per kilometer. This will, in turn, assist the decision makers in terms of drafting business plans and allocating resources.

Total paved roads network length (km): The type of surface must also be captured by RONET because the maintenance activities on paved and unpaved roads are different, therefore, the funding needed will also differ. It is therefore important to road authorities to know the lengths of both paved and unpaved roads.

Diesel and petrol roads consumption (million liters/year): In order to determine the revenue that can be collected in the form of levies the total annual diesel and petrol consumption in the road sector must also be known.

Total accidents fatalities (persons/year): This information must be also be known and captured by RONET in order to determine the amount of money the country is losing as a result of fatal accidents. This amount should then be subtracted from the total revenue that the country is collecting annually. In the case of South Africa the responsible institution is the Road Traffic Management Cooperation (RTMC).

Total accidents serious injuries (persons/year): The total number of accidents causing serious injuries must be also be known and captured by RONET in order to determine the amount of money the country is losing as a result of these accidents. This amount should then be subtracted from the total revenue that the country is collecting annually. In the case of South Africa the responsible institution is the Road Traffic Management Cooperation (RTMC).

Discount rate (%): The planning discount rate adopted by the country, which is typically 12% in developing countries.

4.2. Study limitations

This study was limited to the Free State province as its data was readily available to the researcher. In cases where more information was needed other departments and consulting firms were consulted, however, it was difficult to obtain some of the information because of confidentiality of information. One other limitation was that other models that are currently being used in SA are available commercially and one needs a license to operate them.

4.3. Assumptions

One of the assumptions that were made when the model was tested was the count of the Free State population. The last census was carried out in 2011 and is outdated, especially with regard to the rural population. One other assumption that was made was that of the volume of diesel and petrol that were sold in the province as there is no institution that keeps such records. Another assumption was that the model is programmed in South African Rand, when it is actually programmed in American dollars. If the model was to be used in South Africa it will have to be re-programmed to be applicable to local conditions.

4.4. Comparisons

This model was compared to the DTims and HDM-4 (Viktor and Abbas, 2015), which are the only softwares currently being used by road authorities and consulting firms in South Africa. The advantage that RONET has over other softwares is that it does not need a specialist to operate it and it is also a simplified version of the HDM-4. Another advantage is that it does not need to be calibrated for local conditions. Finally, the most important aspect about RONET is that it is freely available on the internet as it is sponsored by the World Bank, unlike other models that are only available commercially and need a license to operate them.

HDM-4 at program level can assist in preserving the current road network by identifying appropriate actions to maintain and preserve the network, for example, by identifying the optimal combinations of road sections to be earmarked for maintenance and upgrade, involving one-year or multi-year work programs under conditions of budget constraints (Odoki and Kerali, 2000). HDM-4 is a tool for ensuring that an investment in the road network is economically sound and justifiable. It also ensures that discounted benefits exceed or are equal to discounted costs over the economic life of the project, and enables road authorities to make optimal investment decisions that minimize total transport cost (Archondo-Callao, 2009).

Unlike RONET, HDM-4 has a number of limitations in the sense that it uses a wide spectrum of input data at a very detailed and/or technically advanced level. Local data has to be adapted into the HDM-4 model in order for it to produce reliable and accurate data, e.g. road user data, road and pavement data, traffic data, unit cost data and economic data. As indicated earlier, for HDM-4 to give accurate outcomes for a specific country, it first has to be calibrated for that country, especially the Road User Effects model, the Road Deterioration model and the Maintenance Effects model. According to (Odoki and Kerali, 2000) data collection and model calibration can be time consuming and costly, constituting limiting factors in the application of HDM-4.

As indicated above, HDM-4 is not available free of charge, and, in addition to the initial cost of acquiring the software, the following must also be taken into consideration:

- The cost of gathering information,
- The cost of calibrating, and
- The cost of updating the data required.

Table 4.1: The cost of acquiring HDM-4

License	**Price (US Dollars)**
Full License	3 000
Upgrade V1	1 800
Countries with low income and low intermediate income: Full License	2 000
Countries with low income and low intermediate income: Upgrade V1. X license	1 200
Pack of 4 licenses, per license	2 550
Pack of more than 4 licenses, per license	2 400

Unlike RONET and HDM-4, dTims is used more at project level whereas the former two are used more to make decisions at network level. The dTims software has twenty-one (21) integrated modules. The modular nature of the software allows the user the flexibility of the Road Management System (RMS) as a basic system with the option to add modules at a later stage. A basic system would typically comprise only the element, element locations mapper, life cycle cost analyzer, optimizer, report and graph viewer and expressions builder modules. The price of dTims software providing only limited database functionalities is approximately US$13.320. HDM-4 and dTims are complementary systems, according to Odoki and Kerali, 2000 who stated that HDM-4 on its own does not constitute a complete road asset management system. It does constitute a conceptually decision support tool for assessing the worth of road investment. The power of HDM-4 is fully achieved when it is linked to the road asset database maintained by a roads authority or agency. (Odoki and Kerali, 2000).

CHAPTER 5: RESULTS AND ANALYSIS

After RONET has been populated with all the data and all the calculations have been performed, it produces the following results or outputs:

5.1 Length and utilization

This is one of the outputs of RONET that advises road authorities on the length of the road network under their jurisdiction and the utilization of each surface type, i.e. how many vehicles are driving on the network that is paved with asphalt, how many are driving on the surface treated network and how many vehicles are driving on the gravel road network. This is to assist the road authorities when they are planning their road maintenance with prioritizing surface types that are utilized most.

Table 5.1: Network utilization by network type and surface type (km)

	Concrete	Asphalt	S.T.	Gravel	Earth	Total	Percent
Primary	0	0	6,264	0	0	6,264	23%
Secondary	0	0	0	14,500	0	14,500	52%
Tertiary	0	0	0	7,000	0	7,000	25%
Unclassified	0	0	0	0	0	0	0%
Urban	0	0	0	0	0	0	0%
Total	0	0	6,264	21,500	0	27,764	100%
Percent	0%	0%	23%	77%	0%	100%	

Table 5.2: Network length by surface type and road condition (km)

	Very Good	Good	Fair	Poor	Very Poor	Total	Percent
Concrete	0	0	0	0	0	0	0%
Asphalt	0	0	0	0	0	0	0%
S.T.	376	564	1,127	1,566	2,631	6,264	23%
Gravel	2,987	4,430	5,968	3,595	4,520	21,500	77%
Earth	0	0	0	0	0	0	0%
Total	3,363	4,994	7,095	5,161	7,151	27,764	100%
Percent	12%	18%	26%	19%	26%	100%	

The above results are intended to advise the road authorities on the percentage of their network that falls within the *very good* to *very poor* condition so that maintenance activities can be planned accordingly.

5.2. Asset value

This is the output that informs the road authorities about the value of the road network they are responsible for in terms of maintenance and rehabilitation. The importance of this information is that it makes the authorities aware of the financial implications should maintenance be delayed or not performed at all. RONET calculates these values in terms of network maximum asset value by network type and surface type, asset value by network type and road condition, and lastly, asset value in terms of network by traffic level.

Table 5.3: Network maximum asset value by network type and surface type (Million $)

	Concrete	Asphalt	S.T.	Gravel	Earth	Total	Percent
Primary	0	0	1,879	0	0	1,879	66%
Secondary	0	0	0	696	0	696	25%
Tertiary	0	0	0	252	0	252	9%
Unclassified	0	0	0	0	0	0	0%
Urban	0	0	0	0	0	0	0%
Total	0	0	1,879	948	0	2,827	100%
Percent	0%	0%	66%	34%	0%	100%	

Table 5.4: Network maximum asset value by network type and road condition (Million $)

	Very Good	Good	Fair	Poor	Very Poor	Total	Percent
Primary	113	169	338	470	789	1,879	66%
Secondary	63	133	246	110	144	696	25%
Tertiary	60	60	30	47	54	252	9%
Unclassified	0	0	0	0	0	0	0%
Urban	0	0	0	0	0	0	0%
Total	236	362	614	627	988	2,827	100%
Percent	8%	13%	22%	22%	35%	100%	

These results inform road authorities not only about the value of the asset that they are managing, but also of how much of the public funds they are losing when maintenance is neglected.

5.3 Roughness

Table 5.5: Network roughness by surface type and network type (IRI, m/km)

	Primary	Secondary	Tertiary	Unclassified	Urban	Overall
Concrete						
Asphalt						
S.T.	9.2					9.2
Gravel		12.4	11.5			12.1
Earth						
Overall	9.2	12.4	11.5			11.4

Table 5.6 Network roughness by surface type and road condition (IRI, m/km)

	Very Good	Good	Fair	Poor	Very Poor	Overall
Concrete						
Asphalt						
S.T.	3.0	4.0	5.5	9.0	13.0	9.2
Gravel	5.0	7.0	11.0	16.0	20.0	12.1
Earth						
Overall	4.8	6.7	10.1	13.9	17.4	11.4

This is the output that informs the road authorities of how rough their networks are. The unit for measuring this roughness is IRI, m/km. The reason for measuring the roughness is to help the authorities to plan their re-gravelling projects and blading activities on gravel roads as these are the roads mainly affected by roughness. The main purpose why roughness should be kept as low as possible is that it is a contributing factor towards increased Vehicle Operating Costs (VOC) - the higher the roughness, the higher the VOC.

5.4 Network Distribution Graphs

Figure 5.1: Network distributions per surface type

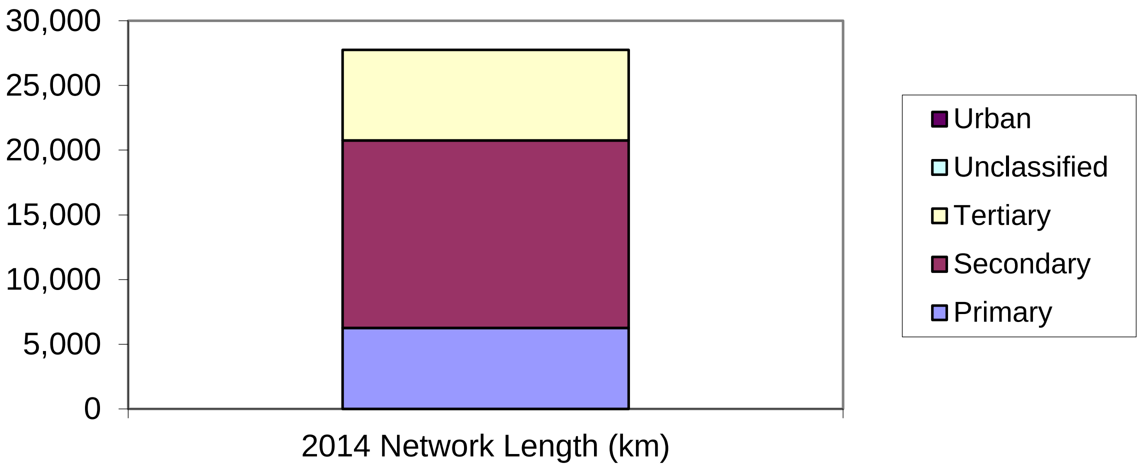
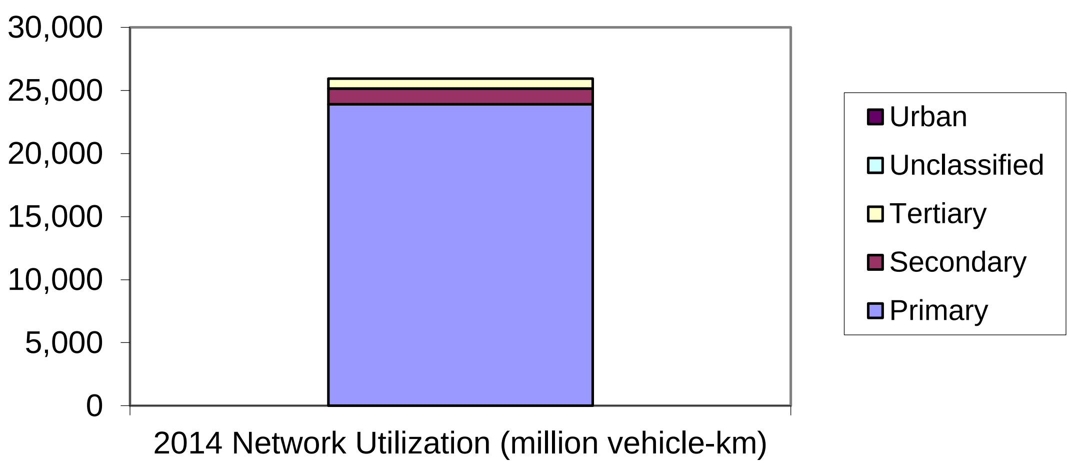


Figure 5.2: Network utilization in 2014 (million vehicle-km)



These are the graphs that advise the road authorities on how much each surface type contributes towards the total network length, how much each type is utilized and ultimately, which one is utilized most. These graphs also advise the authorities about the value of each surface type.

5.5 Road Works distribution

The following tables are the most important as they inform the road authority on how the network is going to behave over a twenty (20) year period. Firstly they determine the required budget from year one to year five, then from year six to year twenty and finally, from year one to year twenty.

Table 5.7: Road authority costs (M$/year) Year 1-5

Network	Paved	Unpaved	Total	Percent
Primary	18.8	3.8	22.7	31%
Secondary	6.8	13.0	19.8	28%
Tertiary	0.0	8.6	8.6	12%
Unclassified	0.0	0.0	0.0	0%
Urban	14.9	6.0	20.9	29%
Total	40.5	31.5	72.0	100%
Percent	56%	44%	100%	

Table 5.8: Road authority costs (M$/year) Year 6-20

Network	Paved	Unpaved	Total	Percent
Primary	126.8	13.3	140.1	44%
Secondary	23.5	69.8	93.3	29%
Tertiary	0.0	35.2	35.2	11%
Unclassified	0.0	0.0	0.0	0%
Urban	29.3	22.4	51.7	16%
Total	179.7	140.6	320.3	100%
Percent	56%	44%	100%	

Table 5.9: Road authority costs (M$/year) Year 1-20

Network	Paved	Unpaved	Total	Percent
Primary	221.1	32.4	253.4	37%
Secondary	57.6	134.8	192.4	28%
Tertiary	0.0	78.2	78.2	11%
Unclassified	0.0	0.0	0.0	0%
Urban	103.7	52.6	156.3	23%
Total	382.3	298.0	680.3	100%
Percent	56%	44%	100%	

Table 5.10: Summary of "Optimal Work Program"

Year	Rehabilitation (M US$)	Periodic Maintenance (M US$)	Recurrent Maintenance (M US$)	Road Agency (M US$)	Road Users (M US$)	Society (M US$)
1	191.6	10.9	4.1	206.7	767.6	974.3
2	22.1	0.4	4.1	26.7	790.2	816.9
3	9.6	2.7	4.2	16.4	813.3	829.7
4	38.5	19.5	4.2	62.2	834.3	896.5
5	0.0	20.1	4.2	24.3	859.3	883.7
6	1.5	10.6	4.2	16.4	884.9	901.3
7	4.2	5.3	4.2	13.7	913.3	927.0
8	0.0	17.9	4.3	22.2	943.8	966.0
9	0.0	12.1	4.3	16.4	971.1	987.5
10	0.0	7.0	4.3	11.3	1,002.8	1,014.1
11	1.8	24.3	4.3	30.4	1,031.8	1,062.1
12	16.5	2.2	4.2	23.0	1,056.8	1,079.8
13	5.0	7.9	4.3	17.1	1,089.8	1,106.9
14	0.0	10.5	4.3	14.8	1,124.7	1,139.4
15	0.0	45.2	4.2	49.5	1,156.7	1,206.1
16	0.0	8.0	4.2	12.2	1,193.6	1,205.9
17	1.8	9.4	4.2	15.4	1,226.5	1,241.9
18	0.0	9.4	4.2	13.6	1,265.6	1,279.2
19	0.0	6.5	4.3	10.8	1,306.9	1,317.7
20	1.7	18.5	4.2	24.4	1,341.0	1,365.4
Years 1-5 Total (M$)	261.8	53.6	20.9	336.3	4,064.7	4,401.0
Years 6-20 Total (M$)	32.6	194.7	63.9	291.2	16,509.1	16,800.4
Years 1-20 Total (M$)	294.4	248.4	84.8	627.6	20,573.9	21,201.4
Years 1-5 Total per Year (M$/year)	52.4	10.7	4.2	67.3	812.9	880.2
Years 6-20 Total per Year (M$/year)	2.2	13.0	4.3	19.4	1,100.6	1,120.0
Years 1-20 Total per Year (M$/year)	14.7	12.4	4.2	31.4	1,028.7	1,060.1
Present Value at 12% (M$)	256.5	93.8	35.3	385.6	7,745.3	8,130.9
Average (IRI)						

Table 5.10 presents a summary of the optimal work program that informs the road authority regarding the funds required over a period of 20 years. The road authority can plan for maintenance and rehabilitation activities way in advance and resources can be planned and allocated accordingly.

HDM-4 has been used in more than 100 developing countries and recently, many other countries have followed suit. The following are some of the reasons that lead to these countries opting to use HDM-4:

- Traffic congestion,
- Effect of cold climate,
- A wider range of pavement types and structures,
- Road safety, and
- Environmental effects in the form of energy consumption, traffic noise and vehicle emissions.

5.6. Summary

Results of this study were presented in this chapter. As expected, based on the literature reviews, the following were observed:

1. RONET is more user friendly as compared to both HDM4 and dTims as does not need a specialist to operate it, saving the road authorities both time and money to train the operator.
2. RONET does not need to be calibrated for local conditions unlike HDM4 and dTims that need to be calibrated for every country where they are going to be used.
3. RONET is freely available on the internet as it is sponsored by the World Bank saving the road authorities a lot of money as compared to the above-mentioned softwares that only available commercially.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The issue of underfunding of the road network in South Africa is becoming more serious every year and one of the fundamental problems is lack of proper planning for the funding of roads. This resulted in more than 30% of roads in South Africa being in poor condition in 2013. Most road authorities do not have a reliable tool that they can use when drafting a business plan, resulting in National Treasury allocating any amount of money available, which in most cases is not enough to address all their maintenance and rehabilitation needs. Hence, the study on RONET was conducted in an effort to determine the feasibility to curb the underfunding of roads in South Africa should it be used.

6.2 Conclusion

RONET was mainly developed with the aim of assisting decision makers in the road sector. It was designed as a tool for advocacy of specific revenue enhancing or cost recovery measures. This new version of RONET provides an interface between road maintenance expenditure and needs with the budget requirements through road user charges. This could be used by road authorities to develop a business case to negotiate and revise road tariffs on a sound basis. Therefore, RONET can be used by decision makers as a tool to improve the efficiency of their decisions and also to provide feedback of the decisions taken at a strategic level. Moreover, it must improve the effectiveness of the decisions in terms of the efficiency of results. The application of RONET will lead to an optimal Maintenance and Rehabilitation (M & R) strategy with good balance between rehabilitation, periodic and routine maintenance. Implementation of the optimal maintenance and rehabilitation strategy would cause a major improvement compared to the current condition of the network. Therefore, in the final chapter of this research study the main conclusions are summarized and some recommendations are made.

RONET version 2.0 implements the following evaluation modules:

The first evaluation module that RONET employs is the Current Condition Assessment, which calculates current road network statistics and network monitoring indicators. The next module is the Performance Assessment module, which evaluates the road network performance under different rehabilitation and maintenance budget scenarios, and presents the consequences to the road agency, the road user and the road infrastructure. Road User Revenues is a module that evaluates revenues being collected from road user charges and compares them with the funding requirements. Road authorities will be able to use RONET for the planning of their maintenance and rehabilitation projects since they will know the exact rate at which their network will deteriorate, how much traffic is travelling on their network, which surface type is the mostly travelled on and what the value of the asset will be. RONET will also assist the provinces and municipalities in South Africa to compile their business plans to ask for more funding from National Treasury, which has not been the case since road authorities never had a tool that assisted them in this regard.

6.3 Recommendations

RONET was initially developed by the World Bank to be used by African countries. Although it has been successfully implemented in Europe, it has never been used in an African country before. It is therefore recommended that it be used in South Africa as a major decision-making tool for road authorities when they are compiling their business plans, whether for a short period or Medium Term Expenditure Framework. It can assist decision makers to achieve the following:

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

6.4 Future work

Future work on RONET may include adding new modules for the evaluation of road user charges, life-cycle economy, axle loading impacts and network improvements. The possibilities of linking RONET with identifiable social impacts due to transport interventions, would be a particularly interesting path to explore in future. RONET as a model has interestingly enough also triggered some interest outside the transport sector, specifically for management of educational infrastructure such as schools. The model may be customized to deal with current characteristics and future forecasts for any kind of infrastructure management described by investments, utilization, deterioration, maintenance, condition, and value of assets at the macro level. Furthermore, RONET may be customized to be used also at project level as it is currently customized to inform the decision makers on the current condition of the network as a whole.

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APPENDICES

The following appendices were extracted from RONET and are the inputs that are populated onto RONET in order for it to produce desired outputs.

Country Data

Name and Year

Country Name	Free State Province
Current Year	2015

Basic Characteristics

Land area (sq. km)	128,000
Total population (million persons)	2.700
Rural population (million persons)	0.60
GDP at current prices ($ Billion)	4.600
Total vehicle fleet (vehicles)	619,419
Discount Rate (%)	12%

Traffic Growth and Pavement Width

Network	Annual Traffic Growth Rate (%/year)	Average Pavement Width (m)
Primary	3.0%	7.4
Secondary	3.0%	6.0
Tertiary	3.0%	5.0
Unclassified		
Urban		

Paved

Primary

Traffic (AADT)	Condition (IRI)	Very Good 3	Good 4	Fair 5.5	Poor 9	Very Poor 13	Total
Traffic I	<300	376.0	0.0	0.0	0.0	0.0	376.0
Traffic II	300-1000	0.0	564.0	0.0	0.0	0.0	564.0
Traffic III	1000-3000	0.0	0.0	1,127.0	0.0	0.0	1,127.0
Traffic IV	3000-10000	0.0	0.0	0.0	1,566.0	0.0	1,566.0
Traffic V	>10000	0.0	0.0	0.0	0.0	2,631.0	2,631.0
Total		376.0	564.0	1,127.0	1,566.0	2,631.0	6,264.0

S.T. Total
6,264.0 A1

Appendix 1 shows the number of kilometers that are in *very good, good, fair, poor* and *very poor* conditions in relation to traffic that is driving on each condition in terms of the International Roughness Index (IRI) of the primary network.

Secondary Gravel

Traffic (AADT)	Condition (IRI)	Very Good 5	Good 7	Fair 11	Poor 16	Very Poor 20	Total
Traffic I	<30	90.0	135.0	980.0	240.0	150.0	1,595.0
Traffic II	30-100	183.0	560.0	1,120.0	360.0	290.0	2,513.0
Traffic III	100-300	290.0	950.0	2,400.0	1,690.0	2,570.0	7,900.0
Traffic IV	300-1000	750.0	1,120.0	622.0	0.0	0.0	2,492.0
Traffic V	>1000	0.0	0.0	0.0	0.0	0.0	0.0
Total		1,313.0	2,765.0	5,122.0	2,290.0	3,010.0	14,500.0

A2

Tertiary Gravel

Traffic (AADT)	Condition (IRI)	Very Good 5	Good 7	Fair 11	Poor 16	Very Poor 20	Total
Traffic I	<30	70.0	102.0	340.0	620.0	450.0	1,582.0
Traffic II	30-100	91.0	103.0	206.0	335.0	580.0	1,315.0
Traffic III	100-300	903.0	0.0	0.0	0.0	480.0	1,383.0
Traffic IV	300-1000	610.0	1,460.0	300.0	350.0	0.0	2,720.0
Traffic V	>1000	0.0	0.0	0.0	0.0	0.0	0.0
Total		1,674.0	1,665.0	846.0	1,305.0	1,510.0	7,000.0

Gravel Total
21,500.0

A3

Appendix A2 and A3 show the number of kilometers that are in *very good, good, fair, poor* and *very poor* conditions in relation to traffic that is driving on each condition in terms of the International Roughness Index (IRI) of the unpaved network.

Historical Average Road Expenditures During Last 5 Years (MR/year)

Network	Road Work	Paved Roads	Unpaved Roads	Total Network
Primary	Rehabilitation	49.0	0.0	49.0
	Periodic Maintenance	12.0	0.0	12.0
	Routine Maintenance	31.5	0.0	31.5
	Total	92.5	0.0	92.5
Secondary	Rehabilitation	0	2.0	2.0
	Periodic Maintenance	0	2.0	2.0
	Routine Maintenance	0	2.0	2.0
	Total	0	6.0	6.0
Tertiary	Rehabilitation	0	2.0	2.0
	Periodic Maintenance	0	1.0	1.0
	Routine Maintenance	0	1.0	1.0
	Total	0	4.0	4.0
Unclassified	Rehabilitation	0.0		0.0
	Periodic Maintenance	0.0		0.0
	Routine Maintenance	0.0		0.0
	Total	0.0	0.0	0.0
Urban	Rehabilitation	0.0		0.0
	Periodic Maintenance	0.0		0.0
	Routine Maintenance	0.0		0.0
	Total	0.0	0.0	0.0
Total Network	Rehabilitation	49.0	4.0	53.0
	Periodic Maintenance	12.0	3.0	15.0
	Routine Maintenance	31.5	3.0	34.5
	Total	92.5	10.0	102.5

A4

Appendix 4 is an extract from RONET and it shows the expenditure during the last five years on the paved and unpaved network. The expenditure is in terms of routine and periodic maintenance as well rehabilitation.

Historical Average Road Works During Last 5 Years (km/year)

		Paved	Unpaved	Total
Primary	Rehabilitation	253.0		
	Periodic Maintenance	214.0		
	Routine Maintenance	54.0		
	Total	521.0		
Secondary	Rehabilitation	180.0		
	Periodic Maintenance	30,500.0		
	Routine Maintenance	0.0		
	Total	30,680.0		
Tertiary	Rehabilitation	0.0		
	Periodic Maintenance	21,530.0		
	Routine Maintenance	0.0		
	Total	21,530		
Network	Road Work	Roads	Roads	Network
Unclassified	Rehabilitation			
	Periodic Maintenance			
	Routine Maintenance			
	Total			
Urban	Rehabilitation			
	Periodic Maintenance			
	Routine Maintenance			
	Total			
Total Network	Rehabilitation	433.0	3,553.8	3,986.8
	Periodic Maintenance	52,244.0	11.2	52,255.2
	Routine Maintenance	54.0	18,475.2	18,529.2
	Total	52,731.0	22,040.0	74,772

A5

Appendix 5 is an extract from RONET and it shows the number of kilometers that were rehabilitated and maintained per year in the last five years.

Historical Average Unit Road Expenditures During Last 5 Years ($/km)

Network	Road Work	Paved Roads	Unpaved Roads	Total Network
Primary	Rehabilitation	193,676		
	Periodic Maintenance	56,075		
	Routine Maintenance	583,333		
	Total	833,084		
Secondary	Rehabilitation	22,222		
	Periodic Maintenance	66		
	Routine Maintenance			
	Total	11,177		
Tertiary	Rehabilitation	11,111		
	Periodic Maintenance	46		
	Routine Maintenance			
	Total	22,266		
Unclassified	Rehabilitation			
	Periodic Maintenance			
	Routine Maintenance			
	Total			
Urban	Rehabilitation			
	Periodic Maintenance			
	Routine Maintenance			
	Total			
Total Network	Rehabilitation	227,009	0	227,009
	Periodic Maintenance	56,187	0	56,187
	Routine Maintenance	583,333	0	583,333
	Total	866,529	0	866,529

A6

Appendix 6 shows the expenditure per kilometer during the last 5 years on the paved network.

The following appendices were extracted from RONET's outputs. These are the results that are generated by Road Network Evaluation Tools after it has been populated with all the necessary data as mentioned in Chapter 4 of this dissertation.

<u>Network Maximum Asset Value</u>

Network Maximum Asset Value by Network Type and Surface Type (Million $)

	Concrete	Asphalt	S.T.	Gravel	Earth	Total	Percent
Primary	0	411	114	33	0	558	65%
Secondary	0	33	61	137	0	231	27%
Tertiary	0	10	0	62	0	72	8%
Unclassified	0	0	0	0	0	0	0%
Urban	0	0	0	0	0	0	0%
Total	0	454	175	231	0	860	100%
Percent	0%	53%	20%	27%	0%	100%	

A7

Appendix 7 is extracted from RONET outputs and it shows the maximum asset value according to network type and surface type.

Network Current Asset Value by Network Type and Surface Type (Million $)

	Concrete	Asphalt	S.T.	Gravel	Earth	Total	Percent
Primary	0	393	88	15	0	496	71%
Secondary	0	28	44	85	0	158	23%
Tertiary	0	8	0	35	0	43	6%
Unclassified	0	0	0	0	0	0	0%
Urban	0	0	0	0	0	0	0%
Total	0	430	132	135	0	697	100%
Percent	0%	62%	19%	19%	0%	100%	

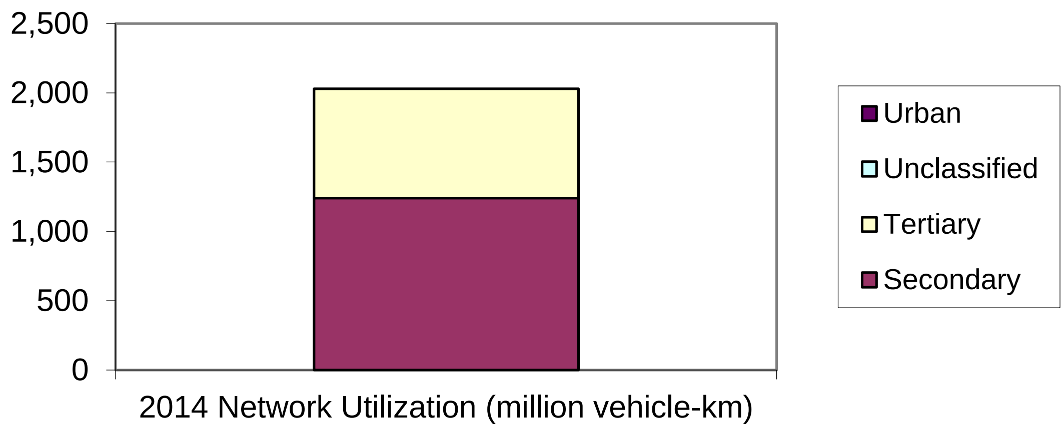
Appendix 8 is extracted from RONET outputs and it shows the network Current Asset Value by Network Type and Surface Type.

Network Roughness Weighted by Km

Network Roughness by Surface Type and Network Type (IRI, m/km)

	Primary	Secondary	Tertiary	Unclassified	Urban	Overall
Concrete						
Asphalt	3.1	4.7	4.5		7.1	4.0
S.T.	7.8	8.4			7.9	8.0
Gravel	19.3	16.5	17.8		14.5	17.0
Earth		11.9	19.9		16.5	17.6
Overall	8.2	13.7	19.5		14.2	16.0

Appendix 9 is extracted from RONET outputs and it shows the Network Roughness by Surface Type and Network Type (m/km)



A10

Appendix 10 is an extract from RONET and it shows the number of vehicles that are driving on the network annually