Federal Road Management for Sub-Saharan African Nations: A Nigerian Case Study

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Applied Science
in
Civil Engineering

Waterloo, Ontario, Canada, 2009

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

The World Bank specifically indicates that poor transport infrastructure and services in sub-Saharan Africa are serious obstacles to poverty reduction (Plessis-Fraissard, 2007). Two thirds of Africa's rural population, who are some 300 million of the world's poorest people, do not have access to an all-weather road. The same holds true for the federal paved network, further compounding the issues of health and economy. In the case of Nigeria, the majority of their federal network was constructed decades ago and little, if any, pavement management has been conducted. Further, federal roads that have been reconstructed or new roads that have been built are done so with inferior materials, inadequate designs and lack of quality control during the building process. Contributing to the poor state of the federal road network are high traffic volumes and traffic loads, as heavily overloaded trucks are commonplace.

Nigeria has understood the need to improve their federal road network if they are to achieve the Millennium Development Goals they have outlined. As such, the Federal Roads Maintenance Agency (FERMA) was created and set in motion a mandate of federal road improvement through more appropriate design, construction, and above all else, pavement management. The major challenge, however, is that they are starting the process without a database, pavement management system, or an appreciation of the condition of their federal road network.

The primary objective of this thesis is to form the foundation of a pavement management system (PMS) that FERMA can immediately implement to make better decisions pertaining to rehabilitation options. Further, it is the intent to allow for appropriate decisions about the best type of maintenance and rehabilitation interventions to apply to the poor state of arterial roads taking into context various factors, least of which are the type and extent of distress present and the benefit cost analysis. The outcome of this thesis will assist sub-Saharan Africa, but principally Nigeria, in their goal of fostering economic growth and creating a more sustainable transportation network. Recommendations on how to simplify input factors necessary for Nigeria to initiate a database and prepare more regionally specific designs have been made, including traffic, climatic and subgrade classifications. Economic analysis included present worth of costs (PWC) that were derived from condition rating curves specific to intervention pavement life and performance. Based on preliminary findings, subject to field validation, a chip-seal specific rehabilitation strategy for low volume federal roads is more cost effective over the 20-year analysis period, and 1-lift of asphalt concrete (AC) is more cost effective over the 20-year analysis period for high volume federal roads. Recommendations for further research have been made.

ACKNOWLEDGEMENTS

Over the past two years there have been many people who have warranted my thanks, appreciation and gratitude. Without the support of Bridget, Zoë and most recently Rowan I could not have embarked upon or accomplished this chapter in our evolving and colourful life together. All my family members have been continuously supportive, which has made this journey easier. The support and encouragement of every member of the Metrontario Group and AnyWay Solutions is gratefully appreciated, with special mention to Matt Fisher, Zeevik Halber, Lawrie Lubin and Lyon Wexler. Special thanks to the ever-generous and supportive Silver family. There are numerous members of the CPATT group at the University of Waterloo who have been available whenever I needed them, for which I am appreciative. I am thankful for having had the opportunity to meet and spend time with Michael Esenwa, without whom this project would not have come to fruition. Lastly, and certainly not least, it is with absolute privilege that I have been able to be mentored by Prof. Susan Tighe. She is truly a remarkable individual who I feel blessed to have had the opportunity to learn from, both academically and personally. I am honoured to have started with her as a supervisor and leave her as a friend.

DEDICATION

Bridget, Zoë and Rowan – my three pillars.

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DEFINITIONS

AASHO: American Association of State Highway officials
AASHTO: American Association of State Highway and Transportation Officials
AC: Asphalt Concrete
ADT: Average Daily Traffic
ADTT: Average Daily Truck Traffic
AfDB: African Development Bank
ASSIST: African Programme of Advisory, Support, Information Services and Training
CBR: Californian Bearing Ratio
ESAL: Equivalent Standard Axle Load
FERMA: Federal Road Maintenance Association
GDP: Gross Domestic Product
HDM4: Highway Design and Maintenance Standards Model
IBRD: International Bank for Reconstruction and Development
IDA: International Donor Agency
ILO: International Labour organization
LGA: Local Government Authority
MR&R: Maintenance, Rehabilitation and Reconstruction
MTO: Ontario's Ministry of Transportation
MTRSMMS: Medium Term Road Maintenance Management Strategy
NCHRP: National Cooperative Highway Research Program
NEEDS: National Economic Empowerment and Development Strategy
PRMM: Performance Based Road Maintenance Management
PWC: Present Worth of Cost
ROCKS: Road Costs Knowledge System
RONET: Road Network Evaluation Tool
SATCC: Southern African Transport and Communications Commission
SRSE: Systematic Road Strengthening and Enhancement
SSA: Sub-Sahara Africa
SSATP: Sub-Saharan Africa Transport Policy
TRL: Transportation Research Laboratory
UCS: Unconfined Compressive Strength
UNCTAD: United Nations Conference on Trade and Development
WASHO: Western Association of State Highway Officials

CHAPTER 1: INTRODUCTION

1.1 Background to the Project

Over the past decade there has been a paradigm shift by international donor agencies involved in sub-Saharan Africa away from funding of infrastructure projects towards those relating to health and education (social projects). In the period between 1980 and 1984 the share of total donor funding to infrastructure projects was close to 25%, whereas it had decreased to less than 10% by the 21st century (AfDB Working Group, 2006). Much of this has been due to the higher prevalence and understanding of the impact of HIV/AIDS, not to mention malaria, on the economic development of the developing world. However, this shift away from infrastructure projects has come at a cost, as there has been an under appreciation for the impact, socially and economically, that transportation infrastructure, irrespective of functional classification, can have on the economic growth of a country. It would appear that the line has only just been drawn to connect the dots between the appreciation for roads and basic access being directly related to health and education. Clearly there is a balance between funding of road infrastructure and funding of health and social projects, given the interconnection of these sectors.

Sub-Saharan Africa, with few exceptions, is unique in that the roads that have been created are inefficient and insufficient to spawn and sustain growth, and require not only substantial upgrading and rehabilitation, but also substantial new road construction. Many nations that have not had the opportunity to fully develop road infrastructure systems are now discovering the standards and methods from neighbouring or western countries which they have been relying upon are not altogether applicable to their circumstances (Arumala and Akpokodje, 1987). This inapplicability stems from differing climatic circumstances (heavy rain events), complex and deep stratigraphy of soils, highly plastic and highly decomposed materials characteristic of tropical/sub-tropical environments, lack of aggregate/high quality materials, and large (and increasing) transport distances of materials to the construction site. There is also a difference in terms of need that is not addressed in the standard manuals and application guidelines of other countries.

Transport is critical to economic development, both low volume/rural roads and major arterials, and there is a direct relationship between a countries economic prosperity and kilometres of paved roads (Owen, 1964; Queiroz and Gautam, 1992). While there are many papers and reports on the merits of the rural road sector (World Bank's sub-Saharan African Transport Policy being a major source; World Bank, 1996)) and the fact that all-season passability and lack of basic access to rural communities impedes economic growth, there is also a need to further develop and rehabilitate the major trunk system within these countries to be able to sustain and accommodate economic growth brought about by improved rural mobility. In the case of Nigeria, the major arterial network is in such disrepair and dilapidation that immediate action is required. In a country that is so rich in potential, pavement infrastructure is critical. Considering President Abasingo's inaugural address of

May 1999, there is certainly a shift towards realizing this importance: ''Transport is the lifeline of the economy and social interactions. An inefficient transport system implies stagnation in all sectors. Our priorities in this sector will be the design and implementing a new policy on road maintenance" (Abasingo, 1999). The formation of the Federal Roads Maintenance Agency (FERMA) and publication of its Strategy for Road Sector Maintenance Management (FERMA, 2007) may be the injection needed to realize this.

After decades of civil strife and repression, Nigeria has finally embarked upon what appears to be a more democratic chapter in its colourfully rich history. Unfortunately, the years of negligent spending and misdirected national policy have left a national transportation infrastructure system in need of desperate rehabilitation and modernisation, especially if the millennium development goals are to be realized and the 20-2020 plan of becoming the 20th largest economy in the world by 2020 is to be realized (FERMA, 2007). Much of the road network requires some form or other of maintenance, rehabilitation or reconstruction (MR&R), however, this must be done with little historical data and funding. What are abundant is desire and seeming commitment to improvement.

While it is difficult to shed the shroud that has been worn for such a long time, there are at least signs of optimism and hope that Nigeria has turned a corner. Despite there having been a realization that transport is at the epicentre of realizing the true potential of such a rich nation, reactions have been slow in practicing what is being preached. Designs that are being produced for pavement infrastructure are inappropriate, and given the fact that they are likely to be constructed with little regard to design tolerances and with no maintenance or rehabilitation plan, it is no wonder that the roads stand little chance in lasting even a fraction of their designed lifespan. With such a myriad of issues to deal with across all sectors of transportation, there is a clear need for decision-making tools and simple, yet effective, strategies to help Nigeria focus what little resources it has in improving its transportation infrastructure. Simple yet effective strategies will assist Nigeria in achieving a more sustainable road infrastructure system.

The intent of this thesis is to assist sub-Saharan Africa, principally Nigeria through FERMA, streamline its MR&R interventions. It is particularly poignant given that the African Development Bank's Country Strategy Paper (AfDB, 2005) identifies one of the major transportation issues as 'the absence of a maintenance plan' and the primary objective of Nigeria's Medium Term Road Maintenance Management Strategy (MTRSMMS) is to apply preventative measures that will help to stabilize the structural strength of road pavements. To accomplish this, a series of decision tables and flow charts are developed based on the functional class of the road, traffic volume and loads, distress type and extent, and the existing pavement layer design. It is envisaged that engineers at the regional, state and federal level will be able to utilize this proposed framework to determine one of a suite of focussed and appropriate MR&R alternatives that can be used to better assess, based on available budget and ability to carry our maintenance, which intervention is the most appropriate. Life cycle costing will be critical in this regard. It is also the intent of this thesis to provide suggestions of more appropriate pavement mix designs, using Nigeria as a case study, that can be applied, based on the current pavement layer design and extent of distress observed. In essence, a toolkit by which engineers can make appropriate decisions would be ideal. Further, with respect to those roads that require major rehabilitation or reconstruction, mix design guidelines should be provided to ensure that layers that are reconstructed are completed to meet the climate, load and future traffic volume.

1.2 Objectives

The objective of this thesis is to assist sub-Saharan Africa to make appropriate decisions about the best type of MR&R intervention to apply to the poor state of arterial roads taking into context various factors, least of which are the type and extent of distress present and the benefit cost analysis. A secondary objective is to provide FERMA with analysis of its mix designs and re-evaluate them to allow for more appropriate pavements to be constructed. It is recognized that these objectives need to be balanced against regional issues that include:

- Budget constraints;
- Materials – quality and availability;
- Soils – condition and variability;
- Maintenance capacity;
- Traffic type and volumes; and,
- Experience and availability of practitioners.

It will be important to incorporate the classification of roads and supply FERMA with decision tools to streamline its intervention selection based on parameters associated with the particular road classification. This may be a combination of gravel and/or sealed roads, but the volume and equivalent standard axle loads (ESAL's) should be the defining parameters.

The outcome of this thesis will assist sub-Saharan Africa, but principally Nigeria, in their goal of fostering economic growth and creating more sustainable transportation network. A methodology for assessment will also be presented. It is not the intent of this work to become a design guide or standard on how to build better roads, rather a preliminary step in assisting Nigeria to maintain the pavement assets it currently has in the interim that a new pavement design guide and standard is created. The creation of a new Nigerian-specific design guide would take considerable time to be implemented, providing further cause and necessity for this thesis and the more appropriate and focussed decisions it plans to outline.

1.3 Scope of Thesis

This thesis will cover four main areas, namely:

- A summary of African transportation, issues and the desire for change, with specific reference to Nigeria. An emphasis will be placed on the types of designs that have been practiced, the types of distresses being observed and the materials available they have to work with;
- An investigation and quantification into the types of distresses observed, their manifestation and MR&R strategies will be critical to understanding the intervention choices derived from the decision tables. Local Nigerian designs are evaluated in terms of appropriateness of the intervention;
- A framework for Nigerian pavement design and management will be provided for pavement design factors. A pavement distress evaluation form for site investigation in Nigeria will be developed. The form is directed to the roads department to unify its data collection and better streamline its priority analysis; and,
- Life cycle costing of stabilized bases versus non stabilized lateritic material versus convention material. The key here is to create better immediate infrastructure, and then implement best management practices and a pavement management strategy to guide Nigeria forward.

As a result of the findings, decision tables and charts are developed for FERMA for both field and regional engineers. To assist FERMA in streamlining current rehabilitation strategies, present worth of cost (PWC) optimizations are conducted to provide cost effective strategies over the life cycle period for a range of intervention costs.

1.4 Research Methodology

The methodology used for this research included an in depth review of current road building practises in Africa with a specific focus on Nigeria, definition and expansion on data sources and how they can be better formatted for pavement engineers, and life cycle cost analysis was performed on various rehabilitation options to provide FERMA with basic information on when to implement rehabilitation interventions. Based on the literature review, restructuring of data information to better suite pavement design and engineering in Nigeria is proposed. These proposed classification were an integral component in performing life cycle cost estimating. From this, recommendations based on pavement input parameters were made for appropriate rehabilitation interventions. Figure 1 shows the overall methodology of the research study.

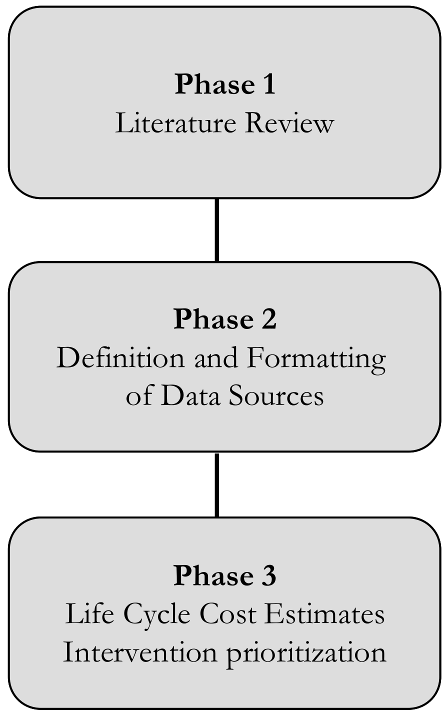


Figure 1.1: Overall research methodology

1.4 Organization of Thesis

Chapter One provides an introduction to the research project. It provides a general background and provides the scope and objectives of the work.

Chapter Two provides a literature review of the issues surrounding transport in Nigeria, its importance, and how pavement management can assist in improving the economy and wellbeing of the country.

Chapter Three describes the research methodology and provide insight into the data sources.

Chapter Four presents life cycle costing of various rehabilitation options and optimum strategies

Chapter Five presents the research conclusions and recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

The following section is intended to provide pertinent background for this thesis. This section will attempt to convey the issues, principally from a transportation standpoint, that are not only facing Nigeria but Africa as a whole. After having read this section the reader should have an appreciation for the differences between western transport-related issues and those being experienced in Nigeria and the principle reasons for them. This section is not intended to provide an exhaustive account of all aspects relating to transportation in Nigeria, however, it will provide the necessary background and references where a more detailed account of the subject can be reviewed, including the principles of road design and asset management.

2.1 African Transport

Africa is a continent rich in resources, culture and promise. With a population of approximately 900 million, coupled with an over-abundance of natural resources, it is a region that possesses great potential. Yet, it remains for the most part, stagnated, poor and underachieved. One of the resounding reasons for not having the ability to reach its potential is the poor state of road infrastructure, which the United Nations (2008) highlights as a principal reason that is keeping the African continent from progressing. In Africa, inadequate transport is the norm rather than the exception. It is not that International Donor Agencies (IDA's) have not tried to rectify the situation, quite the contrary, but for the most part they have been largely unsuccessful (Pleassis-Fraissard, 2007).

Africa is poorly serviced with roads. The road density is on the average 5 km per 100 square km (AfDB, 2003), which is low when compared with other developing regions, such as Latin America and Asia with 12 km and 18 km respectively per 100 square km (World Bank, 2007). The significant difference is partly due to diverse levels of development in general, but it also reflects the basic geographic fact that Africa is a very large continent, often with vast distances between the main population and production centers. The large size of the continent and the wide spread of population only raises the significance of transport in almost all development decisions. This lack of adequate transportation impacts the level of business activity by lowering productivity and limiting the entry of new enterprises. Businesses in Africa either supply to fragmented regional markets, or restrict themselves to market opportunities with profits large enough to cover the high transport costs (Ramachandran, 2008).

Backlogs in maintenance and inefficiencies in operations have serious effects in many other sectors. Expensive and poor quality trunk services (Figure 2.1) reduce the competitiveness of African products. As noted, typical pavements exhibit severe potholing and shoulder deterioration.

Inadequate and ill-maintained local infrastructure prevents large parts of the population from participating in the modern economy (African Union, 2005).

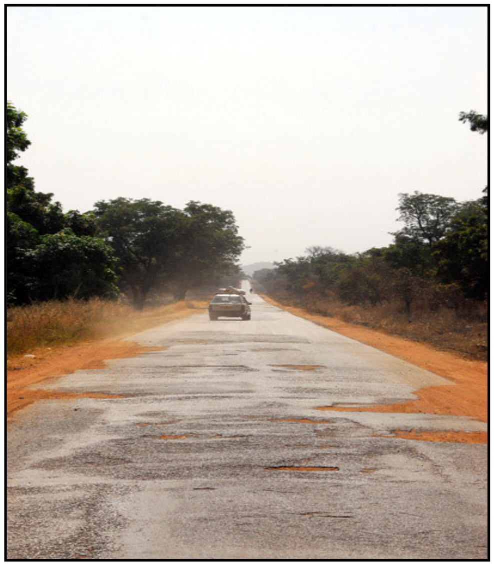


Figure 2.1: Generally, paved roads in Africa are poorly maintained creating a fragmented system with significant potholing, shoulder deterioration and unsafe driving conditions.

The relatively sparse road network does not imply a lack of importance of road transport. Rather, road transport is the most important mode. Decades of under-capitalization, poor management and general neglect of the railways have propelled road transport to the most important means of transport in Africa. Road transport accounts for over 80% of all freight and passenger movements in Africa and there are no signs that this position will be threatened during the foreseeable future (AfDB, 2003). The existing road networks in sub-Saharan African countries were originally established to service the specific needs and interests of the colonial powers who utilized Africa as an import and export market to fuel domestic economic growth. Therefore, after having achieved independence, African nations inherited a transportation system that was outward looking rather than geared towards improved trade and transport with neighbouring African countries (AfDB, 2003). One of the early goals of the independent African nations was to break this pattern of dependence and create new, closer African ties.

One such project was the east-west Mombasa-Lagos Trans-African Highway as a means to encourage inter-African trade and development. This project, however, provides valuable insight into why international donor aid into Africa has largely failed in the past. As early as 1969, the Japanese government proposed extending the Mombasa Highway to Lagos, Nigeria on the Atlantic Ocean into a four lane, 6,260 kilometre paved highway. By 1971, the deal had the support of all six nations through which the route would pass (Kenya, Uganda, Zaire (now the Democratic Republic of Congo), Central African Republic, Cameroon, and Nigeria) and six international aid agencies.

They hoped to have at least two lanes of all-weather road open by 1978. It did not take long for problems to emerge. Dictator Idi Amin took control of Uganda and threatened Kenya, which then closed the highway. The fight reflected a constant plague for foreign aid to Africa – corrupt dictators, and donors who gave them money to protect political and economic interests. Nowhere was this exchange clearer then in Zaire, now known as the Democratic Republic of Congo. Zaire needed to build roads from scratch, however the country was ruled by Mobutu Sese Seko, one of the most brutal dictators in African history. Mobutu took power during the cold war, at a time when the US and the Soviet Union were scrambling for influence in Africa. In the mid-1970's, he was a funnel for arms flowing to anti-communist rebels. Billions of dollars poured into Zaire to keep him happy, and to maintain the flow of Zairian gold, diamonds and copper to the West. Mobutu stopped plans for the highway in 1974. Despite Mobutu in Zaire, the road in Kenya remained in good condition and by the 1970's Kenya's economy was booming. A further underlying problem which soon came to head was the lack of a maintenance plan to keep the critical asset in a functioning capacity.

There are a multitude of examples that can be provided to help illustrate the general state of transportation in Africa and how it differs to roads in the developed world. For those not having had the privilege of setting foot into sub-Saharan Africa it is difficult to fully appreciate how desperate the situation is. This can be best illustrated by the following example, which as a preface, is not unique but encompasses the economic, social and environmental issues that are facing the majority of nations as they strive to deal with growth. The following account of a trucker's journey in Cameroon was documented in The Economist (2002, cited in Buys et al., 2006)), which poignantly highlights the massive issues that need to be overcome throughout sub-Saharan Africa. The following description also serves as a stark contrast to transportation issues faced in western countries, such as Canada:

> *"The plan was to carry 1,600 crates of Guinness and other drinks from the factory in Douala where they were brewed to Bertoua, a small town in Cameroon's south-eastern rainforest. According to a rather optimistic schedule, it should have taken 20 hours including an overnight rest. It took four days. When the truck arrived, it was carrying only two-thirds of its original load…we were stopped at road blocks 47 times…our road was rendered impassable by rain three times, causing delays of up to four hours. The Cameroonian government has tried to grapple with the problem of rain eroding roads by erecting a series of barriers that stop heavy vehicles from passing while it is pouring. …Early on the second evening we met a locked rain barrier in the middle of the forest. It was dark, and the man with the key was not there – he retuned shortly before midnight. The hold-up was irritating, but in the end made no difference. Early the next morning, a driver coming in the opposite direction told us that the bridge ahead had collapsed, so we had to turn back."*

From a western perspective, it is important to note that roads serve a multitude of functions, other than transport, in sub-Saharan Africa. It is commonplace for major roads to dissect towns and cities, rather than circumnavigating them. Major routes and roads in general, serve not only as transport routes, but also provide a meeting place for the local community where markets are established and a community interacts. Roadside markets and shops spill onto the road and the shoulders, if existent, and become a thriving focal point of African society (Figure 2.2). This roadside consumption is widespread and causes substantial bottlenecking.

Figure 2.2: Typical African roadside market.

2.1.1 A Brief History

There have been two distinct modern eras in road transport in Africa. The first major era, described as the road and motor vehicle sector boom era, was between the early 1960's and 1980's. This era overlapped with the United Nations Transport and Communications Decade for Africa (1978 - 1988), whose objectives included the final construction and improvement of the major highways and the development of rural roads (Akinyemi, 1998). During this period, new road construction and reconstruction consumed, on average, approximately 1.1 percent of the gross domestic product (GDP) of each country (Mason and Thriscutt, 1989). Further, there was significant investment by IDA's, such as the European Union, which invested over $3 billion on road projects between 1970 and 1990.

Meanwhile, during the same period, the economy of many countries started to stagnate or deteriorate. Much of the deterioration was a consequence of political change away from democratic rule, resulting in an immediate lack of funding for infrastructure that was needed to maintain and increase the transportation network. For example, in Nigeria, despite average maintenance expenditures that were 70% to 500% higher than the desirable routine maintenance expenditures in other developing countries, as well as adoption of several maintenance approaches, potholes and bumps were ubiquitous on the roads (Akinyemi, 1983). In a survey carried out by Mason and Thriscutt (1989) on roads in west and central Africa between 1981 and 1982, only 4% of paved roads were sealed, strengthened or reconstructed each year, while 3% of gravel roads were either re-gravelled or rehabilitated. At the end of the survey period, more than 50% of paved roads and 20% to 30% percent of gravel roads required substantial rehabilitation. The increase in the poor state of both rural and arterial roads further stagnated economic growth and produced a discontinuous, inefficient road network. Compounding these issues was the disproportionately high cost of transportation, where families were spending as much as 45% of their income on transportation, not to mention expenditure of time that was required to do so. Due to the poor state of the roads and the mix of uses utilizing the roads (and shoulders), traffic accidents were further crippling many African nations.

With increased international realization and concern about the problems, the second major era, described by Akinyemi (2001) as the era of "externally initiated and financed transport sector reform programmes", started around the end of the 1980's and early 1990's. One of the well known programmes was the World Bank's Sub-Saharan African Transport Programme (SSATP), which was intended to help improve and sustain transport efficiency through policy reform and institutional improvements. Another major programme was the International Labour Organization's (ILO) African Programme of Advisory, Support, Information Services and Training (ASSIST) for labour-based infrastructure works.

The current era in Africa is looking at improving trans-African trade and connectivity. A comprehensive African trunk road framework that will connect all African nations together with major arterials is currently being carried out. To what extent it can be completed or face the issues that the Mombassa-Lagos Trans African Highway did remains to be seen.

2.1.2 Specific Transport Issues in Africa

The World Bank specifically indicates that poor transport infrastructure and services in sub-Saharan Africa are serious obstacles to poverty reduction (Plessis-Fraissard, 2007). Two thirds of Africa's rural population, who are some 300 million of the world's poorest people, do not have access to an all-weather road. They are locked into subsistence living cut off from health care and education. Generally, there is a major fraction of rural Africa that is cut-off from places of economy for at least one part of the year due to the lack of all-season passability of basic access routes. The majority of these routes are gravel or earth roads that could benefit from simple pavement management.

On the other hand, while the majority of roads in sub-Saharan Africa (SSA) are un-surfaced roads, arterial roads are also a major obstacle to not only poverty reduction, but impose a high burden on Africa's economic development. An efficient operation of urban transport infrastructure is required to avoid bottlenecks that constrain growth in other sectors. Africa's unit transport costs are typically three to five times higher than those of developed countries (World Bank, 2006), which is one of the principal reason why SSA contributes only 2% to world trade. Arterial roads restrict further economic development through high vehicle operating costs, land transport times and general poor and unsafe driving conditions of the roads. This is further exacerbated due to the almost non-existent or inoperable state of the waterway and rail transit system in the country placing further stains on an already stressed infrastructure.

The high cost of transport in Africa seriously undermines growth prospects in the continent (Henderson et al., 2001). A United Nations Conference on Trade and Development (UNCTAD) study on African transport infrastructure (UNCTAD, 1999) highlighted the comparative disadvantage of Africa in relation to other continents. On average, freight costs are 5 percentage points higher in sub-Saharan Africa than the average for all developing countries (11.41% for Africa versus 7.08 for America and 7.97 in Asia). In landlocked African countries, the situation is even worse, as costs are typically 10 per cent higher (18.79%). If northern Africa is removed from the equation and only sub-Saharan African economies are considered, the estimated total freight costs on imports is 15.36% (UNCTAD, 1999). In a study of transport costs and trade, Limao and Venables (2000) found that poor infrastructure accounted for 60% of transport costs for landlocked countries, opposed to 40% for coastal countries. It is no wonder that Africa's Landlocked countries are some of the poorest in the world (e.g. Chad). Whereas, Amjadi and Yeats (1995) found that the relatively low level of sub-Saharan African export is essentially due to high transport costs.

Road accidents are Africa's third largest killer (Williams, 2003). Traffic accidents cost 1% to 3% of the Gross National Product (GNP) as road accident fatalities increased by 20-30% annually, and caused between 50-200 fatalities per 10,000 vehicles during this era of transport (Akinyemi, 2001). In addition, 30-60% of the traffic fatalities involved vulnerable road users (TRRL, 1991).

2.2 Nigeria

Nigeria covers an area of 924,000 km^2 in western Africa and is the most populated African nation with 138,283,240 people (CIA, 2008). Extending from the Atlantic Ocean in the south to the fringes of the Sahara desert in the north (Figure 2.3), it has common borders with the Republics of Benin, Niger, Chad, and Cameroon.

Nigeria is composed of more than 250 ethnic groups, with 36 states and 1 territory (Federal Capital Territory). It is mainly divided between a Christian south and an Islamic north. The average of about 150 persons per km^2 masks the considerable differences that exist between the densely populated south-east of the country where the majority of the urban population is concentrated, and the less densely populated north. Close to 60% of the population live in rural areas. A staggering 70% of the population live below the poverty line.

Figure 2.3: Nigeria is located in western Africa and borders Benin to the west, Niger to the north, Cameroon to the east and Chad to the northeast (CIA, 2008).

With a GDP of approximately US$40 billion, Nigeria is Africa's second largest economy. Yet about two-thirds of the population live below the national poverty line. The average annual per capita income stands at a level of US$320.

The following additional statistics will help to provide a more accurate impression of Nigeria, and the uphill battle confronting it. They are:

- 52% of the population, over 70 million, live on less than a dollar a day (Nigerian National Bureau of Statistics, 2006);
- Gross National Income (GNI) per capita is US$640;

- Enrolment in primary education is around 68%, but there are wide regional and gender disparities (DFID, 2007);
- Average life expectancy in Nigeria is 47 years (DFID, 2007);
- 1 in 5 children die before the age of 5 (DFID, 2007);
- Approximately 800 per 100,000 women die in childbirth, although this may exceed 100 per 100,000 in some regions (DFID, 2007);
- 4.4% of 15-49 year olds (2.6 million people) are living with HIV and AIDS;
- The average annual growth rate between 2000 and 2006 was under 6%;
- Nigeria has the third highest number of poor people in the world, after China and India (AfDB, 2005);
- 48% of the population has access to safe and clean water; and,
- The median age is 18.9 years.

In May, 2004, the government finalized the National Economic Empowerment and Development Strategy (NEEDS), which together with the state level (SEEDS) forms Nigeria's home grown strategy for growth and poverty reduction (AfDB, 2005). Nigeria has made good progress in the implementation of key elements of the reform program, particularly in macroeconomic management and in the fight against corruption. However, despite progress made, major economic and structural challenges persist, including the achievement of a more diversified economy away from the oil-sector, reduction of public debt, improvement of education and health service delivery especially to the poor, combating the spread of HIV/AIDS, enhancement of social and economic infrastructure, particularly water and power supply and transport and achieving food security.

Nigeria's economy is dependant on oil production, with agriculture a very distant second (30% of GDP), and is generally not diversified beyond the oil sector. Over the past 5 years, the oil industry has contributed on average 38% to GDP. In 2004, proceeds from oil exports amounted to 97% of all exports and in 2007 oil and gas accounted for 77% of all government revenues (AfDB, 2008). The reliance on oil and the importance of diversifying the economy was evident over four decades. Owen (1964) identified that the reliance on oil presented an unstable economy that was at the mercy of this commodity and that any softening of this sector would significantly impact the Nigerian economy. Owen (1964) stressed the importance of improving the transport infrastructure and stressed that inadequate investment in transport reduces the effectiveness of investments elsewhere, which is something Nigeria can not afford to happen. Obviously, little has changed when we look at today's outlook and priorities for change.

Much of this reliance on oil is now not so much due to the abundance contained in and off the shore of Nigeria, but the poor road infrastructure that exists within the country. At the heart of all of Nigeria's problems is the absence of a solid and reliable transportation infrastructure system. The African Development Bank's Country Strategy Paper for Nigeria (AfDB, 2005) outlines that poor maintenance due to inadequate allocation of funds and, in some cases, faulty design and construction due to lack of institutional capacity or poor contract administration, is at the root of their problems.

2.3 Nigerian Transport

The performance of the Nigerian roads sector has not been satisfactory despite its enormous potentials for growth and development. Traditionally, the poor transport facilities and infrastructure have severely delayed economic development and this weakened transport infrastructure has contributed negative attempts to alleviate poverty in the country. The Nigerian inland waterways and railways are ineffective, as road transport accounts for 90% of the internal movement of goods and people, which makes the grave state of the roads all the more important that they receive much needed rehabilitation interventions.

There have been essentially four major road building movements in Nigerian history. The first major initiative dates back to 1925, when the Road Board was established by the then colonial administration. As of 1951, approximately 1800 km of roads of the 44,414 km total were surfaced. While these roads served to open up Nigeria, they were lacking standard designs, had sharp curves and were constructed on weak subgrades (Central Bank of Nigeria, 2003). The growth of economic activities (oil) prompted the need for improved roads and by 1952, 15,785 km of bituminous roads and 75,200 km of earth/gravel roads were in place. This short period of road improvement could be considered the second wave of pavement infrastructure implementation. The total paved road density increased from about 17 km per 1000 km^2 in 1960 to about 160 km per 1000 km^2 in 1979. Much of this rapid increase in paved roads was due to the discovery of oil in 1958, necessitating improved infrastructure to gain access and extract oil. The third major effort in road construction occurred after the civil war in 1970 where the majority of major arterials were constructed, which are the same roads that are in use today. Further, in the 1980's, a massive rural road construction programme resulted in rural road densities increasing to as much as 490 km per 1000 km^2 in some Nigerian states (Akinyemi, 1983). The fourth phase of pavement infrastructure growth is upon us now, where the approximate 195,000 km of Nigerian roads requires immediate rehabilitation and reconstruction if the country is to forge ahead in its pursuit of economic stability and development.

Of the 195,000 km of classified roads contained within the Nigerian network, 32,100 km (16.5%) are federal roads, linking the state capitals and other major towns to one another; 30,900 km (15.8%) are State roads linking towns and major settlements; and, the remaining 132,000 km (67.7%) are Local Government Authority (LGA) roads, linking smaller communities to one another and to local government headquarters. More than 80% of the network is either in fair or poor condition (AfDB, 2007).

The Bureau of Public Enterprises (2008) outlines four key issues with road transport in Nigeria that are obstacles for progress and for engaging private sector participation. They are:

- Inadequate maintenance: The road network suffers from inadequate routine maintenance, neglect of periodic maintenance and the absence of emergency maintenance in areas affected by flood, storms and other natural calamities. Absence of adequate road maintenance shortens the useful life of the roads, thus resulting in premature and costly road reconstruction, while poor surface increases the operating costs of vehicles and has significant effect on road safety;
- Misuse of roads: A major cause of the declining roads infrastructure is the misuse of roads due to overloaded trucks. Excessively high axle loads on paved and gravel roads especially during the raining season contribute substantially to reducing the life expectancy of roads;
- Dependence on roads: The dependence on roads in Nigeria at the present time is almost total because the Nigerian railway is comatose and air traffic is still low in the country. It is estimated that between 90-95% of the total transport movements is on the road network. Thus, the transport of goods is not optimized towards the most appropriate mode as the railway and inland waterways modes, which are neglected. Therefore, freight and bulk goods are carried over long distances by trucks and tractor-trailers;
- Poor inter-modal transport system: A comprehensive transportation concept that interconnects the various transport modes to make the most use of their individual advantages does not exist at the present time in Nigeria. Hence, freight transports are generally not carried by the most appropriate transport mode. Bulk goods are carried over long distances by trucks and tractor-trailers whereas alternative transport infrastructure is available if they are maintained; and,
- Institutional issues: The Federal Ministry of Works and Housing manages the entire federal road network; their respective state governments manage state roads; while the remaining roads are under the jurisdiction of the local government authorities.

The state of Nigerian roads has remained poor for a number of reasons. The principal reason is poor quality roads were constructed in the first place, due to a combination of faulty designs, lack of drainage, thin wearing course coverings, and negligible quality control. Further, funding of road maintenance has been grossly inadequate. The Central Bank of Nigeria (2005) indicates that since economic reform in 1999, less than 10% of the funding request made by the Federal Ministry of Works and Housing was received, while a little over half of that received to the Ministry was released. A third reason for the poor state of roads is the excessive traffic volume and loads being applied to the pavements. The reliance on road travel is exacerbated by the poor state of rail and waterway transport infrastructure, requiring roads to carry bulk goods on typically overweight trucks. Lastly, there appears to be little to no appreciation for maintenance, and when decisions are made, in most cases they are influenced by politics and not the actual maintenance needs.

In a 2002 survey conducted by the Central Bank of Nigeria (2008) on the state of roads in Nigeria, a questionnaire along with visual inspections were undertaken on 6 geographical areas (south-east, south-west, south-south, north-east, north-west and north-central). The survey indicated that most of the roads, especially in the Southern areas were in very poor conditions and required complete rehabilitation. The story was relatively the same with roads in the Northern zones. Some roads constructed over 30 years ago had not had any rehabilitation interventions at all, resulting in major longitudinal and transverse cracking, depressions, broken bridges and numerous potholes that make transport both very slow, costly and unsafe. The survey concluded that some of the roads require total rehabilitation and asphalt overlay, re-instalment of the shoulders, filling of potholes (that can swallow cars) and re-building of collapsed bridges (Central Bank of Nigeria, 2005). All this with a limited budget.

The majority of documentation on road design, materials and projects stems from the southern part of Nigeria. This is little surprise given the dense population and the presence of oil resources. It is also the region (Lagos – Port Harcourt corridor) which has seen the most road building activity. In the decade prior to 1986, three of the most important dual carriageways were constructed. These included Lagos-Ibidan, Benin-Lagos and Port Harcourt-Enuga expressways. Within 10 years, sections of these roads were exhibiting mild to sever failures, which were attributable to the utilization of inappropriate materials, or inappropriate design given the marginal material available (Akpokodje, 1986).

2.3.1 Nigerian Road Distresses

Failure of roads in Nigeria is the rule, not the exception. History has shown that roads, even if the proper design has been prepared, it is unlikely that the road will be constructed to this standard due to poor quality control resulting in inadequate compaction rates, thicknesses and pavement quality (Pollit, 1950). There is little surprise that the majority of studies on the cause of failures of road pavements have revolved around the southern part of Nigeria, as this is where the majority of roads have been constructed and where some of the more complex environmental constraints are imposed (high water table, rainfall, etc.). Several examples of key projects that have had widespread failure and the reason for them are presented in Table 2.1.

In a study on the geotechnical properties of soils of south-eastern Nigeria and their evaluation for road construction, Akpokodje (1986) concluded that pavement failures appear to be more extensive on the outer lanes and pointed to the fact that all slow moving heavy trucks and trailers tended to use the outer lanes (except when overtaking). In sections where the pavement is built on the highly weathered shale subgrade, widespread failures have occurred. Such failures are presumably initiated in the subgrade which has very low dry density and consequently low load-bearing capacity. Poor drainage conditions in some parts of the road accelerate the failure process of the subgrade.

Table 2.1: Projects in Nigeria that have exhibited pavement failure

Project	Location	Reason for failure	Author
Port Harcourt-Enugu expressway	Southeast	- Poor field compaction - Inferior pavement materials used - Particle size distribution and plasticity of the majority of the soils indicate that they are unsuitable for base materials (yet were used).	Akpokodje, 1986
Port Harcourt-Patani-Warri road	Southeast	- Due to subsurface flow, the road acted like a dam - Poor quality aggregates - Changes in pavement condition due to interaction of local road aggregates with water caused swelling, stripping and potholing.	Abam et al., 2000
Ado – Ekiti	Southwest	- Cohesive soils have an excessively high fine fraction (20%) - High liquid limit of soils greater than 30 - Low CBR of soils	Jegede, 2000
Lagos – Ibadan	Southwest	- Twelve geotechnical properties were investigated - Statistically, differences indicated failures in areas of higher fines content (< 75 microns).	Adeyemi, G. O. and Oyeyemi, F., 1998
Ife – Akure	Southwest	- Limited pre-engineering of various types of fill or course materials - Fine grained micaceous clayey and silty soils used extensively as base course materials	Mesida, E. A., 1986
Awgu – Okigwi (part of the Enugu – Port Harcourt expressway)	Southeast	- Road section built on considerably jointed, fractured and weathered shale as a subgrade. - Road constructed at the base of an escarpment that experiences considerable groundwater discharge, resulting in rapid base deterioration. - Wetting of the base and sub-base materials.	Okagbue, C. O. and Uma, K. O., 1988
Nine major roads	Niger Delta	- Very poor pavement performance in seasonally flooded areas. Caused by the use of highly substandard soil materials. - Poor design, high water table and failure to adhere to design specifications. - No in-situ soils of the Niger Delta meet standard specifications of acceptable base course materials.	Arumala, J. O. and Akpokodje, E. G., 1987

During the wet season (average precipitation of 2500 mm/year), under-cemented ditches between the dual carriageway and on both sides of the expressway, are permanently water-logged, resulting in the ingress of water into the subgrade and base courses.

Failed roads exhibit a multitude of distresses. Distress in the form of cracks of various geometric patterns, rutting and potholes has necessitated expensive repairs and reconstruction of a number of sections of the roads. Ola (1978b) and Ibrahim (1980) attributed failed road sections mainly to overloading by commercial vehicles, use of sub-standard construction materials and inadequate knowledge of the geotechnical characteristics of the soils over which the roads are built.

It was observed by Jegede (1994) that the soil material properties at failed sections of the road had not been thoroughly investigated. Little to no consideration was given to the effect of clay mineralogy and associated engineering soil behaviour, as highway foundation materials and the weakening of pavements was likely to be induced by the surface water ingress through cracks and joints that developed in highway pavements (Jegede, 2000).

Ajayi (1987) noted that road failure often occurs where the pavement is founded on saprolite rather than the strong lateritic horizons. Adeyemi (1992) investigated some geotechnical properties of the residual lateritic soils adjacent to some sections of the Lagos-Ibidan expressway and concluded that the degree of stability of the flexible road pavement increased with both the amount of kaolinite present in the subgrade soils and their California bearing ratio (CBR) and unconfined compressive strength (UCS). Ayangade (1992) could not establish a clear relationship between the index properties of the subgrade and the stability of the road pavement, but noted that there was a positive correlation between the strength characteristics of the foundation soils and the stability of the pavement along some sections.

In a study by Arumala and Akpokodje (1987) on soil properties and pavement performance, nine major roads were studied in the Niger Delta region. The overwhelming conclusion was that little adherence to design standards had been followed, which was attributed to poor supervision by government officials and lowering of the design specifications during construction as a result of insufficient funds. They found that soaked CBR's of subgrades and some base materials was found to be as low as 2% (the Nigerian standard for soaked CBR for a base course is greater than 30) and most of the roads did not have well-defined sub-bases. This is the principal reason why the entire length of the 45 km Kolo Junciton-Ogbia road failed completely only 2.5 years after completion.

2.3.2 FERMA

The federal government of Nigeria, through the Federal Ministry of Works (FMW), initiated a major reconditioning of Nigeria's federal road network in 2002 by forming the Federal Roads Maintenance

Agency (FERMA). FERMA is a parastatal agency under the Federal Ministry of Transport (FMT) whose principal role is to carry out regular routine maintenance on the Federal road network. FERMA came into being in 2002 as a 10-13 year stop gap while a more fully-fledged reform is put into action to incorporate Nigerian roads into a comprehensive pavement management system.

One of the earliest challenges that FERMA was confronted with was how to address the horrible state of the road network stemming from decades of neglect. The Medium Term Strategy for Road Sector Maintenance Management (FERMA, 2007) outlined that during the first four yeas after FERMA inception, maintenance would likely not be a possible intervention, but rather the rehabilitation of failed segments to keep the network in, at the very least, a respectable condition of use for the public. The Agency has been successful in this regard, as the improvement in 'Good' and 'Very Good' federal roads has improved from a combined 15% to 35% over 4 years (Figure 2.4) through rehabilitating failed sections alone, although no reference to the criteria used to assess the pavements was made.

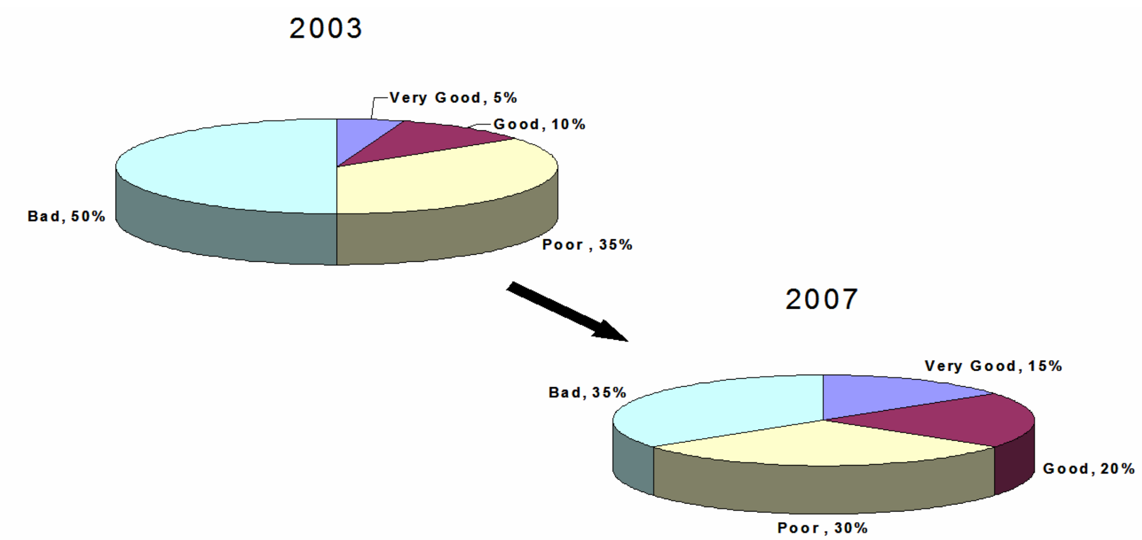


Figure 2.4: Through the initiatives of FERMA and its approach to rehabilitating failed Federal roads, progress has been made in four years.

The principal goal of FERMA following the rehabilitation of the road failures that plagued the federal system is to produce a program that will enhance and upgrade the quality of the road infrastructure. This will be accomplished by adopting two initiatives, which are:

a) Performance based maintenance management (BPMM) programme; and,
b) Systematic road strengthening and enhancement (SRSE) programme.

The objective of the PBMM is to establish a programme in which comprehensive routine maintenance of existing adequate roads within the network are managed in to provide the same state of serviceability for as long as the road is in use (FERMA, 2007). Simultaneously, the SRSE programme which will provide needed periodic structural strengthening on a particular road with the objective of preventing it from imminent collapse and extending its longevity. The two programmes are the maintenance and rehabilitation interventions of a pavement management system.

Despite the progress made, there remain immense challenges, the least of which is funding. Currently, federal road maintenance is funded through the budget. At the initial stages of formation of FERMA (2003-07), only spot improvements and emergency repairs were undertaken. In 2007, an amount of NGN 13.5 billion (USD 106 million) has been allocated to FERMA. Compared to the assessed needs of NGN 22 billion (USD 173 million) this represents only 61% of requirements (AfDB, 2007).

Despite all the uphill battles that are facing FERMA, its primary mandate is to produce a federal system that is in a good, safe and comfortable condition They anticipate having approximately 85% of roads in the system at a 'Very Good' state by 2020.

2.4 Transparency

Politics will always play a role in resource allocation. This is the case for even the most advanced economies of the world. However, what is important is that a mechanism exists to limit external influences that make certain the correct assets are being maintained, rehabilitated or reconstructed. This is particularly important when we take a look at Africa, where transparency is one of the lowest of the world's continents. This is certainly the case for Nigeria.

Transparency International (2007) ranks countries based on their Corruption Perception Index (CPI), an indication of the degree of public sector corruption as perceived by business people and country analysts. The average CPI for all African nations is 2.76, with the highest ranked country being Botswana with a CPI of 5.4 and the lowest being Somalia with a CPI of 1.4. Nigeria has a CPI of 2.2, illustrating the need for greater institutional frameworks and controls needed.

2.5 Pavement Design Theory

In Canada, pavements have traditionally been classified as flexible or rigid. Flexible pavements consist of unbound compacted stone or aggregate under a bituminous surfacing, while rigid pavements consist of a slab of concrete overlying a thin aggregate bed. Primary differences over and above the materials used include the method by which they distribute loading from overlying vehicular traffic. Rigid pavements are not common in Nigeria, therefore flexible pavement design will comprise the balance of this section.

The purpose of structural design is to limit the stresses induced in the subgrade by traffic to a safe level at which subgrade deformation is insignificant while at the same time ensuring that the road pavement layers themselves do not deteriorate to any serious extent within a specified period of time. To accomplish this, there are several different approaches, or theories, associated with pavement design. These include experience based, empirical, and mechanistic-empirical (such as the Mechanistic Empirical Pavement Design Guide – MEPDG).

Experience based pavement design employs standard sections that are derived from successful past designs. They provide standard layer thicknesses based on site conditions including, but not limited to: soil types, traffic levels, roadway classifications and drainage properties. However, experience based designs are limited in providing future properties such as increased traffic, new materials and improved construction and maintenance activities (TAC, 1997).

Empirically based pavement design has been the primary pavement design theory used in North America since the 1970's. The principal reason for this was the creation of the American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures, 1972, 1986, and 1993 which was created as a result of testing conducted in the 1950's by the American Association of State Highway Officials (AASHO) and the Western Association of State Highway Officials (WASHO). The principal objective of the AASHO Road Test was to determine the significant relationships between the number of repetitions of specific axle loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete surfacing on different thicknesses of base and sub-base when loaded on a basement of known characteristics (AASHO, 1962). Presently, pavement designs often exceed the data limits and conditions used in the AASHO Road Test have been exceeded. Pavements with expected traffic as much as 30 times greater are being designed using empirical procedures based upon the AASHO Road Test. The disadvantage of an empirical method is that it can be applied only to a given set of environmental, material and loading conditions (Huang, 2004). If these conditions are changed, the design is no longer valid and a new method must be developed through trial and error to be conformant to the new conditions.

The Transportation Research Board's (TRB) National Cooperative Highway Research Program (NCHRP) has developed a new pavement design guide, the MEPDG. The new guide employs mechanistic-empirical approaches. These approaches provide more realistic characterization of in-service pavements and provide uniform guidelines for designing the in-common features of flexible, rigid and composite pavements. By using these approaches, engineers can create more reliable pavement designs. The new method offers procedures for evaluating existing pavements and recommendations for rehabilitation treatments, drainage, and foundation improvements. In addition, the new guide incorporates procedures for performing traffic analyses, including options for calibrating to local conditions and incorporates measures for design reliability (NCHRP, 2004).

2.5.1 Nigerian Pavement Design

The standard practice of pavement design in Nigeria is the Nigerian Federal Ministry of Works General Specification (Roads and Bridges, Vol. II) which was adopted from TRRL Road Note 31 (1971): A guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical countries, without much modification. Although the exact design specifications of the different roads vary according to the category, they fall within the following general groups (Arumala and Akpokodje, 1987):

i) Subgrade: compacted to 95% to 100% BS compaction with soaked CBR of 5 to 11;
ii) 50 to 120 mm sub-base, compacted to 100% West African Standard compaction;
iii) 50 to 150 mm base of either coarse grained soils compacted to 100% West African Standard Compaction with a soaked CBR of at least 30% or a cement stabilized soil (5% to 7% cement content); and,
iv) 30 to 90 mm double bituminous surface dressing of rolled asphalt.

The principal issue surrounding the adoption of the TRRL Road Note 31 as the Nigerian road design standard is the generality in which it was intended. Due to the area of influence that the document was written, it was not intended to be directly applied to a country as diverse as Nigeria without making modifications for different soils, environmental conditions and road building materials.

There is only one mention in the literature of mechanistic-empirical design being applied to roads in Nigeria (Olowosulu, 2005). In 1982, the Federal Government of Nigeria in conjunction with a highway improvement loan from the International Bank for Reconstruction and Development (IBRD) began a program aimed at creating a system for evaluating, strengthening and rehabilitating the Nigerian highway system. Olowosulu (2005) indicated that this project culminated in the establishment of a Pavement Evaluation Unit and an overlay procedure based on elastic layer theory. No further details on either entity have been found and it is likely that the program ended during the civil turmoil that plagued Nigeria during this time.

2.5.2 HDM-III and HDM-IV

The Highway Design and Maintenance Standards Model (HDM) was developed by the World Bank's Transportation Department to meet the needs of authorities, particularly in developing countries, for evaluation policies, standards and programs of road construction and maintenance (PIARC, 2000). Simply put, it is a road project appraisal model.

The model simulates total life cycle conditions and the cost of a single road, a group of roads with similar characteristics, or a pavement network. The simulation can be done for a series of road agency construction or maintenance strategies and provides the economic decision criteria for evaluating the strategies being analyzed. The HDM model can be used to establish (Kerali, 2008):

- Desired budget levels that would minimize the total costs of road transportation;
- Appropriate policies and standards for construction and maintenance programs that are consistent with minimizing total transport costs under existing resource constraints;
- Long and medium-term investment and expenditure programs; and,
- Appropriate, economically derived intervention criteria to develop short-term programs and annual budgets, based on an appropriate pavement management system.

The most updated version of the program is the HDM-IV Road User Effects (RUE) model (compared to the 1995 HDM-III version). While the HDM-III version has been applied widely in the developing world, developed countries were just starting to apply the program. It was under these circumstances, along with the time elapsed since a comprehensive update, that the model was inappropriate and an updated version that took into account traffic congestion effects, cold climate effects, a wider range of pavement types, road safety, and environmental effects was required. A comprehensive overview of HDM-IV is provided in Kerali (2008).

2.5.3 South African Pavement Design

South African pavement design (TRH4, 1985) is of a very high standard and is utilized or adapted throughout Africa. Much of its utilization stems from the fact that a great deal of consulting engineers and contractors who are completing work throughout sub-Saharan Africa are South African, but also because of the strong foundation that the design has been based upon and the applicability within the sub-Saharan context.

The first simplified mechanistic design procedure in South Africa was developed by Van Vuuren, Otte and Paterson (1974) during 1974. The design guide has been modified constantly since its inception and now provides designs based on material properties (each material having a specific code), design traffic (ESALs), subgrade CBR or strength, service objective (to what type of road category is the design applicable, from major inter-urban to rural), the functional service level, and the design reliability (risk) in addition to factors such as life cycle costing and maintenance and rehabilitation interventions.

The strength of the South African pavement design method lies in the simplicity by which road agency throughout Africa can input known variables and come up with a standard road design. Further, the design method is more appropriate for African soils, climates and circumstances than are other design manuals, making the process more relevant to the continent as a whole. Theyse et al., (1996) provide a comprehensive review of the South African Mechanistic Pavement Design Analysis Method.

2.6 Pavement Design Inputs

The structural design of pavements aims to protect the subgrade from traffic loads by providing pavement layers which will achieve a chosen level of service, with maintenance and rehabilitation during the analysis period, as cost effectively as possible (TRH, 1985). It encompasses factors of time, traffic, pavement materials, subgrade soils, environmental conditions and economics. The various design inputs that are required to compile a competent design are discussed in the following section with specific reference to Nigeria.

2.6.1 Subgrade Type

The Nigerian Building and Road Research Institute has, since 1982, been involved in the development of an Engineering Soil Subgrade Map of Nigeria, however the produced map using the Unified Soil Classification System was not significant in as much as it is sparsely plotted with overly broad isolines. Okunade (1998) utilised the data obtained from the Road Research Institute and plotted AASHTO soil groupings in addition to eleven other maps depicting the variance of other relevant engineering soil properties, such as Group Index, percent sand, silt and fines and Atterberg limits. While the research was part of an unpublished doctoral thesis, isopleths for the states where the majority of road building has been constructed have been published (Okunade 2006a and 2006b). It is the intention of these isopleths to provide a source of primary information for consulting and practicing engineers and will constitute an invaluable aid to road planners and designers.

Nigeria's major soil zones conform to geographic location. Loose sandy soils consisting of wind-borne deposits and river sands are found in the northern regions, although in areas where there is a marked dry season, a dense surface layer of laterite develops. South of Kano (Figure 2.3) the mixed soils contain locally derived granite and loess (wind born deposits). The middle two- thirds of the country, the savannah regions, contain reddish, laterite soils. The forest soils represent the third zone. Sandy material occur principally at the most southern regions of the country, along the various deltas.

While both lateritic and non-lateritic soils occur in Nigeria, the most abundant soils are laterites, which are used most commonly in road construction. This is even more accurate given the southern Nigerian predominance of road construction over the past half century and their prevalence in this region. The climate of southern Nigeria is ideal for laterite formation (Ogunsanwo, 1989). Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminium and develops by intensive and long lasting weathering of the underlying parent rock. Laterites consist mainly of the minerals kaolinite, goethite, hematite and gibbsite which form in the course of weathering. Moreover, many laterites contain quartz as relatively relic mineral from the parent rock. The iron oxides goethite and hematite cause the red-brown color of laterites (McBride, 1994).

Lateritic soils are common in tropical latitudes and are often used in road construction due to their abundance. However, they frequently do not meet specification requirements, commonly having too high a fines content and plasticity (PI). Osinubi (1998) indicated that lateritic soil is the conventional material routinely used in most tropical countries for road pavement construction even though most lateritic soils and gravels are at their best suitable mainly for sub-base course material. Therefore, stabilization is a viable option to improve these soils to make them more appropriate to be incorporated into pavement layers.

Akpokodje (1986) indicated that the poor grading and high fines content of the concretionary laterite gravels, in addition to their weak to slightly strong nature of the coarse particles render the material as troublesome base materials. Teme (1991) indicated that pavements of Nigeria are constructed with aggregates of very poor quality, due to the unavailability of durable igneous or metamorphic rocks. Quarried or borrow pit materials are not generally used in Nigeria due to this reason, and that when sound aggregates are used for pavement construction, the haulage costs are often excessive. What is not appreciated is the abundance of sedimentary rocks and limestone that are predominant throughout the country (Ola, 1977), yet laterites are typically relied upon for pavement layers rather than quarried rocks or aggregates.

Significant is the absence of swelling mineral type (Ola, 1977). This does not imply that the materials are not sensitive to moisture or that there are not pockets of expansive clays within Nigeria, but the southern two thirds of the country are relatively volume stable. The presence of black cotton soils in the north eastern part of the country has been documented by Ola (1978a) and road construction on these soils causes major problems.

2.6.2 Asphalt Cement

The majority of federal roads in Nigeria are flexible pavements consisting of asphalt concrete. There is no literature that mentions rigid pavement design, which is logical given the high cost of concrete in Nigeria and the overabundance of oil. It is the surface that is in direct contact with traffic loads and provides characteristics such as friction, smoothness, noise control, rut and shoving resistance and drainage.

In Nigeria, there are only two grading envelopes for binder and wearing courses. The mix design for both may account for some of the poor pavement performance encountered in Nigeria. It is likely that Nigeria specifications will not account for skid resistance and ride quality of the pavement structure and will blanket-cover the road with the same asphalt mix design (TRL, 1993). Two striking parameters are the bitumen content (%) and the percent air voids. The FMHW specification outlines a bitumen content range of 4.5% to 6.5% for binder course and 5.0% to 8.0% content for wearing courses. Both these values are too high and will cause instability of the produce asphalt concrete. The percent air voids specification for a binder or surface course ranges between 3% and 8%. The Marshall Method mix design specifies that a percentage air voids in total mix should fall between 3% and 5%. The high air void content of the Nigerian asphalt will increase permeability, allowing for water and air to pass into the pavement and underlying layers. This decreases the durability of the asphalt concrete mix and weakens the underlying pavement layer (Esenwa, 2008).

2.6.3 Traffic Data

Deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. For pavement design purposes it is necessary to consider not only the total number of vehicles, but also the wheel loads (axle loads).

The Federal Ministry of Works and Housing (FMWH, 1997) specification does not provide information on various traffic classes or axle loads. The sole mention of a traffic category is for mixed design criteria for Marshall Design specifications, where Heavy, Medium and Light traffic designation are used. No quantification of what constitutes these designations is provided. The Overseas Road Note: 31 (TRL, 1993) provides for 8 different traffic classes based on equivalent standard axle loads, but whether this designation is utilized in Nigeria is unknown. Very little published data exists for traffic loads, and all of the research conducted on road failures attributed the cause to aspects other than load-related failures. Assuming Nigeria follows other African nations, vehicles are typically overloaded, poorly maintained and tires are likely either too hard or under inflated.

2.7 Pavement Management

The performance of a pavement depends largely on the design process and the inputs that are used to derive the design. However, the actions surrounding this design, including construction and subsequent maintenance and rehabilitation interventions are as much a part of the designs performance as is the competency of the design. A well-defined and implemented strategy that concerns itself with the pavement process holistically that manages the pavement asset provides for improved infrastructure longevity. As such, pavement management can be defined as all the activities involved in providing and managing the pavement portion with the objective to use reliable information and decision criteria in an organized framework to produce a cost-effective pavement program (Haas et al., 1994).

Pavement management has progressed from a concept in the 1960's to current, widespread and successful application in many countries around the world. The reasons include a sound underlying framework, an extensive base of technology and foresight on the part of individuals and agencies (Haas, 2001). A pavement management system (PMS) helps in making informed decisions, enabling maintenance of the network in a serviceable and safe condition at a minimum cost to both the road agency and the road users. For this, well documented information is essential to make and create a system that is not only locally assembled, but also one that is sound from an engineering and management standpoint. The elements of a PMS should include (Haas et al., 1994):

- An inventory of pavements in the network;
- A database of information pertinent to past and current pavement condition;
- An analysis methodology;
- Long range budgeting provisions;
- Prioritizing the annual work program;
- A basis for communication of the developed plans; and,
- A feedback system.

A PMS can be used to not only preserve the existing assets, but also to increase the asset value of the system over time. To find a cost effective strategy for proving, evaluating and maintaining pavements in a serviceable conditions, the utilization of a pavement management system is well positioned to streamline these factors and produce a road map for the improvement of the future condition to the economic sustainability of Nigeria.

Different types of data are used for road management and the needs vary depending on which infrastructure element is evaluated. There are two types of data collected for use in pavement management. Firstly, inventory data describes the physical elements of the road system and, secondly, condition data that describes the condition of elements that can be expected to change over time. When considering the developing world, Bennett et al., (2007) outlined the challenge that the developing world faces when confronted with the task of collecting pavement data. Many transportation agencies in developing countries are grappling with a cost/performance dilemma: on the one hand they recognize the need to improve data collection accuracy and increase the extent of surveys on their networks, but on the other hand, funding is often a major obstacle which limits their activities. As such, Bennett et al., (2007) outlined that careful consideration needs to be paid to the initial cost, ongoing costs and the ability of the agency to sustain the technology when choosing the appropriate data collection method or methods.

Periodic identification and evaluation of distresses on a highway surface is important to plan adequate maintenance and rehabilitation strategies and is critical to good pavement management. Identification and evaluation is typically achieved by conducting detailed condition surveys along the pavement network to identify the types of distress, their extent, severity and location. Typical distresses are cracking, surface deformation, surface defects and pavement failures.

2.8 Summary

This chapter presented a literature review of the state of Nigerian roads and the principal issues that the country is facing in its developmental process. A solid pavement infrastructure system is critical to not only economic development, but also social, environmental and health issues that are at the core of Nigeria's obstacles to progress. System-wide failures of pavements, both newly constructed and those built 20 years ago, are well documented and are at the root of a decayed, inefficient and stagnated road infrastructure system that needs to be upgraded if progress is to be made on any front within the country.

FERMA has initiated both immediate and medium-term strategies that will address the poor state of Nigeria's federal roads. This will include the creation of an implementable pavement management strategy in addition to reforming the road design and construction process. Accountability and transparency are keys in achieving this goal.

Nigeria has the potential to produce an abundance of good building materials, such as crushed aggregate, yet such materials do not seem to be incorporated into road projects. While there are very poor soils in the Lagos and Port Harcourt areas, the road failures that have occurred are less a result of the materials used, rather than poor design and road building judgement.

This chapter also presented a brief overview of pavement design, both in North America and those in Africa. The Nigerian design guide is outdated and needs to be modified. The World Bank's HDM-IV and South Africa's TRH-4 are good examples of regional design guides and manuals that could be easily replicated, or adapted, to reflect the needs of the Nigeria.

CHAPTER 3: DATA SOURCES AND METHODOLOGY

The purpose of this chapter is to define data sources available to undertake a detailed analysis of Nigerian pavement design, as well as to classify and format the data sources into a system that can be utilized by pavement engineers and field engineers in Nigeria. The experimental methodology applied was utilized to define the data sources that are needed as input variables in the design of flow diagrams and decisions trees for appropriate maintenance and rehabilitation interventions. Additionally, accurate, defendable data is required to conduct life cycle costing of the various interventions, and to base these iterations on the Nigerian perspective. The aim of the following chapter is to plot out the necessary data needs to conduct the necessary computations on the data to transform them into a useable and more appropriate format, as well as to define and defend the data sources and their relevance to the Nigerian context.

3.1 Data Sources

The Nigerian Federal road network is comprised of 32,100 km of paved asphalt roads (Figure 3.1). One of the defining issues of the Federal road network in Nigeria is the lack of reliable data. For example, the current road classification distribution, according to FERMA (2007), is that 15% of roads are 'Very Good' and 20% of roads are 'Good', yet there is no explanation of how these designations are arrived at. Data about the designs that were applied is significantly lacking. Where designs are available, literature has pointed to the fact that it is likely that they have not been applied to the specifications and, therefore, data about them are rendered inadequate. It is obvious that there is a need to utilize data that can be supported, and where assumptions have been made, they have been done so with logic and regional context. As such, where possible, data will be taken from the literature on Nigerian roads and road related issues. Further, data from neighboring countries and Southern African Development Community (SADC) and Common Market for Eastern and Southern Africa (COMESA) member nations will be relied upon. Where available, data from the World Bank and other international financial institutions (IFI's) and donor groups will be utilized, both on Nigeria and the region as a whole.

The reason for Federal road failures in Nigerian is well defined. The central issues, which have been well overviewed in Chapter 2, included inadequate and inappropriate designs being applied, poor construction materials being used, traffic overloading, and most principally, poor construction quality control measures. There is a great deal of rehabilitation interventions required, as outlined by FERMA (2007), however there is a lack of data on factors required to undertake a thorough analysis. There is, therefore, a need to compile regional data, such as road designs, traffic volumes, truck factors, and costs of various interventions and format them into a usable way that road engineers can utilize. The format should aim to follow outlines that are well documented in African and Internaitonal guides.

Figure 3.1: The paved Federal road network in Nigeria according to traffic classification as outlined by FERMA (2007)

3.2 Subgrades

Papers by Okundade (2006a and b) present a series of 12 engineering parameters in Nigeria through the use of isopleths. While subgrade CBR is presented, the data appears to be incomplete in comparison with other parameters. Two of the more reliable parameters, based on the larger data sets, would seem to be the soil subgrade AASHTO classification and the plasticity index (PI). For example, for the Lower Niger Delta State all of the soil subgrade classifications are outlined, which can be overlaid with the Federal road network (Figure 3.1) to determine the exact classification of subgrades that the pavements are built upon. This was done for other States and a compilation of AASHTO classified soils was created. What is apparent, however, is that the majority of soil types are found throughout Nigeria and that the current Federal system overrides these soils in at least one, if not all, of the climatic zones and the overlaid data does little to provide value. There is a need, therefore, to try and group the soils according to subgrade strength, rather than gradation and Atterberg limits as in the AASHTO Soil Classification System, as it is the subgrade strength that is more desirable from design standpoint.

The South African Structural Design of Flexible Pavements for Inter-Urban and Rural Roads (TRH-4, 1996) utilizes a four-class subgrade designation based on CBR (%) for structural design. The Transportation Research Laboratory utilizes a six-class designation in their Overseas Road Note 31 (1993) based on CBR (%). The Tanzanian Pavement and Material Design Manual (Ministry of Works, 1999) utilizes a three-class subgrade designation. A comparison of the three classifications can be found in the Table 3.1, recognizing that the TRH-4 manual was utilized as a reference in the design of the ORN 31, and both references were utilized in development of the Tanzanian standard.

Table 3.1: Comparison between three subgrade classification systems used in sub-Saharan Africa.

Subgrade strength classes					
ORN 31		**TRH: 4**		**Tanzania**	
Class	**CBR (%)**	**Class**	**CBR (%)**	**Class**	**CBR (%)**
S1	2	SG1	> 15	S15	Min 15
S2	3-4	SG2	7 to 15	S7	7 to 14
S3	5-7	SG3	3 to 7	S3	3 to 6
S4	8-14	SG4	< 3		
S5	15-29				
S6	30				

As Nigeria is at an infantile stage in the development of their pavement management system and road standard, or at least a design manual that is specific to Nigeria, a four-class designation may be more appropriately suited, one akin to the TRH-4 classification. Although, in the series progression of the ORN 31 classification the subgrade number increases with increasing subgrade strength (i.e. S1 is low strength and S6 is the highest), which seems more reasonable than the decreasing format of the South Africa standard. Therefore, a classification using NSG (Nigerian subgrade) is recommended and will be applied as follows:

NSG 1: CBR < 3
NSG 2: CBR from 3 to 7
NSG 3: CBR from 7 to 15
NSG 4: CBR > 15

3.3 Traffic

The only traffic data that is available for Nigeria's Federal roads is from FERMA (2007) where each major section of Federal road is assigned an average daily traffic (ADT) (Figure 3.2 and Table 3.2). It is likely that the majority of data is not derived from manual traffic counts, but is derived from a traffic simulation or model. Further, it is likely that the majority of Federal roads in Nigeria are two lane roads, other than those leading from Lagos to Benin City and out of Port Harcourt, which are dual carriageways. The data is also likely to be one direction of flow.

Another important factor is the severe overloading that is encountered on Federal roads. In Nigeria, 90% of all trade travels over roads due to the lack of an established rail system. A persistent lack of weight restriction and enforcement on trucks is pandemic all over Africa, and it is likely that severe overloading on trucks in Nigeria occurs. The Southern African Transport and Communication Commission (2001) outlines that where axle loading and traffic data is unavailable, the likelihood of overloading is high and that this should be accounted for in the road design or rehabilitation intervention (Table 3.3). Therefore, as the objective of evaluating the traffic parameters in Nigeria with the intention of deriving suitable traffic classes, rather than more accurately define the loads occurring on the roads, standards utilized within sub-Saharan Africa are referred to. Attention should be paid, however, when undertaking analyses that require equivalent standard axles loads (ESALs).

The South African Standard (TRH-4) utilizes ten pavement classes for design purposes based on equivalent standard axle (ESA). The first five designations are for very lightly trafficked roads with very few heavy vehicles. These classifications do not suit the Federal roads in Nigeria. The remaining five designations include:

T1: Lightly trafficked roads, mainly cars, light delivery and agricultural vehicles; approximate ADT per lane less than 700;

T2: Medium volume of traffic with few heavy vehicles; approximate ADT per lane = 700 to 1500;

T3: High volume of traffic and/or many heavy vehicles; approximate ADT per lane = 700 to 1500 with 20% heavy trucks;

T4: Very high volume of traffic and/or a high proportion of fully laden heavy vehicles; approximate ADT per lane = 1500 to 2200; and,

T5: Excessively high volume of traffic and/or a high proportion of fully laden heavy vehicles; approximate ADT per lane = > 2200.

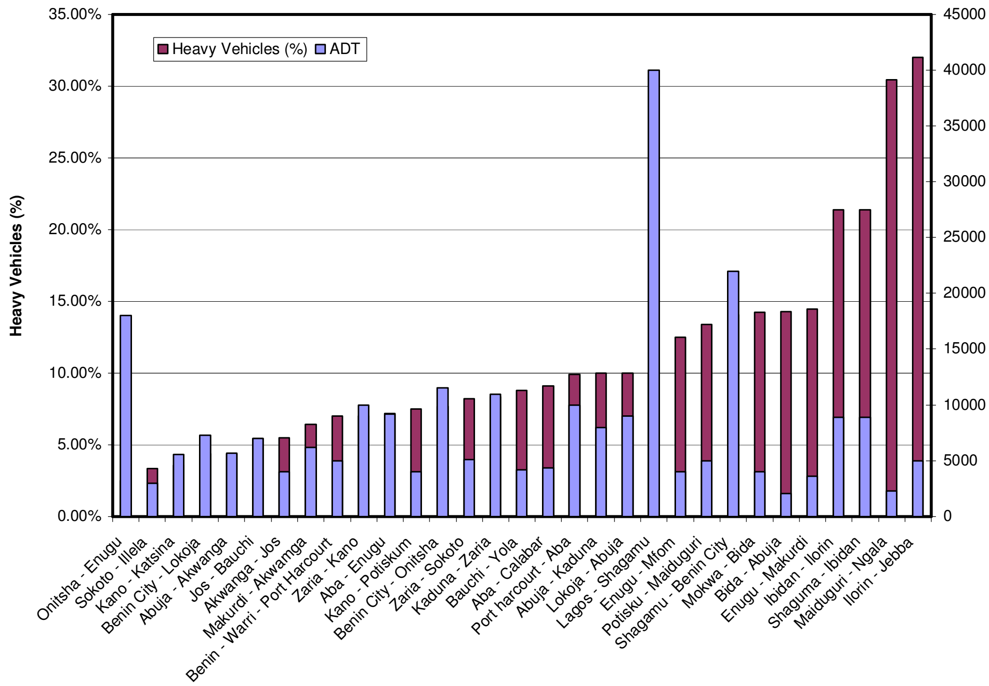


Figure 3. 2: Average daily traffic (ADT) and the percentage of heavy vehicles on Federal roads in Nigeria.

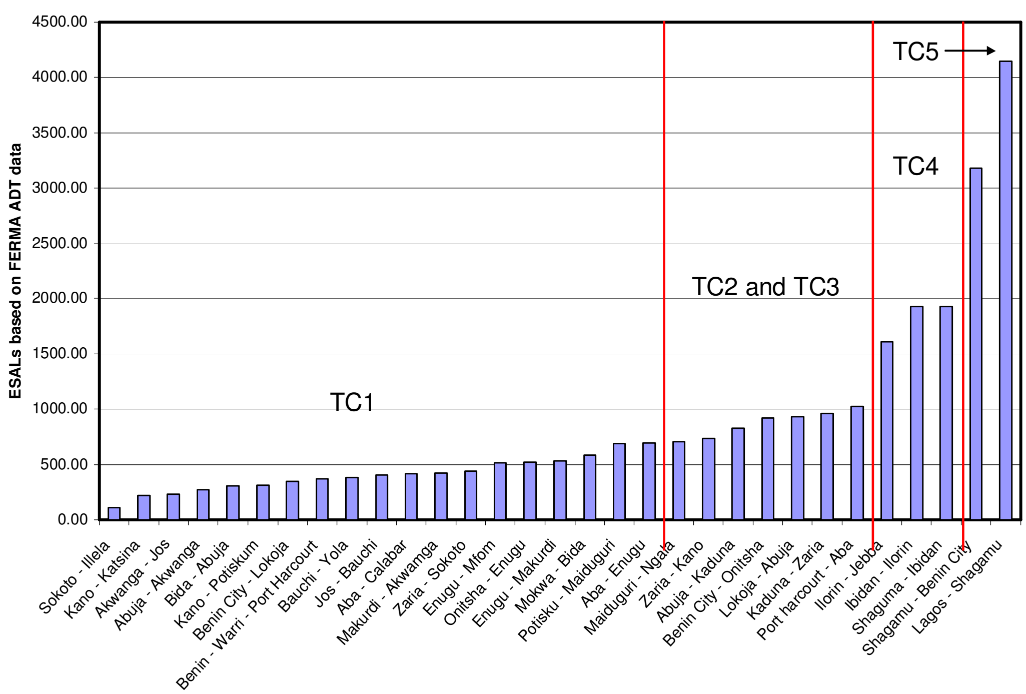


Figure 3. 3: Designated Nigerian Federal road traffic distribution for MR&R interventions

Table 3. 2: Traffic data for the major Federal roads in Nigeria (FERMA, 2007)

Major Federal road	ADT	Heavy vehicles (%)	ESAL*
Sokoto – Illela	3000	3.33%	111.6
Kano – Katsina	5600	3.57%	221.6
Akwanga – Jos	4000	5.50%	235.1
Abuja – Akwanga	5700	4.39%	271.8
Bida – Abuja	2100	14.29%	307.2
Kano – Potiskum	4000	7.50%	314.8
Benin City – Lokoja	7300	4.38%	347.9
Benin – Warri – Port Harcourt	5000	7.00%	368.6
Bauchi – Yola	4200	8.81%	385.3
Jos – Bauchi	7000	5.43%	406.5
Aba – Calabar	4400	9.09%	416.0
Makurdi – Akwamga	6200	6.45%	423.2
Zaria – Sokoto	5100	8.24%	438.7
Enugu – Mfom	4000	12.50%	514.0
Onitsha – Enugu	18000	2.50%	520.2
Enugu – Makurdi	3600	14.44%	532.3
Mokwa – Bida	4000	14.25%	583.7
Potisku – Maiduguri	5000	13.40%	687.3
Aba – Enugu	9200	7.17%	694.2
Maiduguri – Ngala	2300	30.43%	706.4
Zaria – Kano	10000	7.00%	737.2
Abuja – Kaduna	8000	10.00%	828.8
Benin City – Onitsha	11500	7.65%	922.5
Lokoja – Abuja	9000	10.00%	932.4
Kaduna – Zaria	11000	8.36%	960.3
Port ▯ arcourt – Aba	10000	9.90%	1026.0
Ilorin – Jebba	5000	32.00%	1613.6
Ibidan – Ilorin	8900	21.35%	1928.0
Shaguma – Ibidan	8900	21.35%	1928.0
Shagamu – Benin City	22000	14.09%	3175.6
Lagos – Shagamu	40000	10.00%	4144.0

* ESALs are based on the ADT being representative of one lane traffic

Table 3. 3: Truck factors utilized for determining pavement loading where data is unavailable (SATCC, 2001).

Vehicle class		Normal conditions	Abnormal conditions	Typical range
Bus	2-axle (35+ seats)	0.7	1.2	0.4 – 1.8
Trucks	2-axle	0.7	1.5	0.3 – 2.0
	3-axle	1.7	2.0	0.5 – 3.0
	4-axle	1.8	2.5	0.7 – 3.5
	5-axle	2.2	3.2	1.0 – 4.5
	6-axle	3.5	4.7	1.2 – 6.0
	7 or more axles	4.4	6.0	2.0 – 8.0

Similarly, ORN 31 (1993) utilizes 8 traffic classes with the first three reserved primarily for low volume roads. Conversely, Tanzania has a seven class system with only the first classification (TLC02) reserved for roads with an ESAL of less than 200,000. The remaining classes are similar to both the South African and TRL manuals. Taking into consideration the three regional manuals from South Africa, Tanzania and the ORN, a Nigerian specific traffic classification (TC) for pavement management purposes utilizing Average Daily Traffic (ADT) and Average Daily Truck Traffic (ADTT) can be derived as follows (Figure 3.3):

TC1: Low volume; ADT < 700; limited heavy vehicles (ADTT < 35);
TC2: Moderate with few trucks; ADT 700 to 1500; few heavy vehicles ADTT < 75);
TC3: Moderate trucks; ADT 700 to 1500; heavy vehicles (ADTT < 225);
TC4: High; ADT 1500 to 2200; heavy vehicles (ADTT < 400); and,
TC5: Congested heavy traffic: ADT > 2200; heavy vehicles (ADTT > 400)

The above classification is a recommended structure that can be readily adopted by Nigeria to better designate their traffic classifications. The intention of the designation is both to provide a sensible format for designating traffic classes and to provide a means of addressing the appropriate rehabilitation interventions based on logical traffic classifications that are applied in Chapter 4.

3.4 Environment

For the purpose of pavement design, Nigeria can be divided into three climatic zones (Figure 3.4):

- A humid zone in the southern part of the country;
- A dry, sub-humid zone in the middle; and,
- A semi-arid northern region.

The moisture regime has a major influence on pavement performance, as the strength of the subgrade varies with moisture content. This is particularly relevant in southern Nigeria where the soils are particularly plastic (highly weathered) and are more susceptible to moisture, and it is the region with the most highly trafficked and loaded roads. Prior to MR&R interventions, detailed data on the temperature conditions on the project area should be obtained. Temperature conditions can be expected to correlate closely with site altitude. The pavement temperature should be taken into account, as it impacts the performance of bituminous mixes with regards to:

- Load distribution properties;
- Resistance to deformation;
- Resistance to fatigue cracking; and,
- Rate of ageing.

While the three climatic zones reflect the macro-climate of Nigeria, it is recognized that there may be localized areas with different moisture conditions. To simplify the zones in Nigeria, a dry (north), moderate (central) and wet (south) designation will be used.

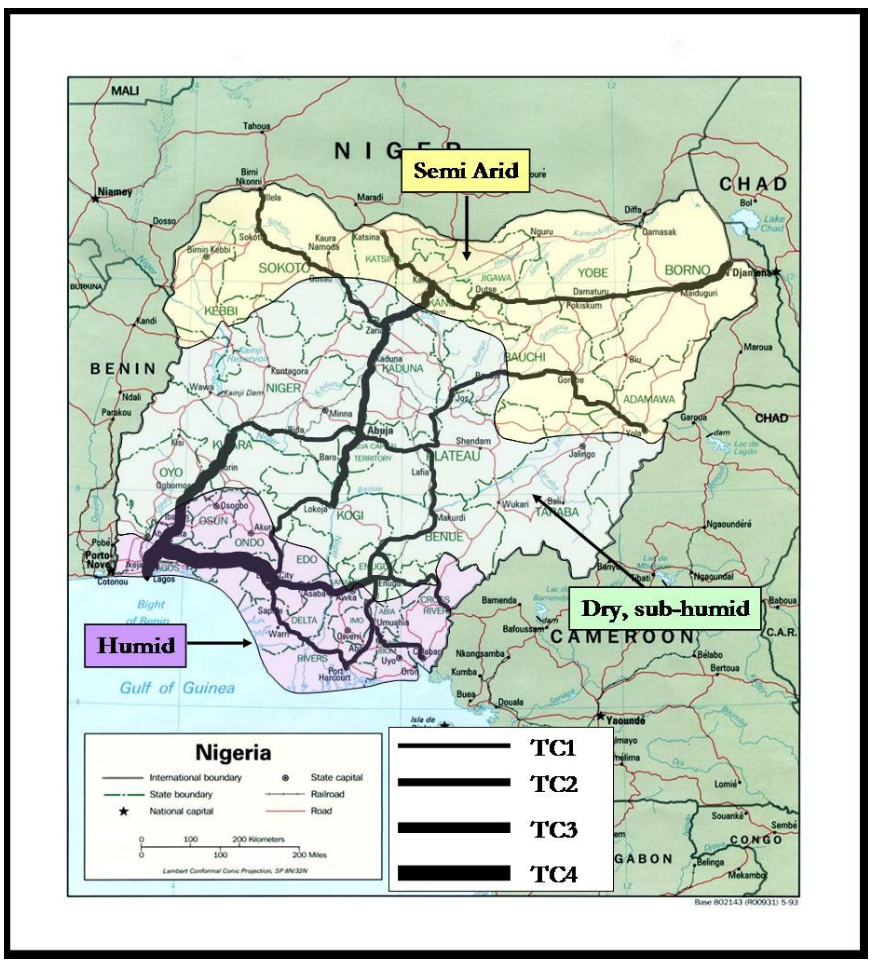


Figure 3. 4: The three major climatic zones of Nigeria (CIA, 1989)

3.5 Conditions

In FERMA's strategy paper FERMA (2007), a four-class designation is utilized for road quality. This includes Bad, Poor, Good, and Very Good. There is no information available that explains what the various designations have been based, however it would appear as though the four class system, as it is set up for Nigeria, leads to a skewed result towards the road network being in an adequate condition. Having two good conditions of the road (Good and Very Good) and only one bad condition (Bad) will always skew the perception that there are more roads of good quality. In an odd number class designation, for example five (Very Good, Good, Fair, Poor and Very Poor), there is less room for having skewed results as there is balance between the two dipoles. In an evaluation of soil properties and pavement performance in the Niger Delta, Arumala and Akpokodje (1987) utilized a visual condition survey data collections form based on a Slight, Moderate, Severe or No distress evaluation (Figure 3.5).

The World Bank RONET program, which is derived from HDM-4, utilizes a five class designation for the condition of primary asphalt roads, including Very Good, Good, Fair, Poor, and Very Poor. The RONET designation for each of these class types is as follows:

Very good: Roads in Very good condition require no capital road works;

Good: Roads in Good condition are largely free of defects, requiring some minor maintenance works, such as preventative treatment of crack sealing;

Fair: Road in Fair condition are roads with defects and weakened structural resistance, requiring resurfacing of the pavement (periodic maintenance), but without the need to demolish the existing pavement;

Poor: Roads in Poor condition require rehabilitation (strengthening or partial reconstruction); and,

Very poor: Roads in Very poor condition require full reconstruction, almost equivalent to new construction.

The Ministry of Transportation of Ontario (MTO, 1989) developed a rating scheme consisting of a rater evaluating two different parameters (Figures 3.6 and 3.7). These include the riding quality of the pavement surface (an indication of a pavements functional condition), and the extent and severity of pavement distress, which is an indication of the structural condition. After a distress survey or condition rating has been conducted, MTO assigns a Pavement Condition Rating (PCR) according to the following designations:

Very good: Pavement is in excellent condition with just a few bumps or depressions from slight surface deformation. No surface defects such as streaking, potholes or cracking distresses. Ride is very good. Routine maintenance;

Good: Pavement is in good condition with just a few bumps or depressions from slight to moderate surface deformation. Intermittent slight to moderate surface defects ad or cracking distresses. Ride is good. Corrective maintenance on an annual;

Fair: Pavement is in fair condition with intermittent to frequent bumps of depressions from slight to moderate deformation. Intermittent to frequent moderate surface defects and/or cracking distresses. Ride is fair. Corrective maintenance to hold serviceability level on a semi-annual basis or sooner when necessary. May be a candidate for major corrective maintenance as holding strategy depending on performance level and history. Candidate for rehabilitation program in 3 to 5 years;

Poor: Pavement is in poor condition with frequent bumps or depressions from moderate surface deformation. Frequent moderate to severe defects and or cracking distresses. Localized slight to moderate alligator cracks may be present indicating pavement structural failure. Ride is poor. Corrective maintenance to retard rapid deterioration of serviceability level. Candidate for rehabilitation program in 1 to 3 years; and,

Very poor: Pavement is in very poor condition with extensive bumps or depressions from moderate to severe surface deformation. Extensive to severe surface defects and/or cracking distresses. Frequent slight to moderate alligator cracking may be present, indicating pavement structural failure. Ride is very poor. Corrective maintenance when and where necessary to maintain minimal safety and serviceability level. Rehabilitation within 1 year.

The SATCC (2001) and the South African TRH12 (1997) guides utilize five degrees of severity to classify distress. These include:

Slight: Distress difficult to discern. Only slight signs of distress visible;

Between slight and warning: Easily discernable distress but of little immediate consequence;

Warning: Distress is notable with respect to possible consequences. Start of secondary defects; maintenance is already possible or needed e.g. cracks can be sealed;

Between warning and severe: Distress is serious with respect to possible consequences. Secondary defects have developed (noticeable secondary defects) and/or primary defect is serious; and,

Severe: Secondary defects have developed (noticeable secondary defects) and/or extreme degree of primary defect.

The Tanzanian Pavement Rehabilitation Guide (Ministry of Works, 1999) utilizes a simplified three-class designation for pavement distress:

Sound: Adequate condition;

Warning: Uncertainty exists about the adequacy of the condition; and,

Severe: Inadequate condition.

There would seem to be two perspectives with respect to rehabilitation in Southern Africa. The TRL system uses Very Good to Very Poor, while the TRH12 based method assigns an adjective to describe the state of the road (Severe to Slight). Given the regional relevance of the South Africa system (which both the SATCC and Tanzanian guides were based) it would make sense for Nigeria to adopt a similar distress classification. Therefore, a Nigerian condition rating (NCR) that follows the TRH12 should be adopted and has been utilized in this study.

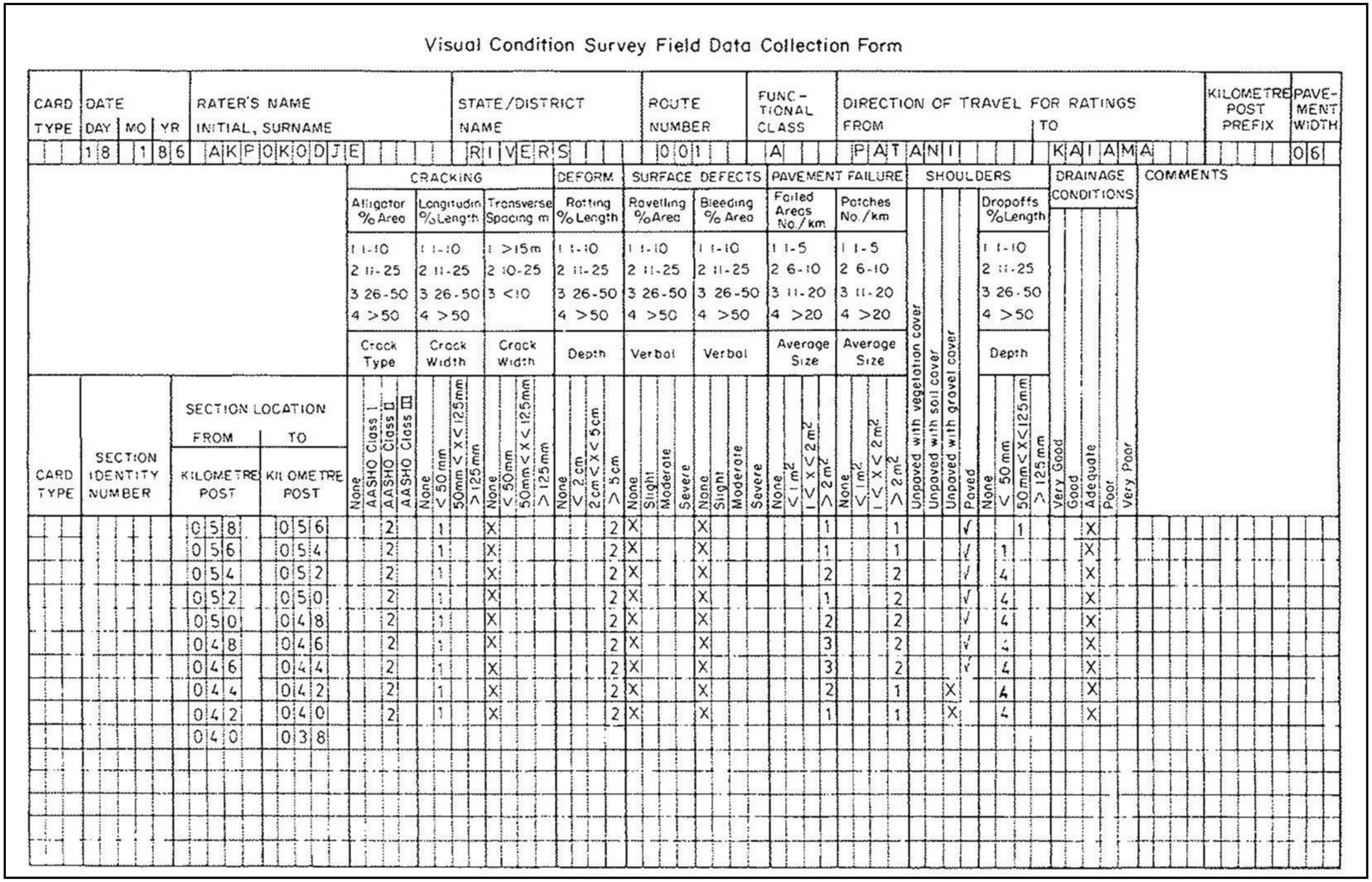
The designation of road condition requires the extent of distresses on the road to be known. Further, this classification would differ depending upon whether you were plotting occurrence of potholes or riding condition rating. There is certainly room for a composite index. One that is weighted with the International Roughness Index (Queiroz and Gautam, 1992) would be reasonable given the valuable data it provides in decision making criteria, as well as the simple and cost-effective method of acquiring the data.

3.6 Typical Pavement Designs

The designs outlined in ORN 31, which was the basis for the original Nigerian method, is similar to the TRH-4 method used in South Africa. Similarly, the Tanzanian Pavement and Materials Design Manual (1999) utilizes a similar system that provides example designs based on the type of base course, traffic loads, climatic zone and subgrade strength.

There is little data on what designs have been applied to roads in Nigeria, other than the information that is available on the type of asphalt they use (FMWH, 1997), and the fact that aggregate is used infrequently. Typically, reliance on borrow pit material is commonplace and designs are applied even if suitable aggregate can not be sourced. Blasting and quarrying of rock is not a common practice. Numerous studies have pointed to the poor quality control and neglect of design during the construction process, where pavement layers are either constructed with inferior materials to those that have been specified, layers are constructed thinner than specified, or both. Arumala and Akpokodje (1987) indicate that the majority of Federal roads fall into the following range:

- i) Subgrade: compacted to 95% to 100% BS compaction with soaked CBR of 5 to 11;
- ii) 50 to 120 mm sub-base, compacted to 100% West African Standard compaction;
- iii) 50 to 150 mm base of either coarse grained soils compacted to 100% West African Standard Compaction with a soaked CBR of at least 30% or a cement stabilized soil (5 to 7% cement content); and,
- iv) 30 to 90 mm double bituminous surface dressing of rolled asphalt.



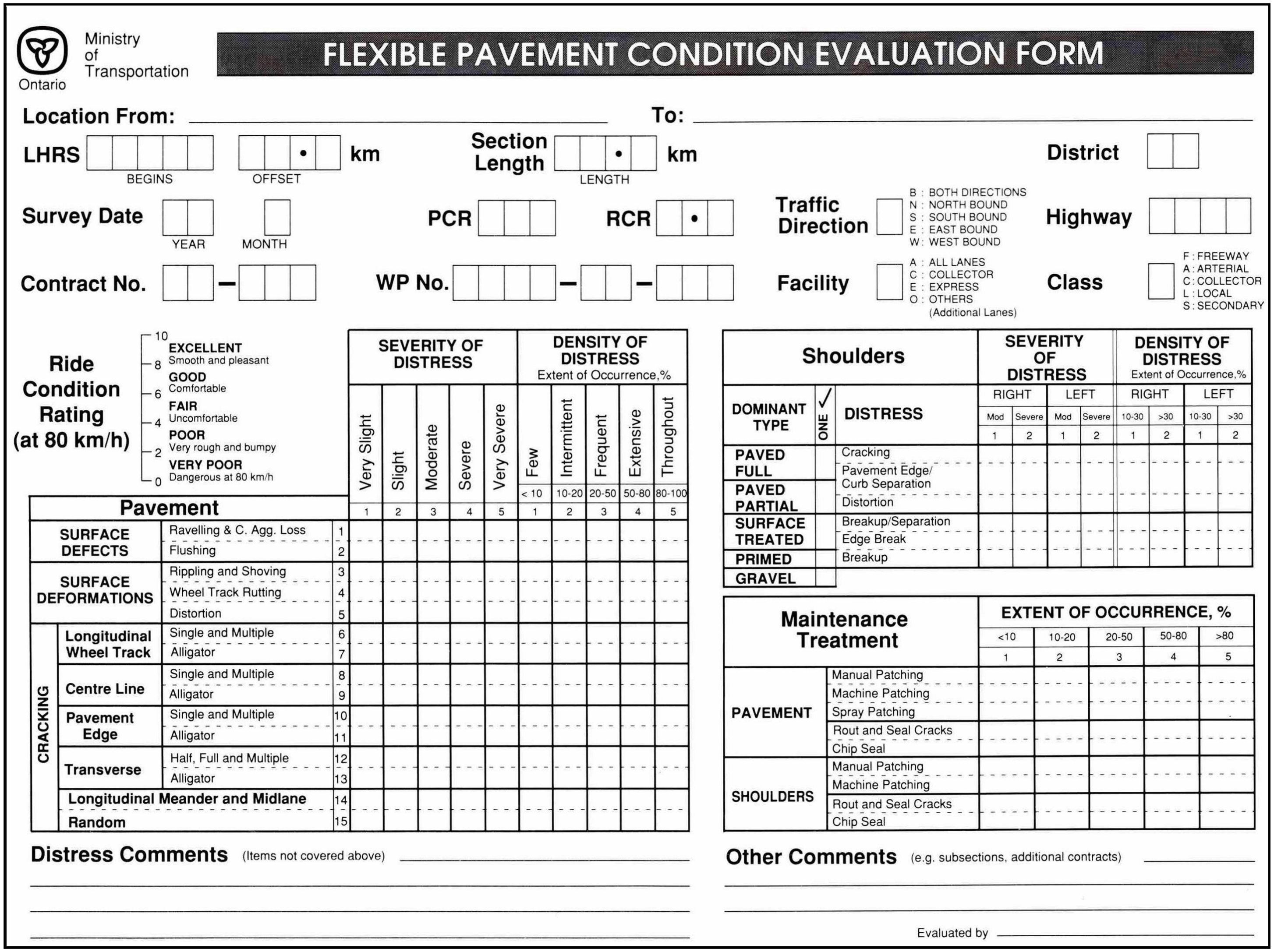
Visual Condition Survey Field Data Collection Form

CARD TYPE	DATE DAY MO YR	RATER'S NAME INITIAL, SURNAME	STATE/DISTRICT NAME	ROUTE NUMBER	FUNCTIONAL CLASS	DIRECTION OF TRAVEL FOR RATINGS FROM	TO	KILOMETRE POST PREFIX	PAVEMENT WIDTH
	18 1 86	AKPOKODJE	RIVERS	001	A	PATANI	KAIAMA		06

	CRACKING			DEFORM	SURFACE DEFECTS		PAVEMENT FAILURE		SHOULDERS		DRAINAGE CONDITIONS	COMMENTS
	Alligator % Area	Longitudinal % Length	Transverse Spacing m	Rutting % Length	Ravelling % Area	Bleeding % Area	Failed Areas No./km	Patches No./km		Dropoffs % Length		
	1 1-10 2 11-25 3 26-50 4 >50	1 1-10 2 11-25 3 26-50 4 >50	1 >15m 2 10-25 3 <10	1 1-10 2 11-25 3 26-50 4 >50	1 1-10 2 11-25 3 26-50 4 >50	1 1-10 2 11-25 3 26-50 4 >50	1 1-5 2 6-10 3 11-20 4 >20	1 1-5 2 6-10 3 11-20 4 >20		1 1-10 2 11-25 3 26-50 4 >50		
	Crack Type	Crack Width	Crack Width	Depth	Verbal	Verbal	Average Size	Average Size		Depth		
CARD TYPE / SECTION IDENTITY NUMBER / SECTION LOCATION FROM KILOMETRE POST – TO KILOMETRE POST	None / AASHO Class I / AASHO Class II / AASHO Class III	None / < 50 mm / 50mm < X < 125mm / > 125 mm	None / < 50mm / 50mm < X < 125mm / > 125 mm	None / < 2 cm / 2 cm < X < 5 cm / > 5 cm	None / Slight / Moderate / Severe	None / Slight / Moderate / Severe	None / < 1 m² / 1 < X < 2 m² / > 2 m²	None / < 1 m² / 1 < X < 2 m² / > 2 m²	Unpaved with vegetation cover / Unpaved with soil cover / Unpaved with gravel cover / Paved	None / < 50 mm / 50mm < X < 125mm / > 125 mm	Very Good / Good / Adequate / Poor / Very Poor	

FROM KILOMETRE POST	TO KILOMETRE POST	Crack Type	Crack Width (Longitudinal)	Crack Width (Transverse)	Rutting Depth	Ravelling	Bleeding	Failed Areas Average Size	Patches Average Size	Shoulders	Dropoffs Depth	Drainage Conditions
058	056	2	1	X	2	X	X	1	1	√	1	X
056	054	2	1	X	2	X	X	1	1	√	1	X
054	052	2	1	X	2	X	X	2	2	√	4	X
052	050	2	1	X	2	X	X	1	2	√	4	X
050	048	2	1	X	2	X	X	2	2	√	4	X
048	046	2	1	X	2	X	X	3	2	√	4	X
046	044	2	1	X	2	X	X	3	2	√	4	X
044	042	2	1	X	2	X	X	2	1	X	4	X
042	040	2	1	X	2	X	X	1	1	X	4	X
040	038											

Figure 3. 5: A visual condition rating form utilized by Arumala and Akpokodje (1987) to evaluate pavements in the Niger Delta. The form is not specific to Nigeria.



Ministry of Transportation Ontario

FLEXIBLE PAVEMENT CONDITION EVALUATION FORM

Location From: ______ To: ______

LHRS [ ] BEGINS [.] OFFSET km — Section Length [.] LENGTH km — District [ ]

Survey Date [ ] YEAR [ ] MONTH — PCR [ ] — RCR [.] — Traffic Direction [ ] (B : BOTH DIRECTIONS, N : NORTH BOUND, S : SOUTH BOUND, E : EAST BOUND, W : WEST BOUND) — Highway [ ]

Contract No. [ ]–[ ] — WP No. [ ]–[ ]–[ ] — Facility [ ] (A : ALL LANES, C : COLLECTOR, E : EXPRESS, O : OTHERS (Additional Lanes)) — Class [ ] (F : FREEWAY, A : ARTERIAL, C : COLLECTOR, L : LOCAL, S : SECONDARY)

Ride Condition Rating (at 80 km/h)

- 10 EXCELLENT Smooth and pleasant
- 8 GOOD Comfortable
- 6 FAIR Uncomfortable
- 4 POOR Very rough and bumpy
- 2 VERY POOR Dangerous at 80 km/h
- 0

Pavement			Very Slight 1	Slight 2	Moderate 3	Severe 4	Very Severe 5	Few < 10 1	Intermittent 10-20 2	Frequent 20-50 3	Extensive 50-80 4	Throughout 80-100 5
			SEVERITY OF DISTRESS					DENSITY OF DISTRESS Extent of Occurrence,%				
SURFACE DEFECTS	Ravelling & C. Agg. Loss	1										
	Flushing	2										
SURFACE DEFORMATIONS	Rippling and Shoving	3										
	Wheel Track Rutting	4										
	Distortion	5										
CRACKING Longitudinal Wheel Track	Single and Multiple	6										
	Alligator	7										
Centre Line	Single and Multiple	8										
	Alligator	9										
Pavement Edge	Single and Multiple	10										
	Alligator	11										
Transverse	Half, Full and Multiple	12										
	Alligator	13										
Longitudinal Meander and Midlane		14										
Random		15										

Shoulders			SEVERITY OF DISTRESS RIGHT Mod 1	Severe 2	LEFT Mod 1	Severe 2	DENSITY OF DISTRESS Extent of Occurrence,% RIGHT 10-30 1	>30 2	LEFT 10-30 1	>30 2
DOMINANT TYPE	✓ ONE	DISTRESS								
PAVED FULL		Cracking								
PAVED PARTIAL		Pavement Edge/ Curb Separation								
		Distortion								
SURFACE TREATED		Breakup/Separation								
		Edge Break								
PRIMED		Breakup								
GRAVEL										

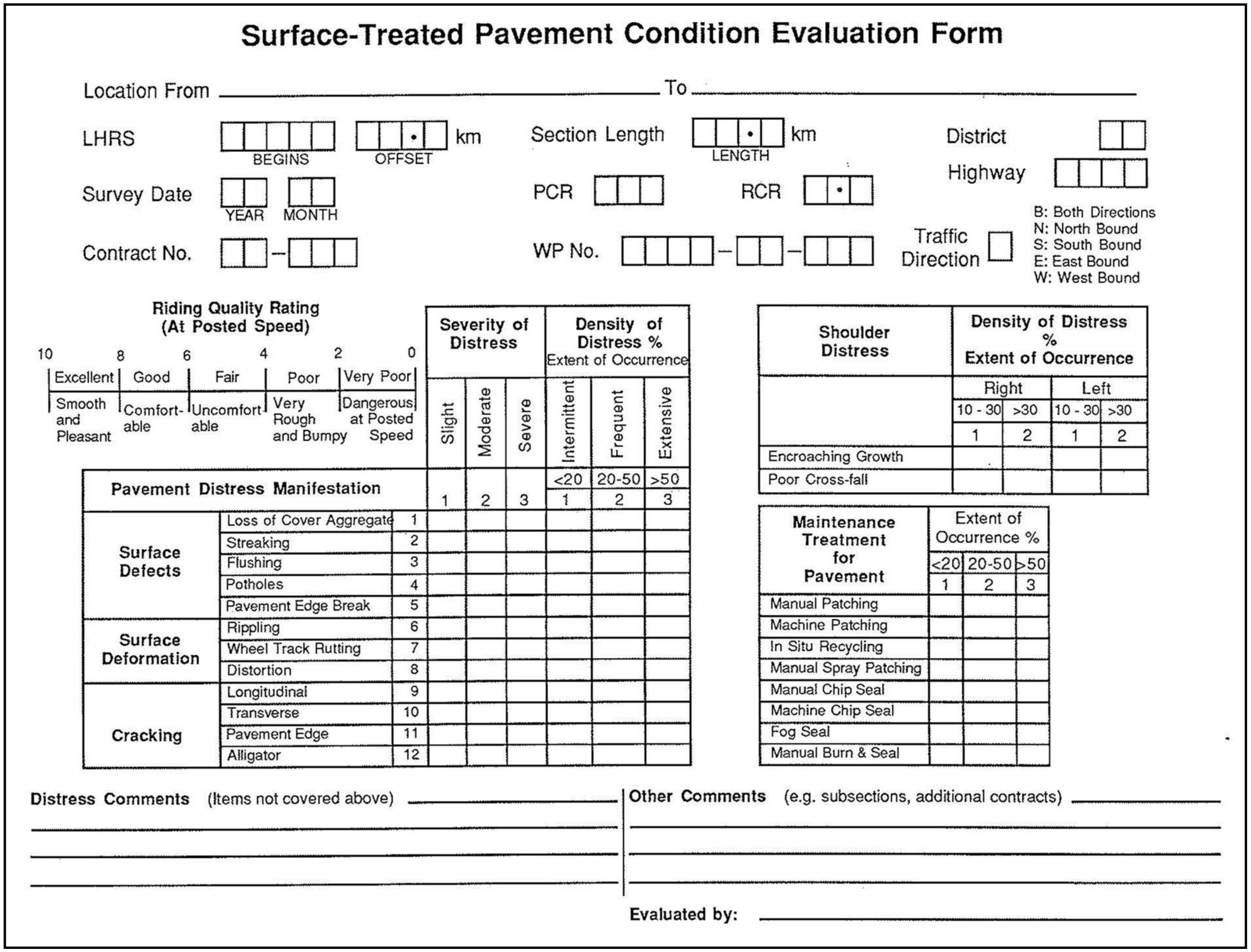
Maintenance Treatment		EXTENT OF OCCURRENCE, % <10 1	10-20 2	20-50 3	50-80 4	>80 5
PAVEMENT	Manual Patching					
	Machine Patching					
	Spray Patching					
	Rout and Seal Cracks					
	Chip Seal					
SHOULDERS	Manual Patching					
	Machine Patching					
	Rout and Seal Cracks					
	Chip Seal					

Distress Comments (Items not covered above) ______

Other Comments (e.g. subsections, additional contracts) ______

Evaluated by ______

Figure 3. 6: A flexible pavement condition rating evaluation form utilized by Ontario's Ministry of Transportation (MTO, 1989)



Surface-Treated Pavement Condition Evaluation Form

Location From ______________________ To ______________________

LHRS [ ][ ][ ][ ][ ] BEGINS [ ][ ][•][ ] OFFSET km | Section Length [ ][ ][•][ ] LENGTH km | District [ ][ ]

Survey Date [ ][ ] YEAR [ ][ ] MONTH | PCR [ ][ ][ ] | RCR [ ][•][ ] | Highway [ ][ ][ ][ ]

Contract No. [ ][ ]–[ ][ ][ ] | WP No. [ ][ ][ ][ ]–[ ][ ]–[ ][ ][ ] | Traffic Direction [ ]

B: Both Directions
N: North Bound
S: South Bound
E: East Bound
W: West Bound

Riding Quality Rating (At Posted Speed)

10 – 8	8 – 6	6 – 4	4 – 2	2 – 0
Excellent	Good	Fair	Poor	Very Poor
Smooth and Pleasant	Comfortable	Uncomfortable	Very Rough and Bumpy	Dangerous at Posted Speed

Pavement Distress Manifestation			Severity of Distress: Slight	Moderate	Severe	Density of Distress % Extent of Occurrence: Intermittent	Frequent	Extensive
			1	2	3	<20 1	20-50 2	>50 3
Surface Defects	Loss of Cover Aggregate	1						
	Streaking	2						
	Flushing	3						
	Potholes	4						
	Pavement Edge Break	5						
Surface Deformation	Rippling	6						
	Wheel Track Rutting	7						
	Distortion	8						
Cracking	Longitudinal	9						
	Transverse	10						
	Pavement Edge	11						
	Alligator	12						

Shoulder Distress	Density of Distress % Extent of Occurrence: Right 10 - 30	Right >30	Left 10 - 30	Left >30
	1	2	1	2
Encroaching Growth				
Poor Cross-fall				

Maintenance Treatment for Pavement	Extent of Occurrence %: <20	20-50	>50
	1	2	3
Manual Patching			
Machine Patching			
In Situ Recycling			
Manual Spray Patching			
Manual Chip Seal			
Machine Chip Seal			
Fog Seal			
Manual Burn & Seal			

Distress Comments (Items not covered above) ______________________

Other Comments (e.g. subsections, additional contracts) ______________________

Evaluated by: ______________________

Figure 3. 7: A surface-treated pavement condition evaluation form for distress manifestations (MTO, 1989)

Based on the parameters that have been selected for Nigerian subgrades, traffic volumes and loads, and environmental factors, typical designs can be derived from the Overseas Road Note 31 (Table 3.4). It is unlikely, that roads are actually constructed to this standard, and if they are, they are likely in a poor state due to the lack of maintenance or rehabilitation interventions that have been applied. The designs in Table 3.4 are more akin to a design that would be applied if reconstruction was the chosen intervention. Nevertheless, as there exists no details on the actual designs that are applied in Nigeria, the designs outlined in Table 3.4 are reasonable as a starting point with which to base decision tree models and life cycle costing and are likely representative of designs that would be applied in Nigeria.

3.7 Nigerian Maintenance and Rehabilitation Costs

The sheer lack of data in Nigeria on all fronts further drives home the urgent need for simple tools that the Federal Roads Maintenance Agency can use to start preserving the remaining pavement assets they have. One of the most important data sources to accomplish this is the cost of applying a given maintenance or rehabilitation intervention in the Nigerian context.

The lack of well organized and archived data is a common theme in the developing world, and was the reason for the World Bank to initiate the Road Costs Knowledge System (ROCKS). The main objective of the system was to develop an international knowledge system on road work costs to be used, primarily in developing countries, to establish an institutional memory, and obtain average range of unit costs based on historical data that could ultimately improve the reliability of new cost estimates and reduce the risks generated by cost overruns (World Bank, 2006). The database that is publicly available contains regional data for Africa that outlines the costs associated with carrying out various maintenance and rehabilitation interventions (Table 3.5).

Within the ROCKS database there are a number of entries of Nigerian projects that have been completed by the World Bank. Of these entries, there are 13 that have sufficient data on the maintenance or rehabilitation intervention applied and the costs associated with it (Table 3.6). A disadvantage of this data is that it summarizes the total cost of the project (in USD per kilometre and per square meter) rather than an itemized cost of each activity associated with the project (e.g. the cost of a 40 mm AC overlay only).

A complementary program to ROCKS that was developed by the World Bank solely for sub-Saharan Africa is the Road Network Evaluation Tools (RONET). The RONET program was specifically created to assist decision makers to accomplish the following tasks (World Bank, 2007):

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

Table 3. 4: Typically flexible pavement designs that should be applied to Nigerian Federal roads according to ORN 31 (TRL, 1993)

Traffic	Nigerian subgrade					Legend
	NSG1	**NSG2**	**NSG3**	**NSG4**		
TC1	150 mm 200 mm 200 mm	150 mm 250 mm	150 mm 175 mm	150 mm		
TC2	200 mm 225 mm 200 mm 50 mm 175 mm 225 mm 200 mm	200 mm 275 mm 50 mm 175 mm 275 mm	200 mm 200 mm 50 mm 175 mm 200 mm	200 mm	50 mm 175 mm	
TC3	200 mm 275 mm 200 mm 50 mm 175 mm 275 mm 200 mm	200 mm 325 mm 50 mm 175 mm 325 mm	200 mm 250 mm 50 mm 175 mm 250 mm	225 mm	50 mm 200 mm	Surface dressing (e.g. Chip seal) AC Granular base PI < 6; CBR > 80 Granular base; CBR > 30 Selected sub-grade; CBR > 15
TC4	125 mm 225 mm 225 mm 200 mm	125 mm 225 mm 250 mm	125 mm 225 mm 175 mm	125 mm 225 mm		
TC5	150 mm 250 mm 250 mm 200 mm	150 mm 250 mm 270 mm	150 mm 250 mm 175 mm	150 mm 250 mm		

Table 3. 5: Road Costs Knowledge System (ROCKS) data for Africa (median cost per two-lane km except Routine Maintenance, which is per lane km).

Work type	Activity	Africa region USD(CDN)*	Low	High	Number of observations	World data USD(CDN)*
Routine Maintenance	Routine Maintenance; bituminous 2L	2,323 (3,802)	2038	3086	18	1,964 (2,311)
Surface treatment resurfacing	Slurry seal or Cape seal Single surface treatment Double surface treatment	12,970 (15,259) 18,353 (21,592) 18,767 (22,079)	9686 14359 19196	14098 23600 27186	3 9 18	8,695 (10,229) 18,254 (21,475) 27,968 (32,904)
Asphalt mix resurfacing	Asphalt overlay < 40 mm Asphalt overlay 40 mm to 59mm	41,241 (48,519) 51,332 (60,391)	30228 46661	55403 67898	10 24	37,911 (44,601) 68,183 (80,215)
Strengthening	Asphalt Overlay 60 to 70 mm Asphalt Overlay 80 to 99 mm Asphalt Overlay > 99 mm	91,905 (108,124) 127,548 (150,057) 181,992 (214,108)	79479 102532 146969	117874 150828 210151	6 11 4	81,270 (95,612) 112,285 (132,100) 157,360 (185,129)
Reconstruction	Reconstruction bituminous	190,031 (233,566)	192317	236912	92	178,945 (210,524)

* 1 CDN = 0.85 USD

Table 3. 6: Nigerian projects contained in the ROCKS database with costing

Project	Location	Yr	Work type	C$/km	C$/m2	Comments
ICRA0091	Multi-state	99	Rehab with AC	119,187	17.02	Thickness or AC or road design unknown
ICRA0092	Multi-state	99	Rehab with DSD	97,295	13.89	Thickness or DSD or road design unknown
ICRA0116	Multi-state	98	AC overlay 40 – 59 mm	111,853	15.32	Road design unknown
RACA0238	Multi-state	93	Double surface	29,074	3.99	20 mm resurfacing thickness
RACA0239	Multi-state	93	Bituminous reconstruction	96,847	13.27	20 mm resurfacing thickness
RACA0242	Multi-state	93	Patching	-	9.65	2 lane road; distress extent unknown
NGAA001	Bauchi-Tafawa Balewa-Dawaki Rd Section III	99	Bituminous reconstruction	244,966	33.55	Rolling terrain; hot, sub-tropical; base work = 51%; asphalt work = 18%. 40 mm resurface
NGAA004	Rehab of Jos - Bauchi Road	01	Bituminous reconstruction	300,605	41.18	Rolling terrain; hot sub-tropical; asphalt work = 46%; 40 mm resurfacing.
NGAA005	Rehab of Okigwe - Afikpo Road	01	Bituminous reconstruction	930,274	127.44	Rolling terrain; hot sub-tropical; base work = 18%; asphalt work = 15%; 40 mm resurfacing.
NGAA006	Rehab of Ekwulobia -Oko-Umunze - Ibinta - Imo State Border	02	Bituminous reconstruction	438,484	60.07	Rolling terrain; hot sub-tropical; base work = 26%; asphalt work = 22%; 40 mm resurfacing.
NGAA007	Construction of Langtang - Lalin - Tunkus - Shendam Road	02	Bituminous reconstruction	542,974	74.38	Rolling terrain; cool sub-tropical; base work = 24%; asphalt work = 21%; 50 mm resurfacing.
NGAA008	Auchi-Ekperi-Agenebode road	99	Bituminous reconstruction	198,246	29.59	Sub-humid rolling; Base work (natural gravel) = 13%; asphalt work = 36%; 40 mm resurfacing.
NGAB0003	Lamata	04	AC overlay < 40 mm	89,973		Humid tropical

To validate the model, Archando-Callao (2008) utilized four SSA countries, including Mozambique, Uganda, Tanzania and Ghana. While data from either of these countries could assist in fine tuning the costs associated with implementing various maintenance and rehabilitation interventions in Nigeria, a copy of a trial RONET simulation by Achando-Callao (2008) for Nigeria was obtained. The RONET simulation for Nigeria contains costing data for various MR&R interventions, which are summarized in Table 3.7.

In comparing the data obtained from ROCKS for African roads, the data available for Nigeria obtained from ROCKS and the data obtained from the RONET simulation for Nigerian roads, there is some overlap. Firstly, the price for routine maintenance that was used for the RONET analysis is well above the African maximum cost obtained from ROCKS. The resurfacing cost for applying an asphalt overlay (approximately 50 mm) is equivalent in both the ROCKS and RONET data, as is the overlay cost. Other than the routine maintenance cost, while appreciably different from a percentage standpoint, in reality there is only a 2000 USD difference between the two data sets. As such, the ROCKS data for Africa will be utilized in this study. The median, minimum and maximum costs associated with each intervention will be utilized to generate a range of values.

3.8 Pavement Service Life

The service life of a given asphalt wearing or surface course is critical to the pavements longevity. It is also an important factor when selecting the appropriate maintenance or rehabilitation intervention to apply, from a technical and economic standpoint. Both the South African and SATCC standard provide suggested typical ranges of surfacing life periods for various surfacing types. For granular bases, the following typical surfacing life can be expected (SATCC, 2001):

Bitumen sand or slurry seal:	6 to 8 years
Bitumen single surface treatment:	6 to 10 years
Bitumen double surface treatment:	8 to 10 years
Cape Seal:	8 to 10 years
Continuously graded asphalt:	8 to 11 years
Gap-graded asphalt:	8 to 13 years

In the Nigerian General Specification for Roads and Bridges (FMWH, 1997), only two asphalt mix designs are specified. These include a binder or lower base course and a wearing or surface course. There is no provision for alternative mix deigns that take into account traffic factors, surface temperatures, and other environmental factors that are critical to an asphalt concrete mix design. A site survey conducted by Esenwa (2008) outlined the following common problems observed on working paving sites in Nigeria:

Mix deficiencies:	Mix overheated, mix under-heated, too much bitumen, too little bitumen, non-uniform mixing, excess coarse aggregate, excess fine aggregate, excess moisture, segregation, and contamination;
Paving deficiencies:	Uneven surface wearing course, spot bleeding, ravelling, cracking of asphalt, honey combing of asphalt, and inadequate compaction of asphalt.

Given the above observations and taking into account the range of typical surface life, the lower value of surface life seems overstated with respect to Nigeria. Given the complications with production and application, the life of the applied wearing course is likely to be significantly lower than that stated in the literature.

3.9 Summary

This chapter presented the difficulties associated with, and reliance on, data from Nigeria. While some data does exist, it has generally been collected and stored in an unstructured format that renders it of little applicability. What has been shown to be reasonable is that data from regional authorities and sources can be utilized, together with World Bank experience, to derive data that is not only representative of the Nigerian situation, but also defendable. At the very least, the data that has been compiled, and the assumptions that have been made, serve as a logical and sound starting point with which to develop and further validate as more data is collected.

This chapter identified the various input factors that are required to calculate the life cycle cost analysis and those that are required to streamline maintenance and rehabilitation interventions. These variables included traffic volumes and loads, environmental factors such as climatic zones, typical designs applied to roads in Nigeria, subgrade types and strengths, condition rating, and reasonable surface life of various wearing course options. These factors are presented in Figures 3.8 to 3.11.

Table 3.7: Data from RONET (World Bank, 2007b) on MR&R interventions for asphalt roads in Nigeria.

Capital Road Works Unit Costs							
			Two-Lane Unit Costs of Road Works (USD(CDN)/km)				
Surface Type	**Current Condition**	**Road Work**	**Primary**	**Secondary**	**Tertiary**	**Unclassified**	**Urban**
Asphalt Mix	Good Condition	Preventive Treatment	5,000 (5,882)	4,000 (4,704)	3,000 (3,529)	3,000 (3,529)	5,000 (5,882)
	Fair Condition	Resurfacing (Overlay)	45,000 (52,941)	36,000 (42,352)	27,000 (31,765)	27,000 (31,765)	45,000 (52,941)
	Poor Condition	Strengthening (Overlay)	130,000 (152941)	104,000 (122,353)	78,000 (91,765)	78,000 (91,765)	130,000 (152941)
	Very Poor Condition	Reconstruction	230,000 (270,588)	184,000 (216,471)	138,000 (162,353)	138,000 (162,353)	230,000 (270,588)
	No Road	New Construction	350,000 (411,765)	280,000 (329,412)	210,000 (247,059)	210,000 (247,059)	350,000 (411,765)
Surface Treatment	Good Condition	Preventive Treatment	2,000 (2,352)	1,600 (1,882)	1,200 (1,412)	1,200 (1,412)	2,000 (2,352)
	Fair Condition	Resurfacing (Reseal)	18,000 (21,176)	14,400 (16,941)	10,800 (12,706)	10,800 (12,706)	18,000 (21,176)
	Poor Condition	Strengthening (Overlay)	90,000 (105,882)	72,000 (84,706)	54,000 (63,529)	54,000 (63,529)	90,000 (105,882)
	Very Poor Condition	Reconstruction	180,000 (211,765)	144,000 (169,412)	108,000 (127,059)	108,000 (127,059)	180,000 (211,765)
	No Road	New Construction	300,000 (352,941)	240,000 (282,353)	180,000 (211,765)	180,000 (211,765)	300,000 (352,941)

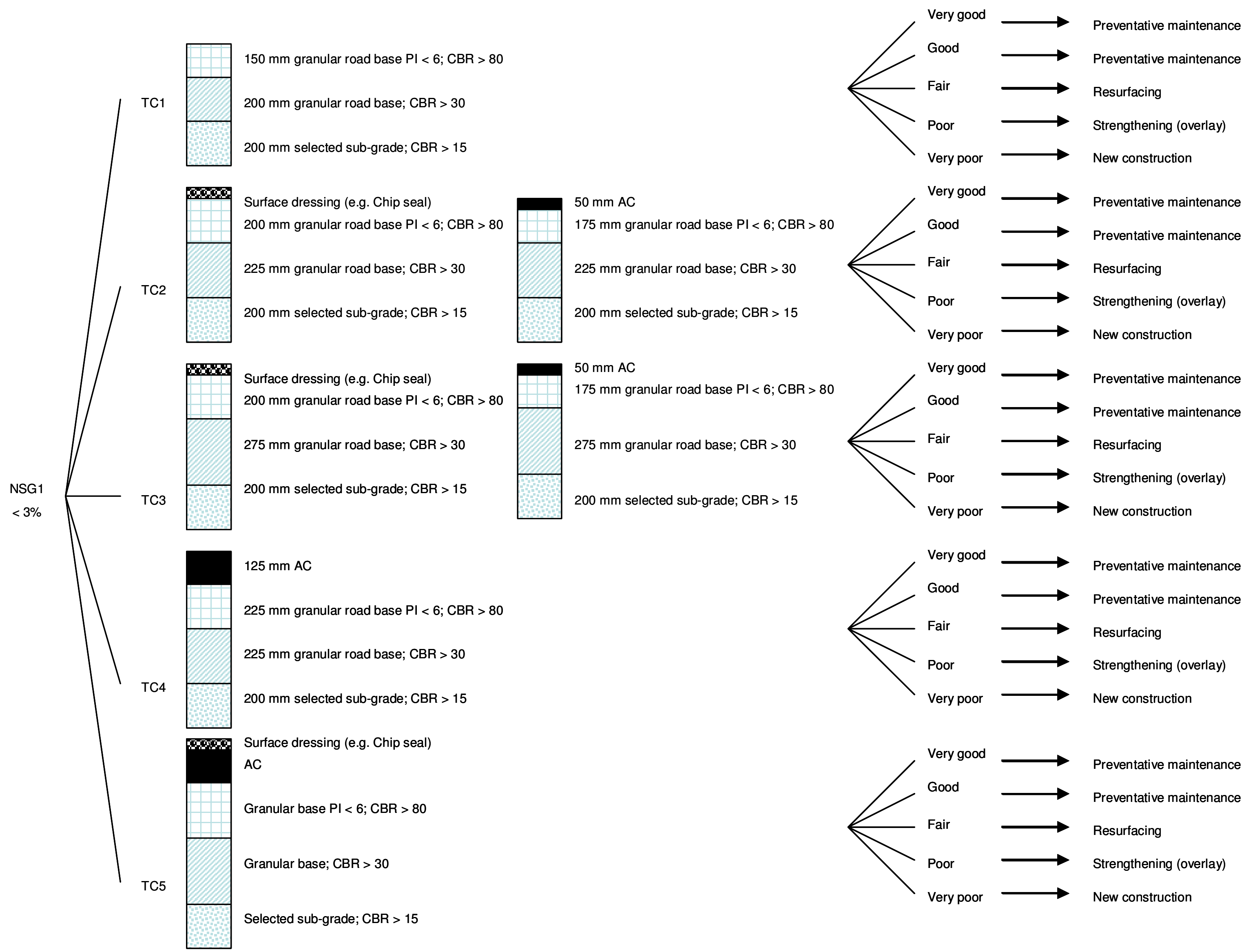


Figure 3. 8: A summary of the maintenance and rehabilitation criteria for subgrade NSG1

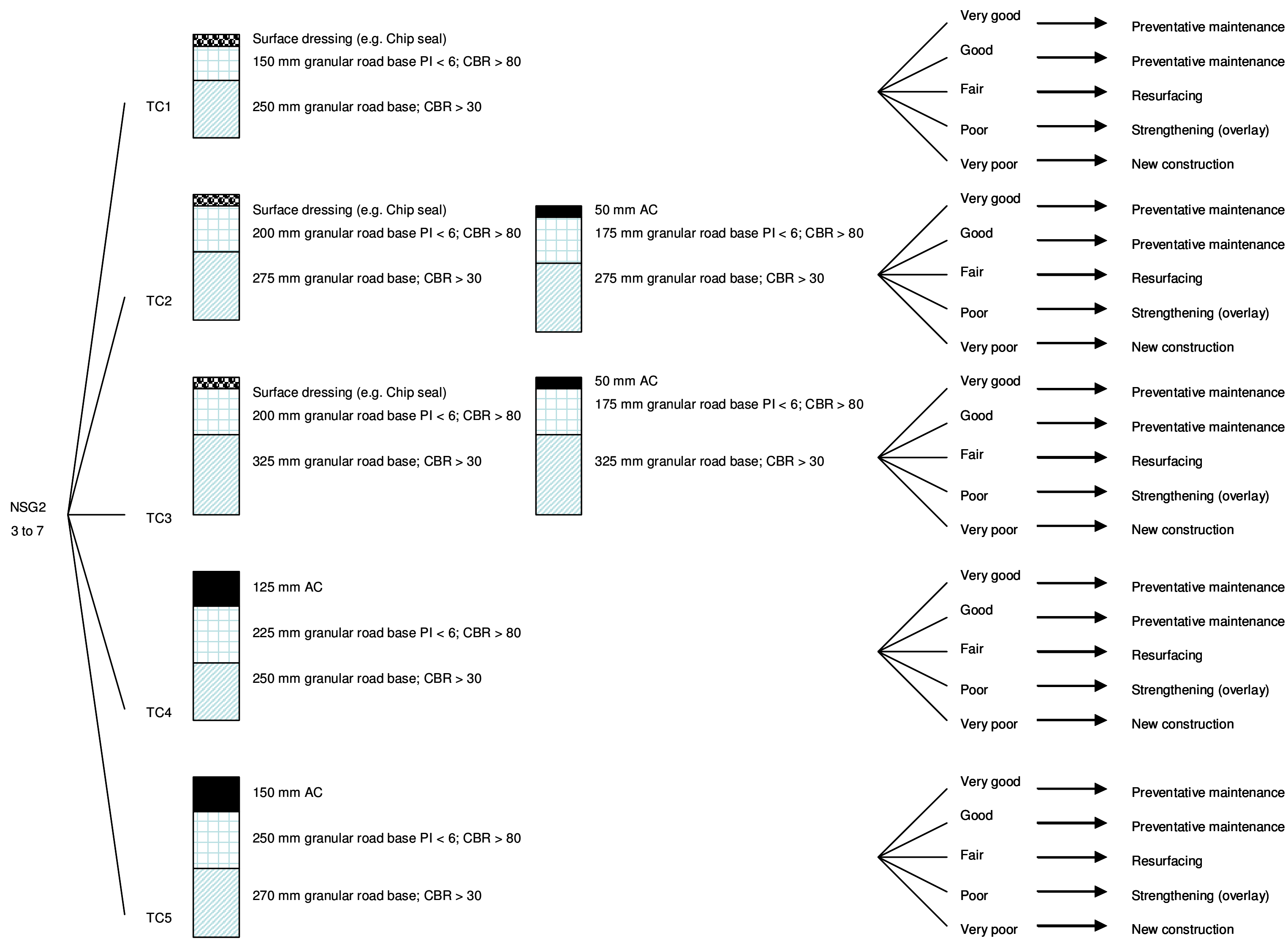


Figure 3. 9: A summary of the maintenance and rehabilitation criteria for subgrade NSG2

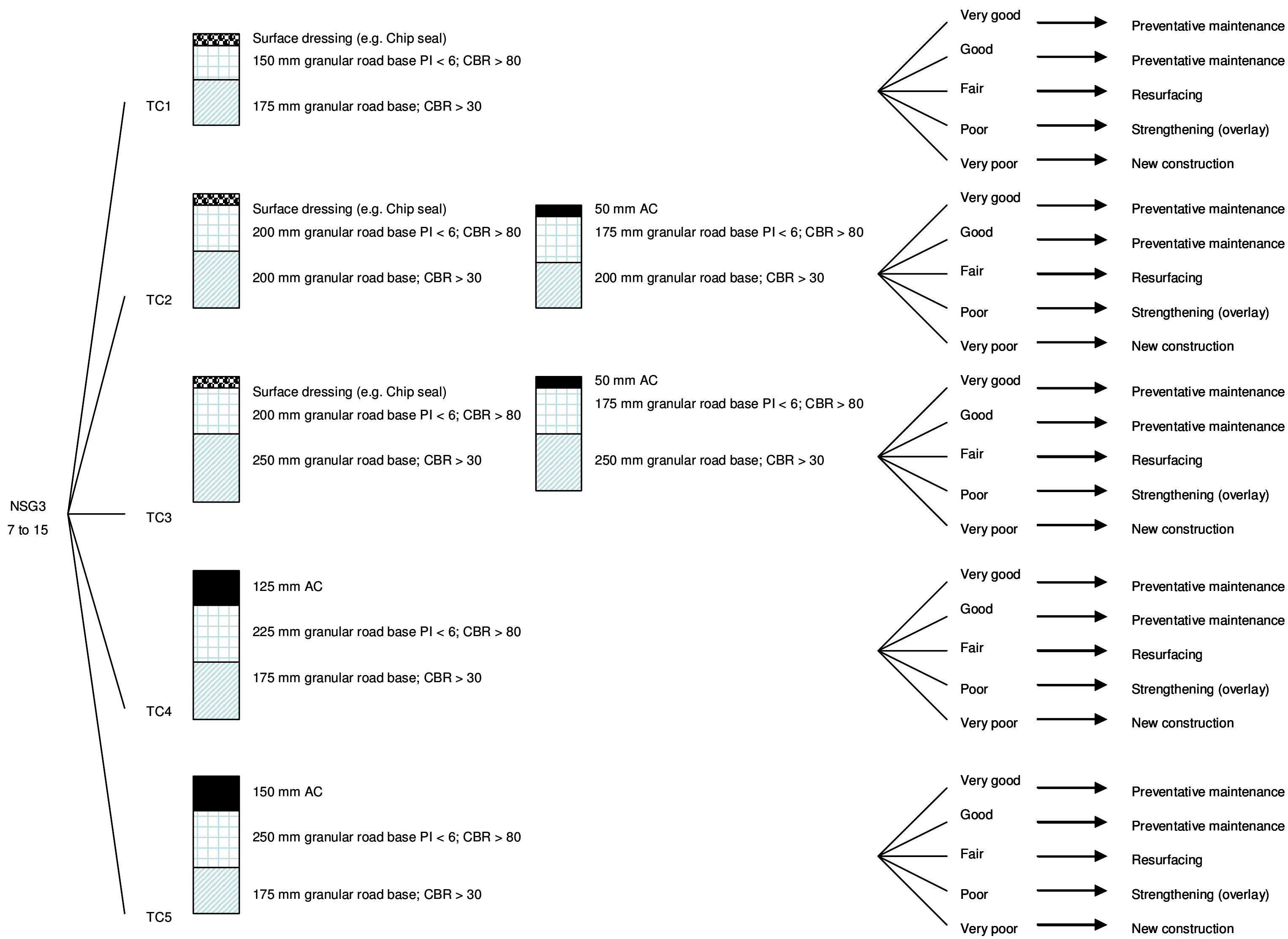


Figure 3. 10: A summary of the maintenance and rehabilitation criteria for subgrade NSG3

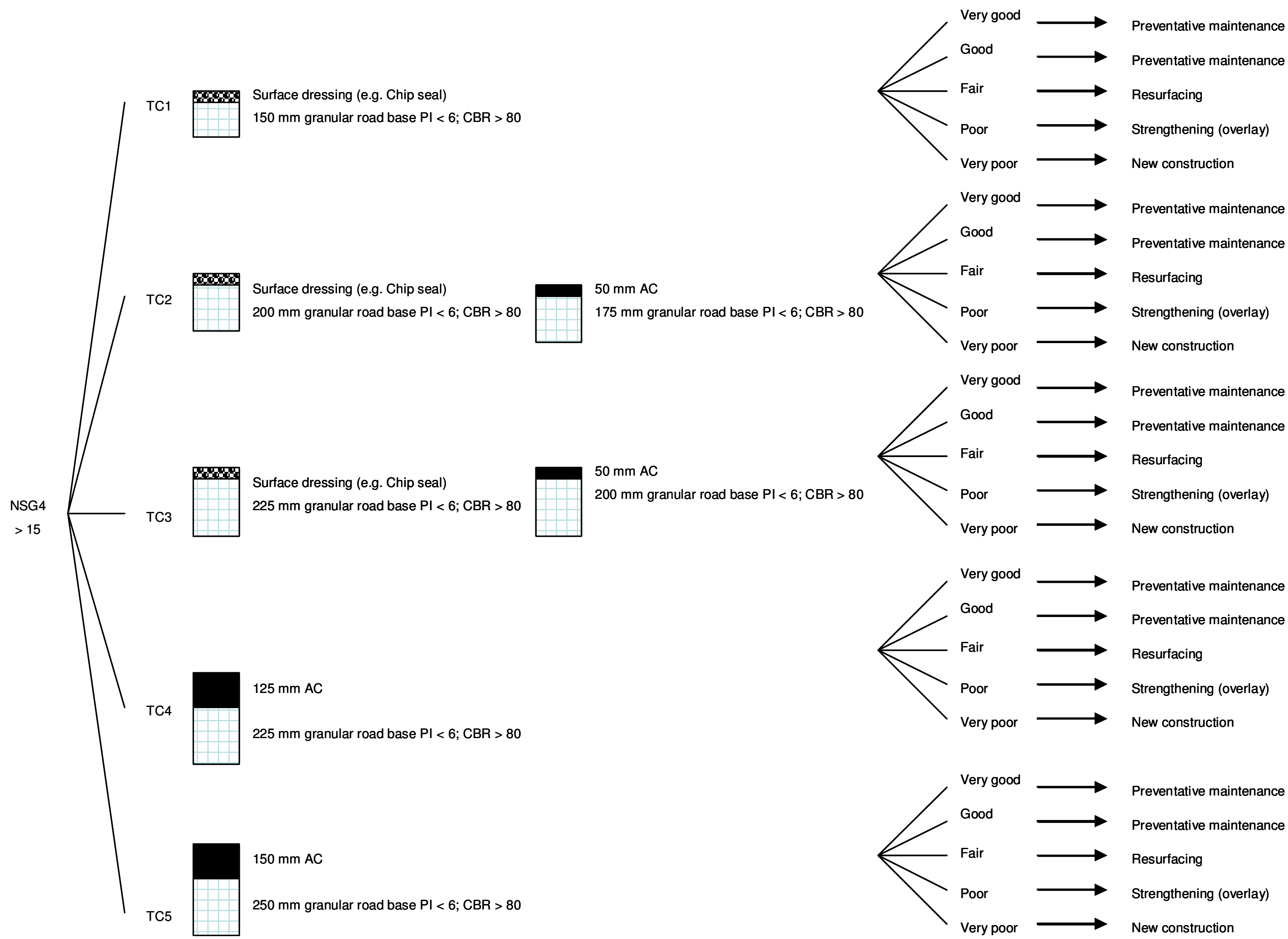


Figure 3. 11: A summary of the maintenance and rehabilitation criteria for subgrade NSG4

CHAPTER 4: DECISION TREES AND LIFE CYCLE COSTING

It is the intention of this chapter to utilize the data and information acquired in the proceeding chapter and provide simple tools that can be utilized by the Federal Roads Maintenance Agency of Nigeria to streamline their maintenance and rehabilitation interventions. It is the intention that these tools provide an easy reference by which a member of FERMA or a site engineer can have access to maintenance or rehabilitation interventions that suits the distress being observed at the project level. Such tools include flow diagrams and decision trees. It is also important that these streamlined maintenance and rehabilitation intervention decisions are supported by life cycle costing so that decision makers can have surety that the correct implementation has been applied, or will be applied.

4.1 RONET

The World Banks Road Network Evaluation Tool was created to provide road managers the ability to better monitor the current condition of road networks, plan allocation of resources, and assess the consequences of macro-policies on the road network. It is specific to sub-Saharan Africa and provides a powerful tool to evaluate the road network. RONET is a tool for assessing the performance of road 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 initiatives. It is this last aspect where the true potential for the program (an elaborate programmed series of Excel spreadsheets) lies, in the ability to provide decision makers with a simple output that allows for funding requirements for a 20 year term to be visualized and budgeted for.

While still a program that requires further evaluation and validation, despite that Madagascar, Mozambique, Uganda and Ghana have been used in this capacity, it is a useful tool. One disadvantage would seem to be the limited ability to focus on a specific sector of the network, or a single facet of the macro-program. For example, for the Federal road network in Nigeria, the program lacks the flexibility to focus on only one road design type, in FERMA's case asphalt concrete roads on a granular base, and fine filtering the input parameters to focus on only one set of conditions. The power of the program seems to lie in evaluating an entire network with different road design types. Nevertheless, the outputs are valuable to an agency that is looking to secure funding in the long term that will allow for improved pavement performance at the network level.

The RONET program relies on a series of inputs that are specific to the network to be evaluated. These include the management type, network type, types of terrain, environmental factors, road condition classes, traffic levels, and traffic categories. The program also requires specific country data, including basic diagnostic parameters of the country, such as land size, population, etc., traffic growth and pavement width, capital road works unit costs, recurrent road works unit costs, and traffic levels characteristics. After data has been inputted, a Performance Assessment Overview is conducted and a series of network level outputs is provided.

4.1.1 RONET Analysis

There is little data available on specific intervention costs in Nigeria with which to apply to the RONET model. In an attempt to evaluate the future cost requirements needed to improve the federal road network in Nigeria, as budgeting and resource allocation is going to be one of the most important tools for FERMA to address the hurdles that need to be overcome, regional intervention data from sounding SSA countries were utilized. By utilizing intervention costs that are known for other African nations a good approximation of the likely cost in Nigeria can be obtained. The majority of roads in the FERMA network are surfaced roads and averages for these intervention types were utilized in the RONET evaluation. The Optimal Work Program output from the RONET evaluation that was performed for the federal road network in Nigeria is summarized in Table 4.1 and the Network Performance Outputs that are generated as part of a RONET analysis are presented in entirety in Appendix A.

Nigeria FERMA

Optimal Work Program

Year	Rehabilitation (M US$)	Periodic Maintenance (M US$)	Recurret Maintenance (M US$)	Road Agency (M US$)	Road Users (M US$)	Society (M US$)	Net Benefits (M US$)	Average Roughness (IRI)
1	3,494.8	29.0	62.6	3,586.3	3,618.1	7,204.5	-2,752.2	4.25
2	0.0	0.0	62.6	62.6	3,745.8	3,808.4	846.2	4.44
3	0.0	0.0	64.8	64.8	3,880.1	3,944.9	927.1	4.65
4	434.9	0.0	68.8	503.7	3,999.3	4,503.0	3,204.7	4.33
5	0.0	58.0	69.0	127.0	4,140.3	4,267.3	380.5	4.51
6	0.0	94.2	69.9	164.1	4,278.3	4,442.4	163.6	4.70
7	0.0	0.0	73.7	73.7	4,436.3	4,510.0	282.0	4.94
8	0.0	0.0	74.3	74.3	4,603.0	4,677.3	312.4	5.19
9	1,957.1	137.7	76.6	2,171.4	4,504.7	6,676.1	-1,475.8	3.37
10	0.0	0.0	78.6	78.6	4,659.4	4,738.0	691.3	3.54
11	0.0	94.2	72.4	166.6	4,803.2	4,969.9	692.0	3.70
12	0.0	43.5	72.6	116.1	4,963.9	5,080.0	832.9	3.87
13	0.0	101.5	72.9	174.4	5,123.9	5,298.3	2,612.6	4.01
14	372.8	0.0	77.4	450.1	5,276.8	5,726.9	426.8	3.73
15	0.0	58.0	80.2	138.2	5,455.4	5,593.6	247.6	3.90
16	0.0	87.0	79.6	166.6	5,644.4	5,811.0	65.6	4.09
17	0.0	145.0	73.6	218.6	5,815.7	6,034.3	78.0	4.26
18	0.0	0.0	72.7	72.7	6,025.7	6,098.4	265.7	4.50
19	0.0	0.0	74.1	74.1	6,247.2	6,321.2	319.1	4.74
20	0.0	0.0	75.4	75.4	6,480.9	6,556.3	377.0	5.01
Years 1-5 Total (M$)	3,929.7	87.0	327.8	4,344.5	19,383.6	23,728.0	2,606.3	
Years 6-20 Total (M$)	2,329.8	761.1	1,123.9	4,214.9	78,318.8	82,533.7	5,890.9	
Years 1-20 Total (M$)	6,259.5	848.1	1,451.8	8,559.3	97,702.4	106,261.7	8,497.2	
Years 1-5 Total per Year (M$/year)	785.9	17.4	65.6	868.9	3,876.7	4,745.6	521.3	
Years 6-20 Total per Year (M$/year)	155.3	50.7	74.9	281.0	5,221.3	5,502.2	392.7	
Years 1-20 Total per Year (M$/year)	313.0	42.4	72.6	428.0	4,885.1	5,313.1	424.9	
Present Value at 12% (M$)	4,680.2	295.2	585.4	5,560.8	36,827.2	42,388.0	2,725.5	
Average (IRI)								4.29

Table 4. 1: RONET Optimal Work Strategy output for Nigeria's federal road network

* IRI in m/km

4.1.2 RONET Results

The RONET Optimal Work Program output for federal roads in Nigeria indicates that an USD3.9 billion (CDN4.7 billion) investment over the next 5 years to improve the road network through rehabilitation measures is required, and USD6.2 billion (CDN7.5 billion) over the next 20 years for rehabilitation is needed to improve the service level to that which FERMA has earmarked. This is over and above funding that would be required for routine or periodic maintenance, new construction, or that would be required to address State and Municipal roads throughout the country. What it does provide, however, is a good reference for the funding that will be required, from a budgeting standpoint, in the first 5 years of the program. FERMA (2007) estimates that, in addition to their annual budgetary need of 40 billion Naira (Naira/CDN exchange rate: 0.00985; CDN394 million) that is required for routine and general maintenance of the road network, an additional 70 billion Naira (CDN690 million) will be required per annum to address rehabilitation. While no background data is given to the magnitude of FERMA's budgetary needs, it is much larger than that of the RONET analysis which is based on regional, Africa-specific data. The difference could be attributed to input data used for the RONET analysis, but this would infer that the prices for basic interventions are significantly higher in Nigeria than they are for the countries utilized to obtain a sub-Saharan average that were used in the RONET analysis.

Given the state of the Nigeria federal road network, and the past tradition of maintenance and rehabilitation, the budget that FREMA has outlines is more in line with inefficient practices, while the RONET derived analysis relies on sate of the art practices and application efficiencies. The FERMA budget assessment over the next 5 years was likely derived with little appreciation for pavement management and intervention streamlining, which would account for the larger budget requirement. It is unknown whether the budget that FERMA has outlined includes reconstruction of seriously failed roads within the network, or expansion of roads to dual-carriageways. What the two sets of network data do provide is an estimation of the potential savings that FERMA can achieve by implementing a pavement management strategy, as outlined through the RONET analysis process.

What RONET does not provide is a means of deciding which is the most appropriate maintenance or rehabilitation intervention. While it does give a target number for FERMA to aim towards from a budgeting standpoint that is over and above what they have estimated internally, it does not provide the ground level evaluation tools and assessments that are required to deduce the most appropriate intervention.

4.2 Optimum maintenance strategy

As outlined by Haas et al. (1994), the feasible set of alternatives available for rehabilitation and maintenance may be much smaller than the total available set because of costs, physical restraints, condition of the existing pavement and regional factors. This is certainly the case for Nigeria, where the available interventions are likely limited to those that are in common practice throughout sub-Saharan Africa. These include surface treatments, hot-mix resurfacing, pothole repair, rout and seal cracking, hot-mix patching and other well practiced, simple techniques. The costs associated with these interventions were presented in Chapter 3. The process used to select the feasible maintenance and/or rehabilitation intervention from a series of alternatives can range from simple judgement to a decision tree or flow diagram.

Ogurara and Iriakama (1987) established a means by which a pavement maintenance management system (PMMS) for Nigeria could be constructed. While it took into account the country as a whole, the methodology and prioritization that was utilized presents merit for modified adaptation. The PMMS identified pavement condition attributes that were considered to significantly influence the overall acceptability of the pavement to users. The physical condition in terms of physical distress and surface roughness were considered as the major attributes on Nigerian roads. Their measured values were combined to give an overall pavement condition rating score.

A combined condition rating score including the results from a physical survey and results from International Roughness Index (IRI) data provides a means of prioritizing which sections or roads within the network or project receive maintenance or rehabilitation interventions over another. The physical distresses derived from physical condition surveys should include surface deformation (rutting), surface defects (bleeding), cracking (alligator, longitudinal and transverse) and failures (potholes and patching). By using distress deduct points based on each distress manifestation, a physical distress rating (PDR) has been derived. The rating scheme to derive the PDR is highlighted in Table 4.2. If a distress is not observed, it is given a perfect score for that distress type, and the total of the distress scores are summed to give the PDR.

Similarly, the IRI has been used to produce a Roughness Distress Rating (RDR). According to data from the World Bank ROCKS and RONET programs, the IRI is utilized to determine maintenance and rehabilitation interventions. Table 4.3 summarizes the criteria that are used from IRI data to produce the RDR. The combination of the PDR and the RDR are combined to produce an Overall Condition Rating (OCR) that is utilized, through the decision tree developed in Figure 4.1, to prioritize maintenance and rehabilitation interventions. The decision tree utilizes both the OCR and the RCR data to deduce the appropriate priority of the road or section. While physical distress and roughness are correlated, substantial longitudinal cracking, for example, may not translate into a poor IRI reading, and conversely, a poor IRI reading may not have been expected given an adequate

PDR. Having the ability to streamline priorities based on both factors allows for better allocation of needs based on roads that are exhibiting distresses

Table 4. 2: Physical Distress Rating (PDR) criteria

Distress	Very Good	Good	Fair	Poor	Very Poor
Surface deformation	25 - 20	20 -15	15 - 10	10 - 5	5 – 0
Surface defects	25 - 20	20 -15	15 - 10	10 - 5	5 – 0
Cracking	25 - 20	20 -15	15 - 10	10 - 5	5 – 0
Failures	25 - 20	20 -15	15 - 10	10 - 5	5 – 0
TOTAL	100 - 80	80 - 60	60 - 40	40 - 20	20 - 0
PDR Rating (Total/2)	50 to 40	40 to 30	30 to 20	20 to 10	10 to 0

Table 4. 3: Roughness Distress Rating (RDR) criteria (adapted from the World Bank, 2007b)

Distress	Very Good	Good	Fair	Poor	Very Poor
IRI	≤ 4	4 to 6	6 to 8	8 to 10	> 10
Rating	100 to 80	80 to 60	60 to 40	40 - 20	20 - 0
RDR Rating (Total/2)	50 to 40	40 to 30	30 to 20	20 to 10	10 to 0

On a road from Ibidan to Ilorin in Nigeria, the IRI was calculated to be 6 m/km and the physical distress survey highlighted that the road was in a fair state with respect to both longitudinal cracking and potholing with ratings of 12 and 14 respectively, with some bleeding (18 or a rating of Good). The total PDR would be calculated as follows:

$$\begin{aligned} PDR &= [\textstyle\sum \text{distresses}] / 2 \\ &= [\text{Surface deformation} + \text{Surface Defects} + \text{Cracking} + \text{Failures}] / 2 \\ &= [25 + 18 + 12 + 14] / 2 \\ &= 69 / 2 \qquad = 34.5 \end{aligned} \qquad \text{(Equation 4.1)}$$

A road with an IRI of 6 results in a RCR of 60/2 = 30.

$$OCR = RCR + PDR = 34.5 + 30 = 64.5$$

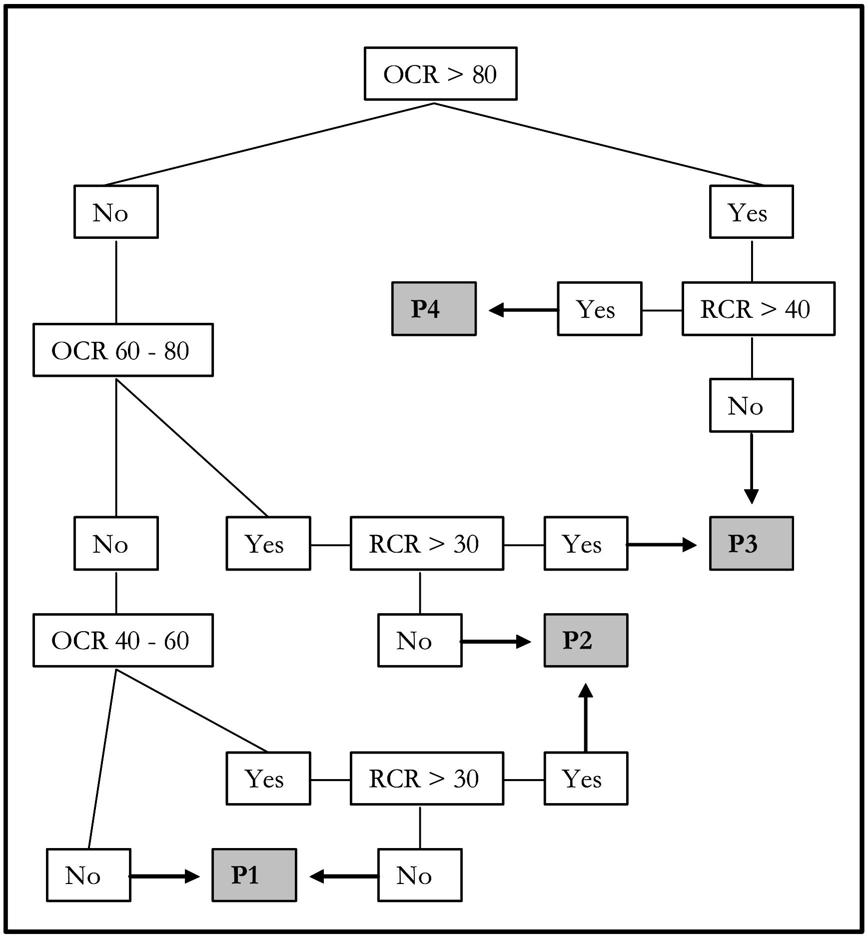


Figure 4. 1: The prioritization process based on Overall Condition Rating (OCR) and Roughness Condition Rating (RCR).

Utilizing the OCR for the Ibidan to Ilorin road, leads us through the flow diagram in Figure 4.1 to the left of the first question: is the OCR greater than 80? The second junction point is whether the OCR is between 60 and 80, which it is. The RCR needs to be considered next, and whether it is greater to or equal to 30, which it is. This leads to a priority of P3.

A road that carries a higher amount of traffic (AADT) or axles loads (ESALs) should be given a higher weighting when calculating the OCR of the road. For this purpose, an adjustment factor should be applied. For federal roads in Nigeria, Oguara and Iriakuma (1987) applied adjustment factors on roads based on three traffic levels for each functional class of road. However, they apportioned more priority through application of their adjustment factors to roads with lower volume and loads, which is contradictory to what should be applied in practice. According to the traffic classification in Section 3.3, a five class designation was used to define traffic loads and volumes on federal roads in Nigeria. The appropriate adjustment factors for each traffic level are presented in Table 4.5. The adjustment factor for the specified traffic class should be applied to the OCR to provide an adjusted OCR.

Table 4. 4: Adjustment factors based on traffic classification to be utilized for priority analysis

Traffic class	Level	Number of vehicles	Adjustment factor
TC1	Low volume	ADT < 700; limited heavy vehicles	1.00
TC2	Moderate with no trucks	ADT 700 to 1500; limited heavy vehicles	0.95
TC3	Moderate trucks	ADT 700 to 1500; heavy vehicles	0.90
TC4	High	ADT 1500 to 2200; heavy vehicles	0.85
TC5	Congested heavy traffic	ADT > 2200; heavy vehicles	0.80

The ability to assess the condition of pavement in a consistent and uniform manner is to the benefit of the pavement management system. As such, a guide for the estimation of pavement condition rating and of associated maintenance and/or rehabilitation strategies is required. The Ontario Ministry of Transportation (MTO, 1989) provides a good means of classifying the condition of a pavement according to the extent of distresses observed or recorded (Table 4.4).

4.3 Cost Model and Life Cycle Cost Analysis

Life-cycle cost analysis (LCCA) is an evaluation technique applicable for the consideration of certain transportation investment decisions. The LCCA approach enables the total cost comparison of competing preservation alternatives. The most meaningful way of comparing combined costs over a life cycle is to calculate the present worth of cost (PWC). In this method, all future costs are discounted to the present worth of costs by using an acceptable discount rate. The rehabilitation option with the lowest expected PWC for a standard level of service should be selected as the most appropriate rehabilitation option. The PWC is calculated using the following formula:

$$PWC = P + \sum A_j (1 + r)^{-j} + S_n (1 + r)^{-n} \qquad \text{(Equation 4.2)}$$

Where:

- PWC = Present worth of costs ($)
- P = Initial rehabilitation costs ($)
- A_j = Relevant costs occurring during the analysis period after j years (present $)
- S_n = Salvage value costs at the end of the analysis period n years later ($)
- n = Analysis period (years)
- r = Discount rate (%/100)

Table 4. 5: A guide to classifying condition rating according to observed or recorded distress (MTO, 1989)

Condition rating – value	Condition rating – description	Recommended intervention
80 – 100	Pavement in excellent condition with few bumps or depressions (slight surface deformation). No surface defects such as streaking, potholes or cracking distresses. Ride is very good (8 – 10).	Routine maintenance
60 – 79	Pavement in good condition with few bumps or depressions (slight to moderate surface deformation). Intermittent slight to moderate surface defects and/or cracking distresses. Ride is good (6 – 8).	Corrective maintenance on an annual basis or sooner when necessary.
40 – 59	Pavement in fair condition with intermittent to frequent bumps or depressions (slight to moderate surface deformation). Intermittent to frequent moderate surface defects and/or cracking distresses. Ride is fair (4 – 6).	Corrective maintenance on a semi-annual basis or as necessary. Possible candidate for holding strategy depending on performance level and history. Candidate for rehabilitation program in 3 to 5 years.
20 - 39	Pavement in poor condition with frequent bumps or depressions (moderate surface deformation). Frequent moderate to severe surface defects and/or cracking distresses. Localized slight to moderate alligator cracking may be present indicating pavement structural failure. Ride is poor (2 – 4).	Corrective maintenance to retard rapid deterioration of serviceability level. Candidate for rehabilitation program in 1 to 3 years.
0 – 19	Pavement in very poor condition with extensive bumps or depressions form moderate to severe surface deformation. Extensive to severe surface defects and/or cracking distresses. Frequent slight to moderate alligator cracking may be present, indicating pavement structural failures. Ride is very poor (0 – 2).	Corrective maintenance when and where necessary to maintain minimal safety and serviceability level. Rehabilitation within 1 year.

The PWC method typically comprises both agency costs and road user costs. Agency costs include the initial rehabilitation costs, maintenance during the life-cycle, future capital costs and the salvage value at the end of the analysis period. Road user costs including delay costs due to rehabilitation activities, vehicle operating costs (VOCs), accident costs and time costs.

The use of the present worth of cost method requires the selection of a suitable discount rate. This rate is dependent on several factors, including the effective rate of borrowing money and the rate of return that money can earn if invested. The World Bank utilizes a 12% discount rate for their RONET program (World Bank, 2008) and Nigerian projects listed in the ROCKS database have also been applied a 12% discount rate. The SATCC (2001) suggests a 3% to 10% discount rate, however given the political, economic and transparency climate in Nigeria a discount rate above 10% is not unrealistic. Therefore, a 12% discount rate in accordance with the World Bank has been applied, in addition to a moderate discount rate of 6% will be applied to the various life-cycle analyses for the various FERMA schedules.

The salvage value, or residual value, is the value of the pavement at the end of the analysis period and is subtracted from the life-cycle cost of the pavement over the analysis period. The salvage value can be determined by using a straight-line depreciation as follows:

$$\text{Salvage value} = [\,1 - A/B\,] * \text{cost of new overlay} \qquad \text{(Equation 4.3)}$$

Where: A = Age of the overlay (years)
B = Expected life of the overlay (years)

Incorporation of road user costs into LCCA is complex, but when information is unavailable, as is the case of Nigeria, the task becomes virtually impossible. Luckily, this cost item can be disregarded in the comparative economic analysis of rehabilitation works for a particular road because it is usually the same for the different options. This is because the various options tend to meet similar design requirements over the same design period (SATCC, 2001).

A summary of the input variables used in LCCA and PWC analyses for the various rehabilitation plans for the various FERMA roads is highlighted in Table 4.6.

4.3.1 Performance Curves

Oguara and Iriakuma (1987) developed performance curves for various maintenance and rehabilitation interventions. The curves, which were slightly convex, did provide an introductory analysis of the rate of deterioration of various interventions in the Nigerian context and their relative costs. The critical overall condition rating score that would trigger a rehabilitation interventions was set at 35, which is similar to hat utilized by the Ontario Ministry of Transportation (MTO, 1989) as outlined in Table 4.4. Application of linear degradation of pavements is not reasonable, as the level of service for a given rehabilitation strategy would be greater earlier in its term and deteriorate more rapidly towards the end of its term based on a load and time domain plot (Fwa, 1990). When time dependent plots are used, the shape varies with an introductory concave phase, a middle linear or transition phase, and a convex shape towards the end of the pavements lifecycle to form an 'S' shaped degradation or performance curve (Fwa, 1990). Given the potential for a myriad of curve types, and based on the work conducted by Oguara and Iraiakuma (1987) that was specific to Nigerian pavements, convex curves were derived for life-cycle costing for this project. For this, curve functions were developed from the Oguara and Iriakuma (1987) study from the performance trends outlined for the various rehabilitation interventions. The functions were utilized to derive performance curves in this study with a rehabilitation trigger value set at 35. As the trigger value is the key component (i.e. rehabilitate when the condition rating reaches 35) the shape of the curve prior to tis point is less of a consequence for this study.

Table 4. 6: Input variables used for PWC and LCCA analyses

Input Variables	
Discount rate	6% and 12%
Cost of cement (CDN$/kg)	0.33
Maximum Dry Density of aggregate base	1800 Kg/m^3
Dosage of cement stabilization	3%
Lane width	3.5 m
Analysis period	20 years

The SATCC (2001) provides lifespan estimates for various MR&R interventions (Section 3.8). For a given intervention, a range of years is provided that represents the time that will pass before the intervention will have to be rehabilitated. The upper data point is representative of quality construction or a road that has lower traffic loading, all things being equal, while the lower limit is representative of a more rapid pavement deterioration as a consequence of less stringent construction control or a higher traffic load over the lifespan of the intervention.

A combination of the work set out in Oguara and Iriakuma, (1987) and SATCC (2001) was used to create performance curves for four rehabilitation interventions (Figure 4.2) that are know to be used in Nigeria (Esenwa, 2008) . These include:

- Chipseal;
- Double Surface Seal;
- Asphalt Concrete – 1 lift; and,
- Asphalt Concrete – 2 lifts.

Each rehabilitation option is composed of three separate performance curves (Figures 4.3 to 4.6). The third curve is representative of drastic pavement deterioration which is indicative of very poor construction practices, or of heavily overloaded pavement. The literature review pointed to several construction-related factors that accounted for the high prevalence of premature pavement failures. These factors included inferior materials being used, poor quality control practices resulting in thinner layers being incorporated into the pavement design, and disregard for the specified pavement design. As a result of these factors, a drastic performance curve was established for each intervention at a point two years less than the minimum performance curve, which is likely more representative of SSA.

Some of the more progressive African nations for example, South Africa have a multitude of MR&R interventions readily available. Conversely, Nigeria does not have interventions over and above those listed above. Additionally, the quality control of the products being produced, such as asphalt concrete (AC), is of such poor quality that recommending further rehabilitation intervention types may result in further pavement problems due to limited experience with these products.

Performance curves were also created using the Oguara and Iriakuma (1987) derived functions for the same series of rehabilitation interventions, but incorporating cement stabilized base-course. Stabilized granular bases with cement are used in Nigeria, and may serve as a cost-effective means of improving both riding quality and pavement longevity. As a result of stabilizing the base at the same time as a rehabilitation intervention, a shift of the performance curve (Figure 4.7) by 10 condition rating points is proposed, in addition to increasing the lifespan by 1-year for the minimum and maximum curve. Improvement in the base over which a wearing course would be overlaid is likely to both improve the condition of the wearing course as well as increase the lifespan of the intervention as a result of a more structurally sound system. An improvement in condition rating was applied for the performance curve. However, no shift in the expected lifespan of the pavement was applied due to poor construction techniques or extreme overloading that would still degrade the rehabilitation intervention irrespective of whether the base was stabilized or not. The base-stabilized performance curves are presented in Figures 4.8 to 4.11.

4.3.2 PWC Calculations

Typical designs in Nigeria according to the Overseas Road Note (ORN) (TRL, 1993) were outlined in Chapter 3. Designs were postulated for both traffic condition (TC) and Nigerian subgrade strength (NSG) and consisted of either a thin wearing course layer (chip seal or double surface seal) or asphalt concrete. It is the upper two layers (base and wearing course) that are those layers which are the major cornerstones of rehabilitation interventions for surfaced flexible pavements.

Performance curves derived for the various rehabilitation interventions were used to produce various strategies over a 20-year rehabilitation life-cycle. A condition rating trigger-value of 35 was utilized to calculate the rehabilitation strategy, which was derived from the work conducted by Oguara and Iriakuma (1987) along with Ontario's Ministry of Transportation (1989), where a condition rating less than 39 is a candidate for near-immediate rehabilitation. Rehabilitation strategies for the various rehabilitation options were carried out for the different traffic classifications and sub-grade types. A summary is provided here, with full rehabilitation life-cycle strategy data presented in Appendix B.

For the lower traffic categories (TC1 and TC2), combinations of chip seal (CS), double seal (DS) and stabilized base (-B) rehabilitation interventions were applied for the 20-year analysis period. Table 4.7 and 4.8 summarize the PWC for the condition rating curves and various intervention costs at a discount rate of 12% and 6%, respectively. The most cost effective option for each condition rating curve and intervention cost is highlighted in light green.

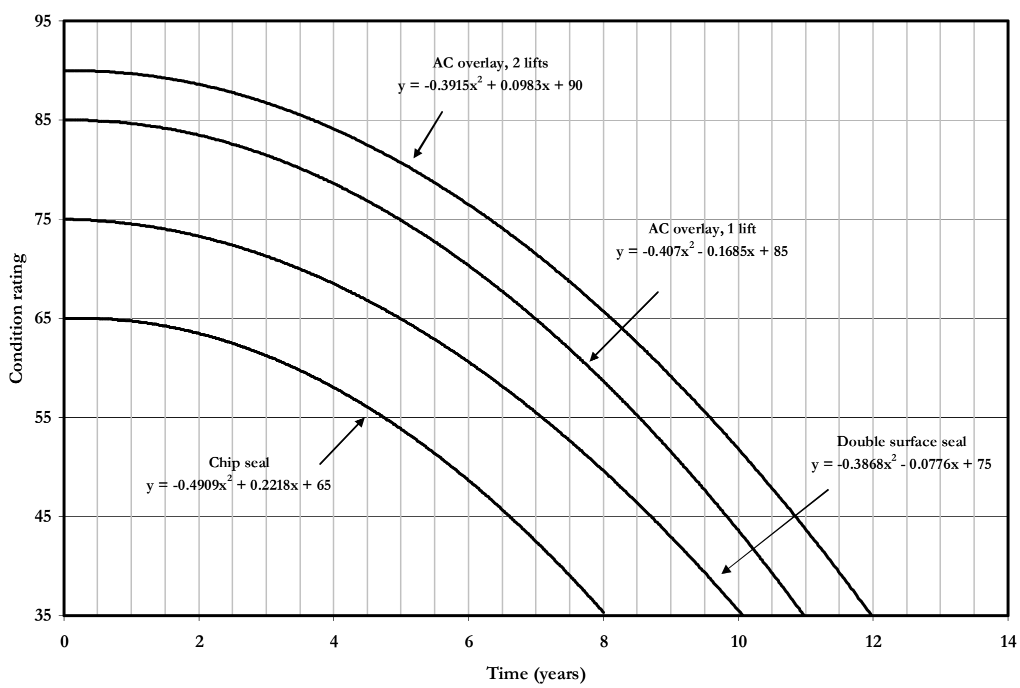


Figure 4. 2: Condition rating curves for maintenance and rehabilitation interventions for flexible pavements in Nigeria (adapted from Oguara and Iriakuma, 1987 and SATCC, 2001).

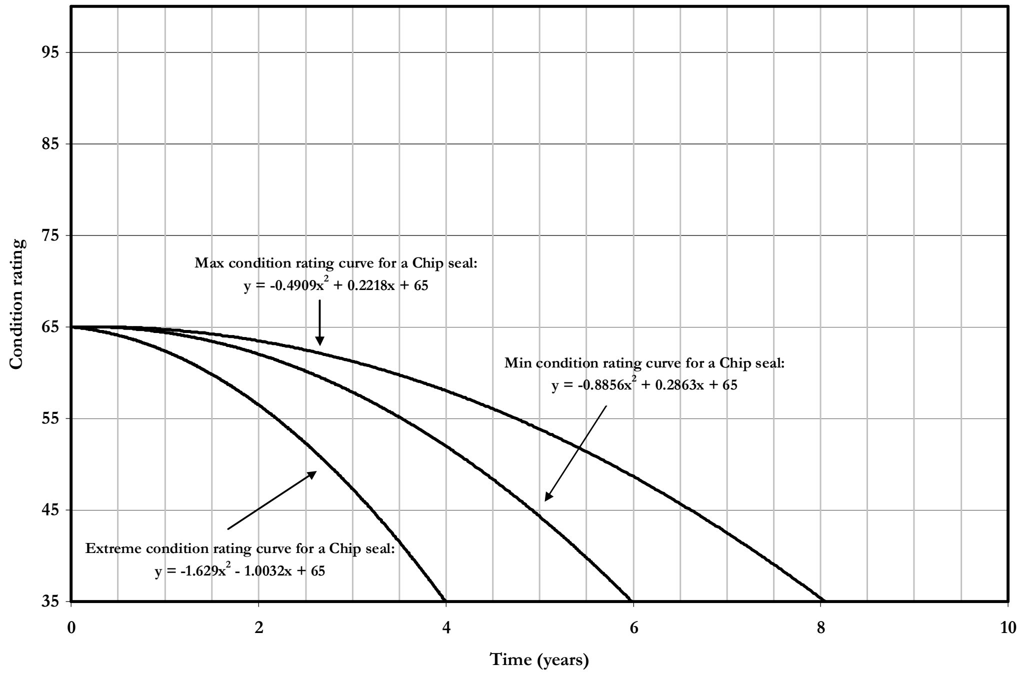


Figure 4. 3: Performance curves for chip seal rehabilitation of federal roads in Nigeria

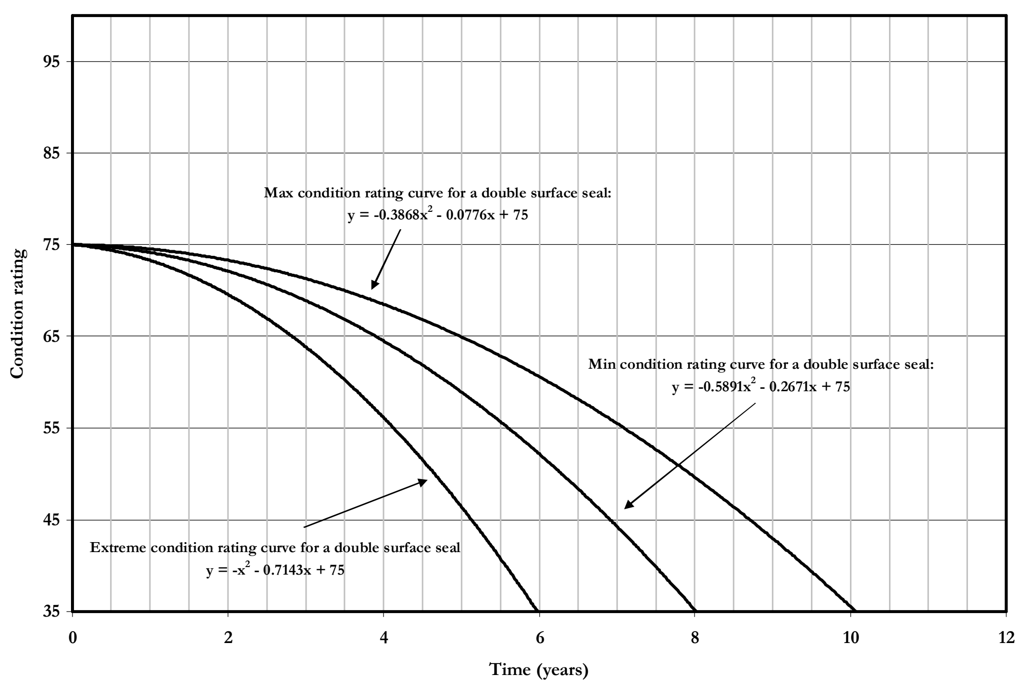


Figure 4. 4: Performance curves for double surface seal rehabilitation of federal roads in Nigeria

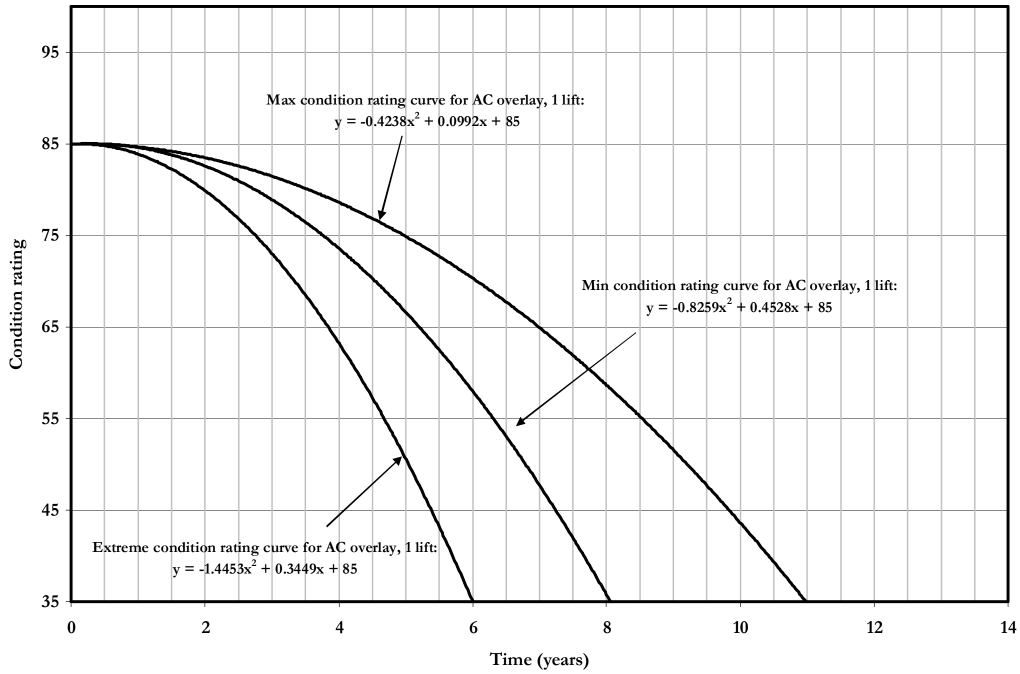


Figure 4. 5: Performance curves for a 1-lift asphalt concrete rehabilitation of federal roads in Nigeria

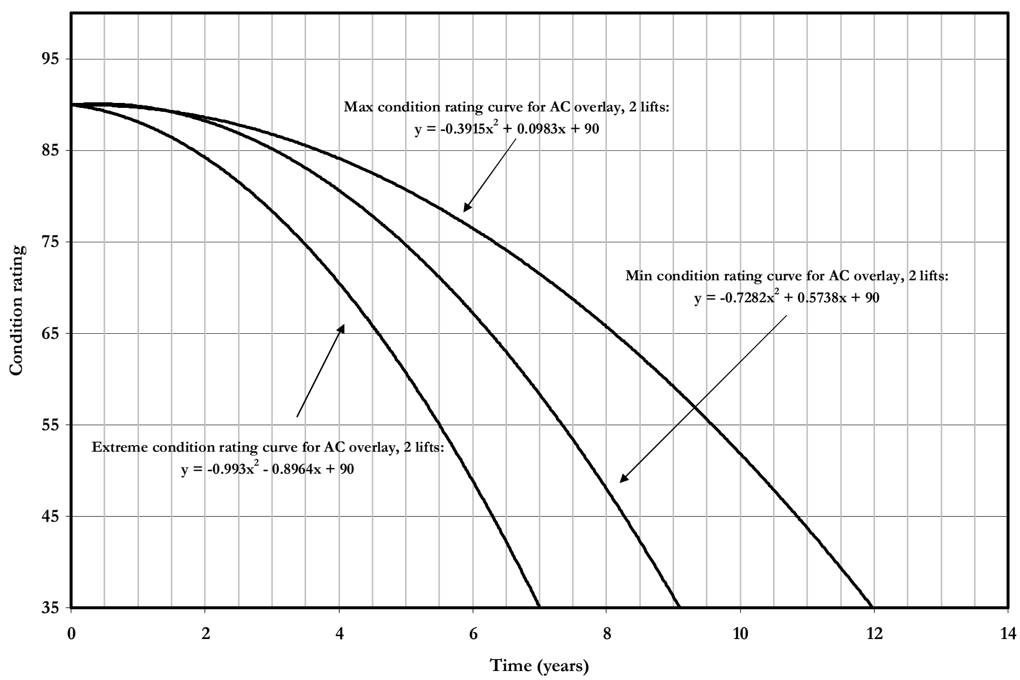


Figure 4. 6: Performance curves for a 2-lift asphalt concrete rehabilitation of federal roads in Nigeria

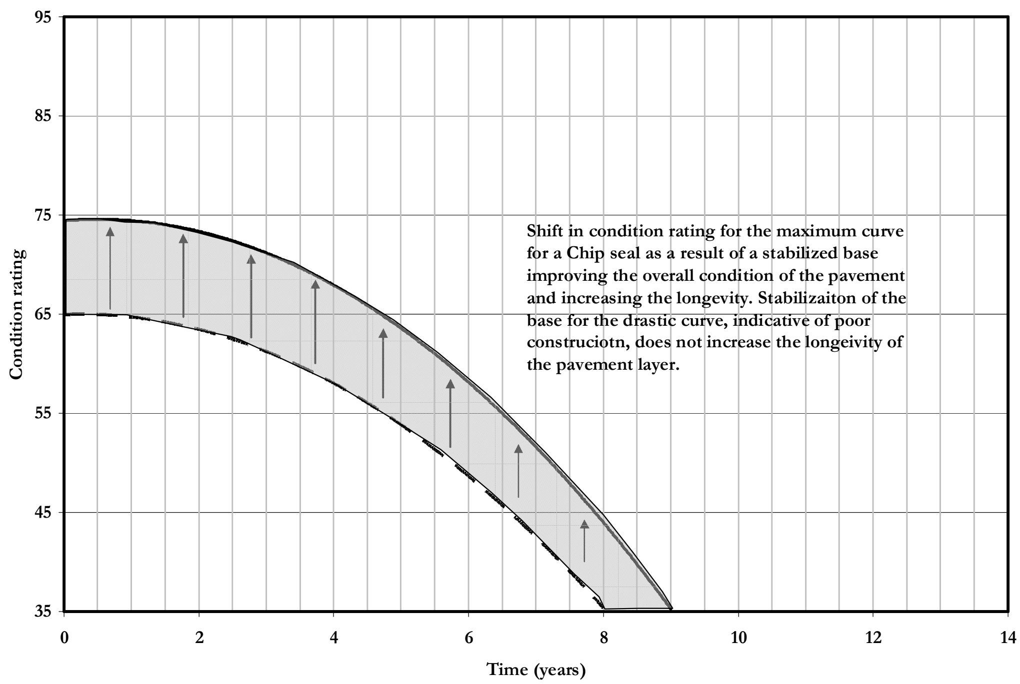


Figure 4. 7: Performance curves for a chip seal with and without a stabilized base. A condition rating shift has been applied to account of the improved overall pavement condition, resulting in an improved longevity of the intervention by 1 year.

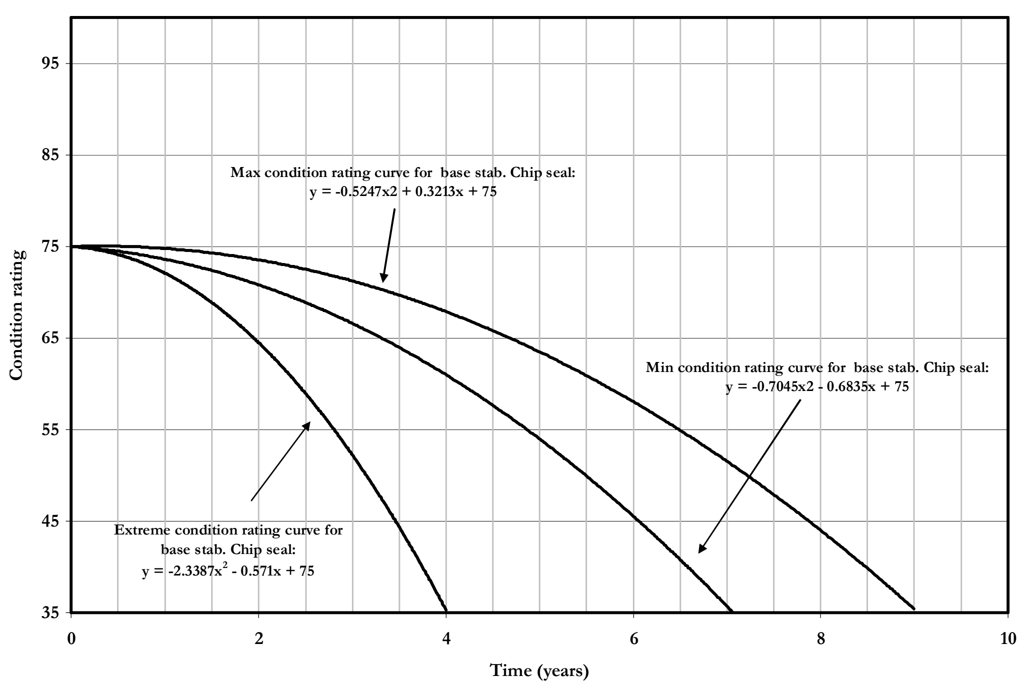


Figure 4. 8: Performance curves for a chip seal with a stabilized base for federal roads in Nigeria

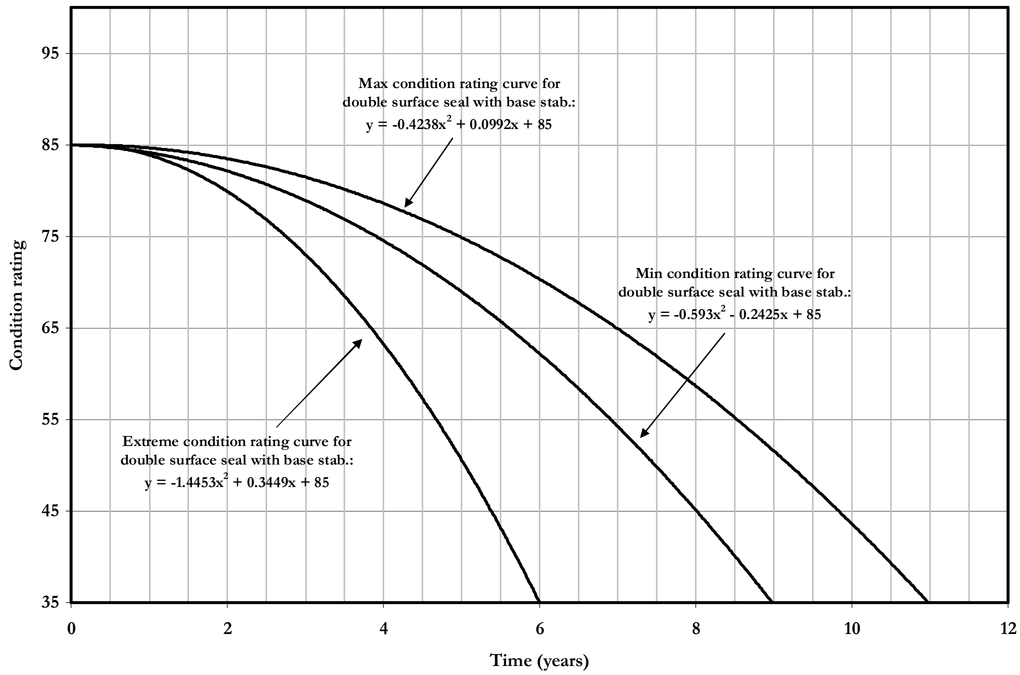


Figure 4. 9: Performance curves for a double surface seal with a stabilized base for federal roads in Nigeria

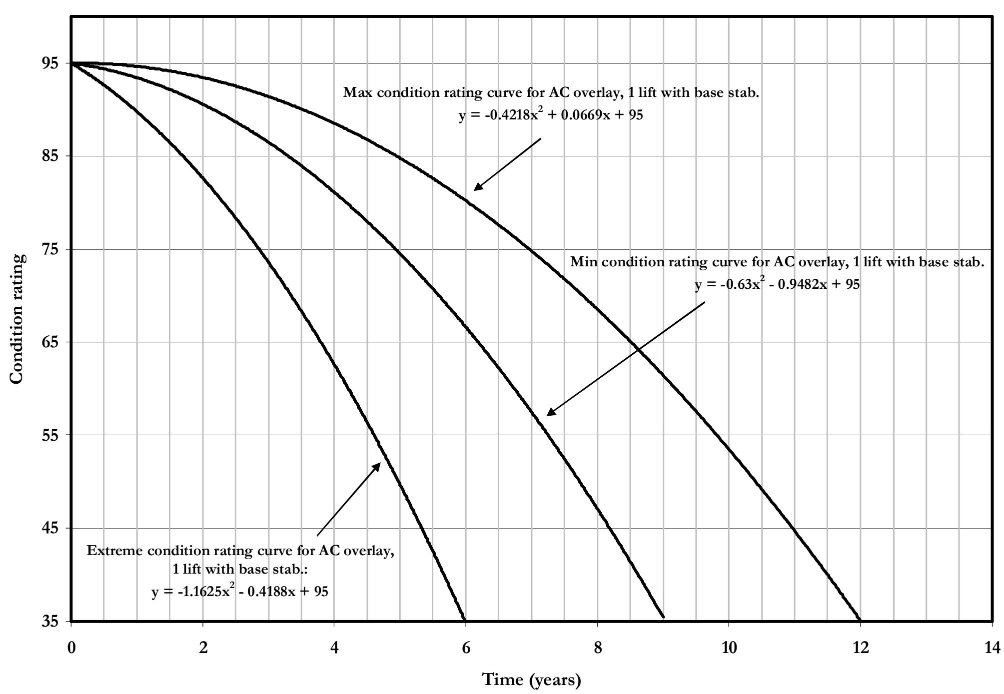


Figure 4. 10: Performance curves for a 1-lift asphalt concrete with a stabilized base for federal roads in Nigeria

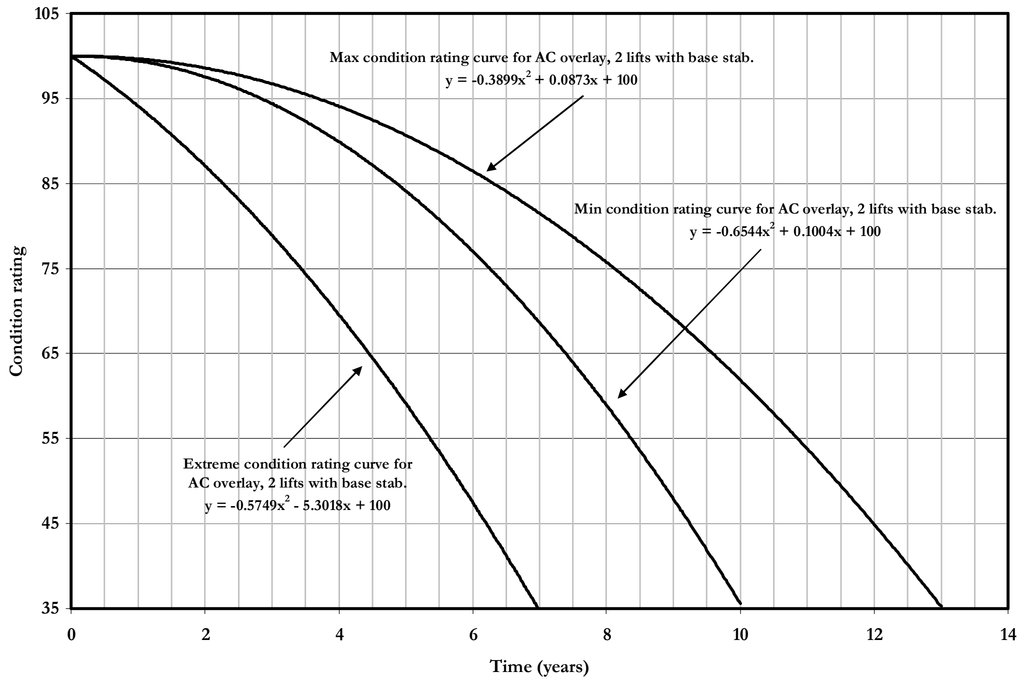


Figure 4. 11: Performance curves for a 1-lift asphalt concrete with a stabilized base for federal roads in Nigeria.

For intermediate traffic volumes and loads (TC3), a combination of thin wearing courses and asphalt concrete is investigated to assess whether upgrading to a higher quality wearing course is desirable from a life-cycle cost standpoint. Costs associated with upgrading to AC from thin wearing courses is more expensive than continuing with the thin surfacing option, irrespective of whether it is a double surface seal or a chip seal. While the AC overlay would likely improve the vehicle operating costs, a thorough assessment by FERMA would need to be made to justify the cost of upgrading the wearing course without strengthening the base as well.

Heavy traffic loads are encountered in the TC4 and TC5 traffic categories, where the latter is more indicative of higher proportions of overloaded trucks. The standard designs for these two traffic categories differ with respect to the underlying base and sub-base layer thicknesses. The AC wearing course is the same standard and thickness and thus the PWC for the two traffic classes can be handled collectively. For this, however, an average base thickness of 238 mm is applied where base stabilization is utilized as part of the life-cycle assessment. Combinations of 1-lift of asphalt concrete (AC-1), 2-lifts of asphalt concrete (AC-2) and stabilized base (designated with a '-B') rehabilitation interventions were applied for the 20-year analysis period. Table 4.9 and 4.10 summarize the PWC for the condition rating curves and various intervention costs at a discount rate of 12% and 6%, respectively. The most cost effective option for each condition rating curve and intervention cost is highlighted and bolded.

Table 4. 7: PWC for Low Volume Nigerian Federal roads at a 12% discount rate

Intervention strategy	Intervention year	PWC		
		MAX Cost	MIN Cost	Africa Cost
Maximum Condition Rating Curve				
CS, CS, CS	1, 8, 16	**44123.31**	**29747.24**	**37030.70**
CS-B, CS, CS	1, 9, 17	50543.00	36109.75	43435.77
DS, CS, CS	1, 10, 18	56310.39	38628.81	41939.52
DS, DS	1, 10	57996.26	39943.14	41413.05
CS-B, DS	1, 9	52076.40	37333.07	42488.39
CS, DS-B	1, 8	49401.31	34357.57	39482.00
Minimum Condition Rating Curve				
CS, CS, CS, CS	1, 6, 12, 18	**48082.35**	**32494.12**	40841.39
CS-B, CS, CS	1, 7, 13	51193.48	36568.34	44107.50
DS, CS, CS	1, 8, 14	56937.54	39072.56	42597.25
CS, CS, DS	1, 6, 12	48913.60	33187.47	**39936.38**
DS-S, CS, CS	1, 9, 15	62700.17	44978.29	48364.19
Drastic Condition Rating Curve				
CS, CS, CS, CS, CS	1, 4, 8, 12, 16	**53217.39**	**36068.67288**	**45857.60**
DS, DS, DS, DS	1, 6, 12, 18	74763.57	51869.64163	52868.80
CS, CS, DS, DS	1, 4, 8, 14	58811.95	40209.86354	47094.10

Where CS = Chipseal, DS = Double Seal, CS-B = CS+stabilized base, DS-B = DS+stabilzied base

Table 4. 8: PWC for Low Volume Nigerian Federal roads at a 6% discount rate

Intervention strategy	Intervention year	PWC		
		MAX Cost	MIN Cost	Africa Cost
Maximum Condition Rating Curve				
CS, CS, CS	1, 8, 16	61468.82	41372.81	51158.12
CS-B, CS, CS	1, 9, 17	67252.06	47293.31	56947.84
DS, CS, CS	1, 10, 18	73685.33	50274.82	56095.39
DS, DS	1, 10	**57996.26**	**39943.14**	**41413.05**
CS-B, DS	1, 9	69995.93	49454.50	55584.81
CS, DS-B	1, 8	68527.99	47740.01	53844.97
Minimum Condition Rating Curve				
CS, CS, CS, CS	1, 6, 12, 18	**67683.94**	**45686.58**	57150.10
CS-B, CS, CS	1, 7, 13	68217.64	47970.74	57924.22
DS, CS, CS	1, 8, 14	74361.86	50752.87	56800.87
CS, CS, DS	1, 6, 12	69234.16	46980.24	**55292.51**
DS-S, CS, CS	1, 9, 15	80175.67	56694.13	62617.28
Drastic Condition Rating Curve				
CS, CS, CS, CS, CS	1, 4, 8, 12, 16	**74933.24**	**50729.51**	**64210.49**
DS, DS, DS, DS	1, 6, 12, 18	101870.83	70532.27	72234.23
CS, CS, DS, DS	1, 4, 8, 14	83996.80	57473.78	65638.41

Where CS = Chipseal, DS = Double Seal, CS-B = CS+stabilized base, DS-B = DS+stabilzied base

Table 4. 9: PWC for high traffic federal roads in Nigeria at a 12% discount rate

Intervention strategy	Intervention year	PWC		
		MAX Cost	MIN Cost	Africa Cost
Maximum Condition Rating Curve				
AC-1, AC-1	1, 11	**94537.84**	**54124.43**	**70557.84**
AC-1, AC-2	1, 11	101081.12	61027.44	75702.46
AC-2, AC-1	1, 12	105943.57	69974.03	79838.80
AC-1-B, AC-1	1, 12	102804.07	62896.53	79103.30
Minimum Condition Rating Curve				
AC-1, AC-1, AC-1	1, 8, 16	**110989.42**	**63001.41**	**82796.87**
AC-2, AC-2, AC-2	1, 9, 18	132039.28	90167.56	99754.20
AC-1-B,AC-1, AC-1	1, 9, 17	117884.57	71036.06	90322.50
AC-2-B, AC-2	1, 10	121171.93	85606.64	93818.60
Drastic Condition Rating Curve				
AC-1, AC-1, AC-1, AC-1	1, 6, 12, 18	129019.84	72723.24	96209.96
AC-2, AC-2, AC-2	1, 7, 14	136125.14	92986.37	102844.50
AC-1, AC-1, AC-2	1, 6, 12	**121594.75**	**71186.27**	**90888.98**

Where AC-1 = asphalt concrete 1 lift, AC-2 = AC 2 lifts, -B indicates a stabilized base

Table 4. 10: PWC results for high traffic federal roads in Nigeria at a 6% discount rate

Intervention strategy	Intervention year	PWC		
		MAX Cost	MIN Cost	Africa Cost
Maximum Condition Rating Curve				
AC-1, AC-1	1, 11	**119403.38**	**69023.59**	**89164.48**
AC-1, AC-2	1, 11	126701.02	78319.84	95033.31
AC-2, AC-1	1, 12	130860.52	84900.89	98483.68
AC-1-B, AC-1	1, 12	127721.02	77823.39	97748.18
Minimum Condition Rating Curve				
AC-1, AC-1, AC-1	1, 8, 16	**147089.63**	**83954.16**	**109760.85**
AC-2, AC-2, AC-2	1, 9, 18	169837.38	115844.64	128293.86
AC-1-B,AC-1, AC-1	1, 9, 17	154139.36	92072.10	117401.47
AC-2-B, AC-2	1, 10	148840.36	104309.45	114698.50
Drastic Condition Rating Curve				
AC-1, AC-1, AC-1, AC-1	1, 6, 12, 18	175838.45	99451.39	131147.23
AC-2, AC-2, AC-2	1, 7, 14	176069.81	120141.37	133007.34
AC-1, AC-1, AC-2	1, 6, 12	**159890.18**	**95652.80**	**119677.25**

Where AC-1 = asphalt concrete 1 lift, AC-2 = AC 2 lifts, -B indicates a stabilized base

4.4 Discussion of Results

Both FERMA (2007) and Oke (2007) outline that an approximate CDN690 million will be required per annum over the next 5 years (total of CDN6.9 billion) to improve the federal road network to a better state. Yet, little explanation for where this figure comes from or the state in which the investments aims to improve the roads is made. The World Bank's RONET program, which is used as a tool to estimate the budget required over a life-cycle to improve the condition of a road network, provides for a different interpretation of the monetary requirement.

The RONET derived figure, which used country specific data, was approximately CDN4.7 billion over a 5-year period for 34,000 km of roads contained under FERMA's umbrella. The difference between the RONET data and that which is highlighted in the literature provides for an understanding of the great deal of uncertainty that surrounds the enormous task of upgrading the federal roads in Nigeria to those which are of an acceptable level for health, economic and social prosperity. It underlines, however, the gross inefficiencies of the current rehabilitation program and what can be achieved once these barriers have been broken.

The discrepancy in budget stems from the uncertainty associated with the overall condition of the federal roads in Nigeria, the costs of materials that will be required for maintenance and rehabilitation interventions and the costs associated with undertaking the interventions. The budget also assumes that the proper interventions will be applied at the appropriate time according to a pavement management strategy. Given historical perspective, it is likely that the budget required to undertake FERMA's lofty goals should be somewhere between the FERMA and RONET derived budgets, with a potential for the actual expenditure to be much higher than the two budget values if history has taught us anything.

Irrespective of the budget size, the fact that the task at hand is a formidable one points to the urgency for a maintenance and rehabilitation strategy that will maximize Nigeria's investment. Nigeria has embarked upon pavement management at the federal road network level as a means of improving the overall condition of their most important national asset. For this, a pavement management strategy is required to start this journey, one that will allow them to implement applicable rehabilitation interventions options at the right time to optimize expenses and stabilize road infrastructure budgets. To do this, the PWC analyses have been undertaken for various traffic classes, rehabilitation interventions, condition rating curves and discount rates.

4.4.1 Low Traffic Volume Roads

Low traffic volume roads (TC1 and TC2) are constructed with a chip seal or double surface seal. For a 12% discount rate, which is not uncommon for sub-Saharan African nations, shows no change in optimum strategy for both the maximum intervention cost and minimum intervention cost. All curves and costs, other than the mean Africa cost, highlight that a chip seal-specific strategy (CS, CS, CS) over the 20-year analysis period is optimal in all cases. Utilizing the mean Africa cost-data alters the optimal maintenance and rehabilitation strategy from chip seal specific to a CS-CS-DS strategy for the minimum condition rating curve only (Figure 4.2). The drastic curve, which is likely the most indicative of Nigeria's state at the present time, does not alter the optimum MR&R strategy.

Application of a more reasonable discount rate of 6% does not alter the optimum rehabilitation strategy under all conditions. The PWC is much greater for all cases, which would be expected given the lower discount rate, and underlies the importance of identifying the most appropriate discount rate to apply to economic analyses. A more refined discount rate will assist in better budgeting as well, as the price life cycle cost for higher discount rates is much greater than for a more reasonable rate. Further underlying the need for more refined input data is the intervention cost to apply, as there is a significant cost fluctuation when varying costs are applied. All of the costs applied are representative of the region and can occur throughout Nigeria. It is quite likely that the prices will vary depending on the region within Nigeria, accessibility to a source of material, in addition to price fluctuations due to black-market trading.

While the optimum strategy does not change between a 12% and 6% discount rate, the ranking of strategies for each data set does vary for the maximum and minimum condition rating curves (Table 4.11). Application of the drastic condition rating curve does not alter the ranking of intervention strategies under all cost functions.

Incorporation of cement stabilization into the rehabilitation strategies does not affect the optimum strategy. The increased cost associated with stabilizing the base with cement, coupled with the relatively small increase in pavement longevity associated with the intervention, is cost prohibitive in the scenarios analyzed. The relatively high cost of cement in Nigeria compared with the global price is likely a key factor in the higher relative PWC when base stabilization is incorporated into the rehabilitation strategy. An assumption of improved pavement performance of 1-year needs validation and may also be a contributing factor of the results achieved. Analysis of additional stabilization technologies, (both traditional and non-traditional) may serve as a means to improve both pavement performance and longevity.

4.4.2 High Traffic Volume Roads

High traffic volume roads are constructed with a single classification of asphalt concrete. This reliance on one property of AC over the entire country of such vast climatic and varying traffic loads is problematic. Asphalt thickness, not characteristic, is what changes in Nigeria where a more durable wearing course is needed, such as highly trafficked roads or intersections where surface temperatures are much higher. Improving the properties and availability of different types of asphalt concrete will go a long way to improving the most important trunk roads contained in Nigeria, rather than trying to optimize the performance of the type of asphalt concrete they currently endorse.

Table 4.11: Rank of rehabilitation strategy according to PWC for low volume federal roads

Rank	Maximum Intervention Cost		Minimum Intervention Cost		Average African Cost	
	12%	6%	12%	6%	12%	6%
	Maximum Condition Rating Curve					
1	CS, CS, CS	DS, DS	CS, CS, CS	DS, DS	CS, CS, CS	DS, DS
2	CS, DS-B	CS, CS, CS	CS, DS-B	CS, CS, CS	CS, DS-B	CS, CS, CS
3	CS-B, CS, CS	CS-B, CS, CS	CS-B, CS, CS	CS-B, CS, CS	DS, DS	CS, DS-B
	Minimum Condition Rating Curve					
1	CS, CS, CS, CS	CS, CS, CS, CS	CS, CS, CS, CS	CS, CS, CS, CS	CS, CS, DS	CS, CS, DS
2	CS, CS, DS	CS-B, CS, CS	CS, CS, DS	CS, CS, DS	CS, CS, CS, CS	DS, CS, CS
3	CS-B, CS, CS	CS, CS, DS	CS-B, CS, CS	CS-B, CS, CS	DS, CS, CS	CS, CS, CS, CS
	Drastic Condition Rating Curve					
1	CS, CS, CS, CS, CS	CS, CS, CS, CS, CS	CS, CS, CS, CS, CS	CS, CS, CS, CS, CS	CS, CS, CS, CS, CS	CS, CS, CS, CS, CS
2	CS, CS, DS, DS	CS, CS, DS, DS	CS, CS, DS, DS	CS, CS, DS, DS	CS, CS, DS, DS	CS, CS, DS, DS
3	DS, DS, DS, DS	DS, DS, DS, DS	DS, DS, DS, DS	DS, DS, DS, DS	DS, DS, DS, DS	DS, DS, DS, DS

Where CS = Chipseal, DS = Double Seal, CS-B = CS+stabilized base, DS-B = DS+stabilzied base

The optimum rehabilitation strategy for high traffic volume roads (TC4 and TC5) over a 20-year period with a 12% discount rate is the same for both the maximum and minimum condition rating curves and all intervention costs. In these cases, 1-lift of asphalt concrete over the 20-year analysis period is optimum. There is considerable price variation between the minimum and maximum costs applied for the interventions, which echoes the need to obtain more precise costing for asphalt concrete over all climatic regions of Nigeria. The drastic curve, which is likely the most indicative of the Nigerian federal road network at this time, especially for the heavily loaded roads (TC5), requires the same optimum rehabilitation strategy for all intervention costs. For the drastic curve, a combination of 1-lift and 2-lifts of asphalt concrete (AC-1, AC-1, AC-2) over the analysis period was determined to be optimum.

Utilization of a 6% discount rate does not change the optimum maintenance strategy for all condition rating curves or intervention costs. It is probable, however, that through refinement or improvement in the properties and availability of different asphalt concrete classifications throughout the country that the discount rate will have a greater impact on the PWC.

The ranking of rehabilitation options for highly trafficked Nigerian federal roads is presented in Table 4.12. The optimum rehabilitation strategy does not change when the different discount rate is applied for all condition rating curves and intervention costs. There is almost no change in ranking moving from a 12% discount rate to a 6% discount rate for all cases analyzed, with only swapping of the secondary and tertiary strategies in some cases. This is the converse to what was found for low volume federal roads when a lower discount rate is applied. For highly trafficked roads, the application of a more moderate discount rate does not affect the optimum rehabilitation strategy. It is likely that the price of AC will be a more sensitive cost factor when determining the PWC.

Incorporation of base stabilization into the suite of rehabilitation interventions for highly trafficked roads does little to influence the optimum strategy. The cost of base stabilization when considering AC overlays is a much smaller fraction of the rehabilitation costs than the same intervention applied to a low volume road with a thin wearing course. Yet, the increase in condition rating and pavement longevity does not produce an adequate benefit over the pavement lifecycle to justify the cost. Validation of the benefit that stabilization has, in addition to other stabilization products over an above cement, should be conducted as it is a common technique used throughout North America and other sub-Saharan African nations.

Application of an accurate discount rate and intervention cost underlies the critical importance in determining a PWC that is budgetable. Improvement in intervention cost accuracy and discount rate forecasting will improve the condition of the federal road network as a consequence of a refined maintenance and rehabilitation strategy. However, it will also enable Nigeria to design better roads from the outset. These two factors are critical to improved pavement network condition and better fiscal management.

4.5 Summary

This chapter assessed the financial requirements that FERMA will need to budget for to improve the federal road network in Nigeria. The RONET determined cost is much higher than the literature quoted figures, underlying the need to further refine the analysis. The result does, at the very least, provide a long term budget forecast that FERMA can utilize to apply the optimum strategies that were determined for the various federal road classifications. It was found that the condition rating curve and discount rate influences the optimum rehabilitation strategy for low volume (TC1 and TC2) federal roads. Conversely, neither the condition rating curve nor the discount rate influences the optimum strategy for highly trafficked and loaded roads. Stabilization in all cases does not impart a great influence on the optimum strategy for all roads. While the inputs used in the PWC analyses requires validation, the results obtained are extremely valuable for FERMA, as this will enable them to streamline their rehabilitation efforts and save money in the long term.

Table 4.12: Rank of rehabilitation strategy according to PWC for high traffic federal roads

Rank	Max Cost		MIN Cost		Africa Cost	
	12%	6%	12%	6%	12%	6%
	Maximum Condition Rating Curve					
1	AC-1, AC-1	AC-1, AC-1	AC-1, AC-1	AC-1, AC-1	AC-1, AC-1	AC-1, AC-1
2	AC-1, AC-2	AC-1, AC-2	AC-1, AC-2	AC-1-B, AC-1	AC-1, AC-2	AC-1-B, AC-1
3	AC-1-B, AC-1	AC-1-B, AC-1	AC-1-B, AC-1	AC-1, AC-2	AC-1-B, AC-1	AC-1, AC-2
	Minimum Condition Rating Curve					
1	AC-1, AC-1, AC-1	AC-1, AC-1, AC-1	AC-1, AC-1, AC-1	AC-1, AC-1, AC-1	AC-1, AC-1, AC-1	AC-1, AC-1, AC-1
2	AC-1-B, AC-1, AC-1	AC-2-B, AC-2	AC-1-B, AC-1, AC-1	AC-1-B, AC-1, AC-1	AC-1-B, AC-1, AC-1	AC-2-B, AC-2
3	AC-2-B, AC-2	AC-1-B, AC-1, AC-1	AC-2-B, AC-2	AC-2-B, AC-2	AC-2-B, AC-2	AC-1-B, AC-1, AC-1
	Drastic Condition Rating Curve					
1	AC-1, AC-1, AC-2	AC-1, AC-1, AC-2	AC-1, AC-1, AC-2	AC-1, AC-1, AC-2	AC-1, AC-1, AC-2	AC-1, AC-1, AC-2
2	AC-1, AC-1, AC-1, AC-1	AC-1, AC-1, AC-1, AC-1	AC-1, AC-1, AC-1, AC-1	AC-1, AC-1, AC-1, AC-1	AC-1, AC-1, AC-1, AC-1	AC-1, AC-1, AC-1, AC-1
3	AC-2, AC-2, AC-2	AC-2, AC-2, AC-2	AC-2, AC-2, AC-2	AC-2, AC-2, AC-2	AC-2, AC-2, AC-2	AC-2, AC-2, AC-2

Where AC-1 = asphalt concrete 1 lift, AC-2 = AC 2 lifts, -B indicates a stabilized base

CHPATER 5: CONCLUSIONS AND RECOMMENDATIONS

The state of the federal roads in Nigeria can be greatly improved through pavement design and management tools. Roads have been constructed, as is the case for sub-Saharan Africa in general, with little consequence of the maintenance and rehabilitation that is required to maintain the asset. Further, the roads that are in use today were constructed decades ago and have long outlived their design life. Nigeria has realized this and has responded to the need for better federal roads through the formation of FERMA, who have a mandate to improve the federal road system through the use of pavement management and appropriate MR&R interventions. The work presented in this thesis is the starting point in FERMA's journey to create a pavement management strategy.

5.1 Conclusions

The federal road network in Nigeria is comprised of approximately 32,100 km of surfaced flexible pavement structures. The state of these roads is questionable given available data on network pavement condition, although FERMA does indicate that 15% of the roads are in 'Very Good' condition and 20% are in 'Good' condition. A network assessment of the true condition of the federal roads would be a valuable tool in better streamlining the rehabilitation interventions required to improve the network.

A RONET analysis utilizing World Bank data for Nigeria was conducted. The investment required over the next ten years was found to be considerably less than that of the requirement that is quoted in the literature. It is interesting to note that the literature values are not supported with any data or explanation, so their magnitude is questionable. Certainly, the budget requirement outlined by the RONET analysis does, at the very least, provide FERMA with a starting point with which to budget towards. Once better data on the distribution of condition rating for the network is determined, along with more accurate rehabilitation intervention costs, a more refined budget can be determined.

Five different traffic classifications were outlined for the federal roads in Nigeria. Essentially, they can be divided into two groups according to the level of traffic and type of wearing course. The low volume federal roads (ADT < 1500) which are surfaces with a thin bituminous wearing course applied as a single seal or double surface seal. On the other side of the spectrum we have more loaded roads with high traffic volume and/or a high percentage of heavy trucks (ADT < 1500) and are surfaced with either 1-lift or 2-lifts of AC. A clear need exists for Nigeria to expand upon the types and designations of AC it uses, as a 'one size fits all' classification of binder and asphalt is not logical over a country with such vast climatic and traffic variations. Focussing on more appropriate flexible pavement wearing courses that are applied with a greater level of quality control will go a long way to improving both the longevity of the surface and produce a network with a better overall pavement condition.

Condition rating curves were created for the various rehabilitation interventions for typical designs utilized for federal roads in Nigeria. Drastic condition rating curves were created to better reflect the present state and rate of degradation of rehabilitation interventions. Other than increasing the life-cycle cost of the pavement, the application of the drastic curve for the ranges of intervention costs did not alter the optimum rehabilitation strategy. For low volume federal roads, utilization of a 6% discount rate instead of the 12% discount rate which is applied by the World Bank for many SSA nations, altered the optimum rehabilitation strategy for the maximum condition rating curve only from a single chip seal specific rehabilitation schedule to one incorporating a double seal specific rehabilitation strategy. For all other cases, a single chip seal was more cost effective than application of a double seal over the 20-year analysis period.

For high volume or loaded roads, 1-lift of AC is more cost effective then application of two-lifts. This held true under all condition rating curves, intervention costs and discount rates.

Utilization of a cement stabilized base as part of the rehabilitation intervention had no influence on the optimum rehabilitation strategy. While this was expected for the lower traffic federal roads where the cost of stabilizing the base was disproportionately high when compared to the cost of applying the surface seal, it was not expected for the higher traffic roads. An improvement factor of 10 condition rating points and a 1-year increase in the pavement performance was apportioned to a stabilized base. It is possible that this is an underestimation and a more refined analysis would prove that stabilization would have a higher influence on the optimum rehabilitation strategy. PWC analyses should be applied for different stabilizers.

The work conducted in this thesis provides a good basis for FERMA to dramatically the condition of Nigeria's federal road network. While assumptions have been made, out of necessity, the information obtained through the PWC analyses is immediately implementable and outlines the value of this work.

5.2 Recommendations

The use of assumptions in the analyses in this document is an unfortunate reality when dealing with federal road networks in the developing world. This certainly proved to be the case for Nigeria, however the difference is that they have shown commitment to improve on their federal road network through FERMA, but also by instituting a pavement management strategy to preserve their most important national asset.

Every effort has been made to utilize the most accurate and representative data. What is required now is validation of the results that were achieved and this would provide an excellent starting point for further research. More refined cost data and condition rating of the federal road network would be an invaluable tool in validating the findings of the optimum rehabilitation strategies outlined in this thesis. Once more data becomes available the life-cycle costs can be fine-tuned and refined to better reflect the federal system, but also at regional levels where material and climatic differences may predominate.

Application of a more reasonable discount rate of 6% does not alter the optimum rehabilitation strategy under all conditions. The PWC is much greater for all cases, which would be expected given the lower discount rate, and underlies the importance of identifying the most appropriate discount rate to apply to economic analyses. A more refined discount rate will assist in better budgeting as well, as the price life cycle cost for higher discount rates is much greater than for a more reasonable rate. Further underlying the need for more refined input data is the intervention cost to apply, as there is a significant cost fluctuation when varying costs are applied.

Application of an accurate discount rate and intervention cost underlies the critical importance in determining a PWC that is budgetable. Improvement in intervention cost accuracy and discount rate forecasting will assist Nigeria through improved condition of their federal roads as a consequence of a refined maintenance and rehabilitation strategy. However, it will also enable Nigeria to design better roads from the outset. These two factors are critical to improved pavement network condition and better fiscal management.

There is considerable price variation between the minimum and maximum costs applied for the interventions, which echoes the need to obtain more precise costing for asphalt concrete over all climatic regions of Nigeria.

Validation of the benefit that stabilization has, in addition to other stabilization products over an above cement, should be conducted as it is a common technique used throughout North America and other sub-Saharan African nations.

Lastly, validation of the condition rating curves is essential, as slight differences in pavement longevity will have impacts on the PWC and resultant optimum strategy to be applied.

REFERENCES

American Association of State Highway Officials (1962). The AASHO Road Test, Highway Research Board of the NAS-NRC Division of Engineering and Industrial Research, Report 5, Special Report 61E, Washington D. C., USA.

Abam, T. K. S., Ofoegbu, C. O., Osadebe, C. C. and Gobo, A. E., 2000. Impact of hydrology on the Port-Harcourt – Patani-Warri Road. Environmental Geology, Vol. 40, pp. 153-162.

Adeyemi, G. O., 1992. Highway geotechnical properties of laterised residual soils in the Ajebo-Ishara geological transition zone of south western Nigeria. Ph.D Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria.

Adeyemi, G. O. and Oyeyemi, F., 1998. Geotechncial basis for failure of sections of the Lagos-Ibadan expressway, south western Nigeria. Bulletin of Engineering Geology and the Environment, Vol. 39-45, pp. 39-45.

AfDB, 2003. Review of the Implementation Status of the Trans African Highways and the Missing Links, Volume 1: Main Report, 58p.

AfDB, 2005. Federal Republic of Nigeria Country Strategy Paper: 2005-2009, Country Operations Department, West Region, Tunis, Tunisia, 71p.

AfDB Working Group, 2006. Building Africa's Development Banks: Six recommendations for the AfDB and it Shareholders. Working Group Report, Center for Global Development, 27p.

AfDB, 2007. Federal Roads Development Project, Report No. AB2099: Appraisal Stage. African Development Bank, 9p.

Ajayi, L. A., 1982. Proposal for engineering classification of Nigerian soils. Proceedings: 1st National Conference of the Nigerian Geotechnical Association, Lagos, Nigeria.

Akinbami, J. F. K. and Fadare, S. O., 1997. Strategies for Sustainable Urban and Transport Development in Nigeria. Transport Policy, Vol. 4, No. 4, pp. 237-245.

Akinyemi, E. O., 1983. Towards a developed national transportation system in Nigeria: technological challenges and mechanisms for progress. In, Ibiejugba, J. and Adeniyi, J. (eds.) Technological Developments and Nigerian Industries, vol. 1, pp. 190-210.

Akinyemi, E. O. 1998. Sustainable urban transport: Current problems and future challenges for engineers in Africa. Proceedings of the International Conference CODATU VIII, Cape Town, South Africa, pp. 769-773.

Akinyemi, E. O. 2001. Four Decades of Transport in Africa. In, World Transport Policy and Practice, Earthscan Publications, ISBN 1853838519, pp. 29-43

Akpokodje, E. G., 1986. The geotehcncial properties of lateritic and non-lateritic soils of southeastern Nigeria and their evaluation for road construction. Bulletin of the International Association of Engineering Geology, Paris, No. 33, pp. 115-121.

Amjadi, A. and Yeats, A. J., 1995. Non-tariff barriers facing Africa: What did the Uruguay round accomplish and what remains to be done? World Bank policy Research paper no. 1439, World Bank, Washington, D.C.

Archando-Callao, R., 2008. World Bank, Personal Communication, October 16, 2008.

Arumala, J. O. and Akpokodje, E. G., 1987. Soil Properties and Pavement Performance in the Niger Delta. Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 20, pp. 287-296.

Ayangade, J. A., 1992. Some geotechnical properties of two highway subgrade soils along Gbongan-Osogbo road, southern Nigeria. Thesis, Obafemi Awolowo Univeristy, Ile-Ife, Nigeria.

Bennett, C.R., Chamorro, A., Chen, C. de Solminihac, H. and Flintsch, G. (2007). Data Collection Technologies for Road Management. Report to the World Bank. Available for download from www.lpcb.org.

Buys, P., Deichmann, U., and Wheeler, D., 2006. Road Network Upgrading and Overland Trade Expansion in Sub-Saharan Africa, Development Research Group, World Bank, Washington, D.C., 58p.

Central Bank of Nigeria, 2003. Highway Maintenance in Nigeria: Lessons from Other Countries. Research Department Occasional Paper Series, Central Bank of Nigeria, Abuja, Nigeria.

Central Intelligence Agency, 1989. Map #504600, Nigeria, NTIS Number: PB-89-928013.

Central Intelligence Agency, 2008. The World Fact Book: Nigeria. Retrieved September 11th, 2008, from https: cia.gov/library/publications/the-worl-factbook/geos/ni.html

Chukweze, H., 1988. Pavement failures caused by soil erosion. Proceedings: 2nd international Conference on Case Histories in Geotechnical Engineering. St. Louis, Missouri, Paper No. 5.00, pp. 936-9.

Esenwa, M., 2008. Asphalt Concrete Pavement: Training Note and Guide. Canada-Nigeria Innovative Partnership for better Roads, April, 2008.

Federal Ministry of Works and Housing, Highways Division, 1970. General Specifications Vol. II (Roads and Bridges). Lagos, Nigeria.

FERMA, 2007. Medium Term Strategy for Road Sector Maintenance Management: The Nigeria Solution, Nigeria, 34p.

Filani, M. O., 1993. Transport and Rural Development in Nigeria. Journal of Transport Geography, Vol. 1, No. 4, pp. 248-254.

Fwa, T. F., 1990. Shape Characteristics of Pavement Performance Curves. Journal of Transportation Engineering, Vol. 116, No. 5, pp. 692-697.

Gwilliam, K. M. and Shalizi, Z,. M., 1996. Road Funds, User Charges and Taxes. TWU Papers, Transport Division, World Bank, Washington, D.C., 16p.

Haas, R., 2001. Reinventing the (Pavement Management) Wheel. Distinguished lecture presented at the Fifth International Conference on Managing Pavements, Seattle, Washington, 47p.

Haas, R., Hudson, W. R., and Zaniewski, J., 1994. Modern Pavement Management, 2nd ed., Krieger Publishing Company, Malabar, Florida.

Hathaway, J. T., 1993. Go Slow: the Political Economy of Urban Transport in Nigeria with and Emphasis on Ado-Ekiti. Geoforum, Vol. 24, No. 2, pp. 165-182.

Henderson, J. V., Shalizi, Z. and Venables, A. J., 2001. Geography and development. Journal of Economic Geography, Vol. 1. pp. 81-105.

Huang, Y. H., 2004. Pavement Analysis and Design, 2nd edition, Pearson Prentice Hall, New Jersey, 775p.

Ibrahim, A., 1980. Lagos-Ibidan expressway: problems and solutions. Proceedings National Engineering Conference of Nigerian Society of Engineers, pp. 201-215.

Jegede, G., 1994. Soil Erosion effect on highway pavement failures at Lloda locality, South Western Nigeria. Proceedings: UNESCO-MAB Conference, pp. 153-158.

Jegede, G., 2000. Effect pf Soil Properties on Pavement Failures Along the F209 Highway at Ado-Ekiti, South-western Nigeria. Construction and Building Materials, Vol. 14, pp. 311-315.

Kerali, H. G., 2008. Overview of HDM-4. Permanent International Association of Road Congresses (PIARC), Vol. 1, pp.43.

Limao, N. and Venables, J., 2001. Infrastructure, geographical disadvantage, transport cost and trade. The World Bank Economic Review, Vol. 15, No. 3, pp. 451-479.

Mason, M. and Thriscutt, S., 1989. Road Deterioration in Sub-Saharan Africa. SSATP Road Maintenance Policy Seminar, Addis Ababa, Ethiopia.

McBride, M. B, 1994. Environmental Chemistry of Soils. Oxford university Press, New York, 406 p.

Mesida, E. A., 1986. Some geotechnical properties of residual mica schist derived subgrade and fill materials in the Ilesha area, Nigeria. Bulletin of the International Association of Engineering Geology, No. 33. pp. 13-17.

Ministry of Works of the United Republic of Tanzania, 1999. Pavement and materials design manual. Ministry of Works of the United Republic of Tanzania, Dar es Salaam.

National Cooperative Highway Research Program (NCHRP), 2004. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, NCHRP.

Ogunsanwo, O., 1989. CBR and shear strengths of compacted laterite soils from south-western Nigeria. Quarterly Journal of Engineering Geology, London, Vol. 22, pp. 317-328.

Okagbue, C. O. and Uma, K. O., 1988. The Impact of Geology on the Performance of a bituminous surfaced Pavement – a Case Study from south-eastern Nigeria. Journal of African Earth Sciences, Vol. 7, No. 1, pp. 257-264.

Oke, O. L., 2007. Sustainable Road Development in Nigeria: A Case Study for Asphalt Pavement Recycling. Journal of Engineering and Applied Sciences, 2 (1), pp. 55-61.

Okunade, E. A., 1998. Isolines and Soil Mapping Values of the Engineering Properties of Nigerian Subgrade Soils. Unpublished Ph.D. thesis, University of Benin, Benin City.

Okunade, E. A., 2006a. Isopleths of Subgrade Properties for Delta and Edo States of Nigeria. Journal of Civil Engineering, Publication of the Nigerian Institution of Civil Engineers, Vol. 5, No. 3, pp. 13-28.

Okunade, E. A., 2006b. Isopleths of Subgrade Properties for the Lower Niger Delta Area. Journal of Civil Engineering, Publication of the Nigerian Institution of Civil Engineers, Vol. 5, No. 4, pp. 44-59.

Ola, S. A., 1977. Geotechnical properties and behaviour of some stabilized Nigerian lateritic soils. Quarterly Journal of Engineering geology, London, Vol. 11, pp. 145-152.

Ola, S. A., 1978a. The geology and geotechnical properties of the black cotton soils of northeastern Nigeria. Engineering geology, Vol. 12, pp. 375-391.

Ola, S. A., 1978b. Geotechnical properties and behaviour of some stabilized Nigerian lateritic soils. Quarterly journal of Engineering Geology, Vol. 2, pp. 145-160.

Oguara, T. M. and Iriakuma, N. D., 1987. Development of a Pavement Management System, for Nigeria. Presented at the Sixth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, Ann Arbor - July 13-17, 1987

Olowosulu, A. T., 2005. A framework for Mechanistic-empirical pavement design for tropical climates. Journal of Civil Engineering, Publication of the Nigerian Institution of Civil Engineers, Vol. 5, No. 1, pp. 44-54.

Osinubi, K. J., 1998. Permeability of lime-treated lateritic soil. Journal of Transportation Engineering, ASCE, Vol. 124, No. 5, pp. 465-467.

Owen, W., 1964. Strategy for Mobility. The Brooking Institute, Transport Research Program, Washington D.C., 249p.

Pleassis-Fraissard, M., 2007. Planning Roads for Rural Communities. Transportation Research Board, Journal of the Transportation Research Board, No. 1989, 10p.

Pollit, H. W., 1950. Colonial road problems – impressions from visits to Nigeria. HMSO, London, U.K.

Queiroz, C and Gautam, S., 1992. Road Infrastructure and Economic Development: Some Diagnostic Indicators. Policy Research Working paper Series 921, The World Bank, 37p.

Ramachandran, V., 2008. Power and roads for Africa. Centre for Global Development, Washington, D.C.

Southern African Transportation and Communication Commission (SATCC), 2001. Draft: Code of Practice for the Rehabilitation of Road Pavements. CSIR, Pretoria.

TAC, 1997. Pavement design and management guide, Transportation Association of Canada.

Teme, S. C., 1991. An evaluation of the engineering properties of some Nigerian limestone as construction materials for highway pavements. Engineering Geology, Vol.1, pp. 315-326.

The Economist, 2002. Trucking in Cameroon: the road to hell is unpaved", 19th December.

Theyse, H. L., de Beer, M. and Rust, F. C., 1974. Overview of the South African Mechanistic Pavement Design Analysis Method. Paper Number 961294 presented at the 75th Annual Transportation Research Board Meeting, Washington, D.C.

TRH, 1985. Structural Design of Interurban and Rural Road Pavements, Committee of State Roads Authorities, Department of Transport, Pretoria, South Africa.

TRH4, 1996. Structural Design of Flexible Pavements for Interurban and Rural Roads, Committee of Land Transport Officials, Ministry of Transport, Pretoria, South Africa.

TRH12, 1997. Flexible Pavement Rehabilitation Investigation and Design, Committee of Land Transport Officials, Ministry of Transport, Pretoria, South Africa.

TRL, 1993. Overseas Road Note 31: A Guide to the Structural Design of Bituminous Surfaced Roads in Tropical and sub-Tropical Countries. Transport and Road Research Laboratory, U.K., 75p.

Van Vuuren, D. J., Otte, E. and Paterson, W. D. O., 1874. The Structural Design of Flexible Pavements in South Africa. Proc. 2nd Conference on Asphalt Pavements in South Africa, Durban, South Africa.

Williams, S., 2003. Road Accidents are Africa's Third Biggest Killer. African Business, October, 2003, Vol. 291, pp. 38-39.

World Bank, 1996. Expanding Labour-Based Methods for Road Works in Africa. Environmentally Sustainable Development Division, World Bank, Washington, D.C., 74p.

World Bank, 2006. Safe, Clean and Affordable: Transportation for Development. Transport Sector Board, The World Bank, Washington, D.C., 39p.

World Bank, 2007. World Development Indicators. The International Bank for Reconstruction and Development (IBRD), The World Bank, Washington, D.C., 404p.

World Bank, 2007b. Road Network Evaluation Tools, Version 1.01, Sub-Saharan African Transport Policy, The World Bank, Washington, D.C.

APPENDICES

APPENDIX A: RONET NETWORK ANALYSIS SUMMARY TABLES

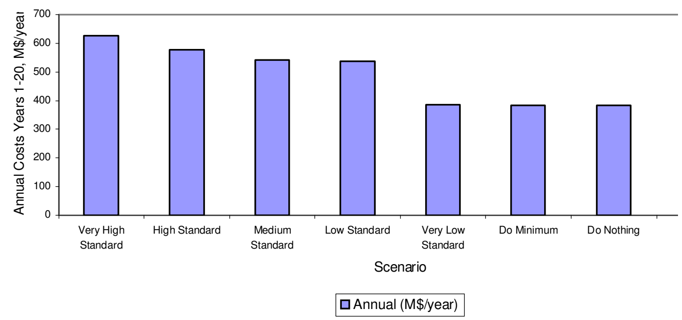
SUMMARY INPUT DATA UTILIZING RONET

Nigeria FERMA

Consequences to Road Agency

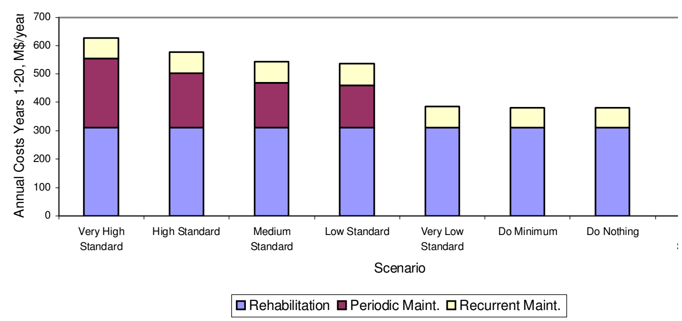
Road Agency Costs (Years 1-20)

Network	Standard	Road Agency Total (M$)	Road Agency Annual (M$/year)	Senario (%)
Total	Very High Standard	12,552	627.6	100%
Network	High Standard	11,553	577.6	92%
	Medium Standard	10,863	543.2	87%
	Low Standard	10,729	536.4	85%
	Very Low Standard	7,711	385.5	61%
	Do Minimum	7,631	381.6	61%
	Do Nothing	7,631	381.6	61%
	Custom Standard	11,553	577.6	92%



Road Agency Costs Breakdown (Years 1-20)

Network	Standard	Annual Costs Years 1-20, M$/year			
		Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total	Very High Standard	313.0	242.5	72.2	627.6
Network	High Standard	313.0	190.8	73.8	577.6
	Medium Standard	313.0	155.3	74.9	543.2
	Low Standard	313.0	146.6	76.9	536.4
	Very Low Standard	313.0	0.0	72.6	385.5
	Do Minimum	313.0	0.0	68.6	381.6
	Do Nothing	313.0	0.0	68.6	381.6
	Custom Standard	313.0	190.8	73.8	577.6



Recurrent Maintenance as a Percent of Total Maintenance Costs

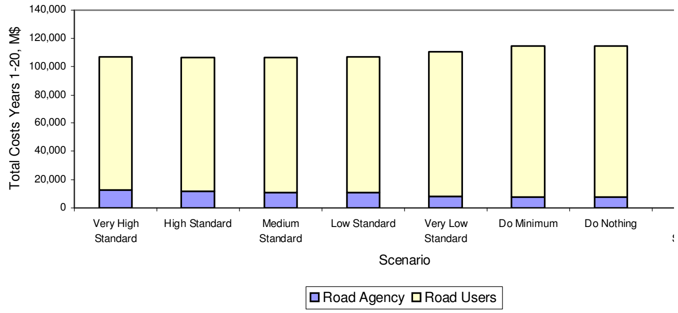
Network	Standard	Total Costs Years 1-20, M$			Recurrent M. /
		Periodic Maint.	Recurrent Maint.	Maintenance	Maintenance (%)
Total	Very High Standard	242.5	72.2	314.6	22.9%
Network	High Standard	190.8	73.8	264.7	27.9%
	Medium Standard	155.3	74.9	230.2	32.5%
	Low Standard	146.6	76.9	223.5	34.4%
	Very Low Standard	0.0	72.6	72.6	100.0%
	Do Minimum	0.0	68.6	68.6	100.0%
	Do Nothing	0.0	68.6	68.6	100.0%
	Custom Standard	190.8	73.8	264.7	27.9%

Nigeria FERMA

Consequences to Society

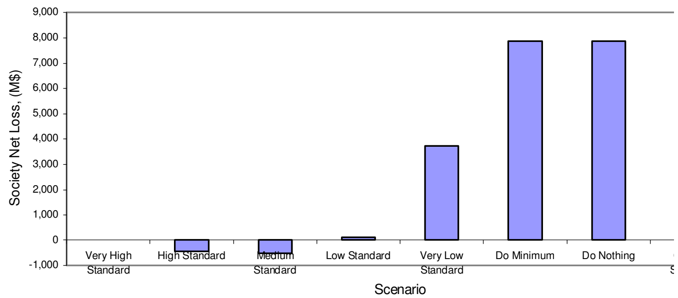
Society Costs (Total Costs Years 1-20)

Network	Standard	Total Costs Years 1-20, M$ Road Agency	Road Users	Society
Total Network	Very High Standard	12,552	94,320	106,872
	High Standard	11,553	94,888	106,440
	Medium Standard	10,863	95,501	106,364
	Low Standard	10,729	96,267	106,996
	Very Low Standard	7,711	102,879	110,590
	Do Minimum	7,631	107,128	114,759
	Do Nothing	7,631	107,128	114,759
	Custom Standard	11,553	94,888	106,440



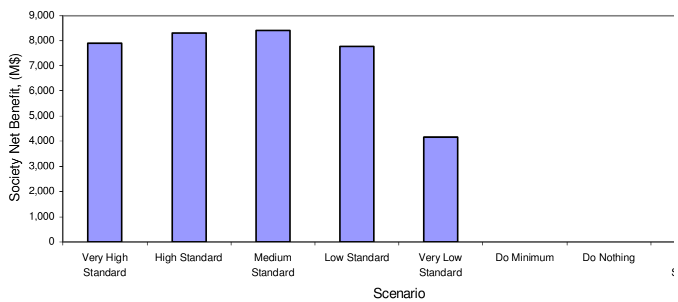
Society Net Loss Compared to Very High Standard (Total Costs Years 1-20)

Network	Standard	Society Costs (M$)	Net Loss (M$)	Net Loss (M$/year)
Total Network	Very High Standard	106,872	0	0.0
	High Standard	106,440	-432	-21.6
	Medium Standard	106,364	-508	-25.4
	Low Standard	106,996	123	6.2
	Very Low Standard	110,590	3,717	185.9
	Do Minimum	114,759	7,886	394.3
	Do Nothing	114,759	7,886	394.3
	Custom Standard	106,440	-432	-21.6



Society Net Benefits Compared to Do Minimum Standard (Total Costs Years 1-20)

Network	Standard	Society Costs (M$)	Net Benefit (M$)	Net Benefit (M$/year)
Total Network	Very High Standard	106,872	7,886	394.3
	High Standard	106,440	8,319	415.9
	Medium Standard	106,364	8,395	419.7
	Low Standard	106,996	7,763	388.2
	Very Low Standard	110,590	4,169	208.5
	Do Minimum	114,759	0	0.0
	Do Nothing	114,759	0	0.0
	Custom Standard	106,440	8,319	415.9



Nigeria FERMA

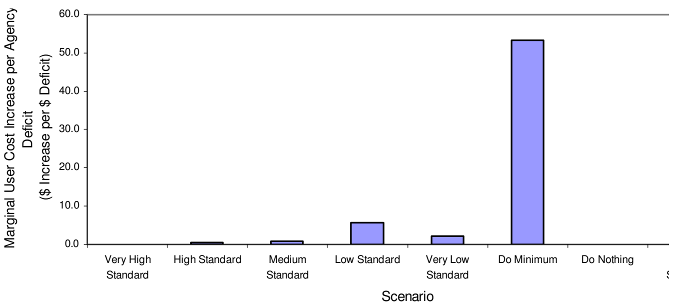
Consequences to Road Users

Impact of Road Agency Deficit on Road User Costs

Network	Standard Scenario	Total Costs Years 1-20, M$ Agency Deficit	Total Costs Years 1-20, M$ Users Costs Increase	Average* User Costs Increase per Agency Deficit	Marginal** User Costs Increase per Agency Deficit
Total Network	Very High Standard	0	0	0.0	0.0
	High Standard	1,000	568	0.6	0.6
	Medium Standard	1,689	1,181	0.7	0.9
	Low Standard	1,823	1,947	1.1	5.7
	Very Low Standard	4,842	8,559	1.8	2.2
	Do Minimum	4,921	12,808	2.6	53.3
	Do Nothing	4,921	12,808	2.6	#DIV/0!
	Custom Standard	1,000	568	0.6	#DIV/0!

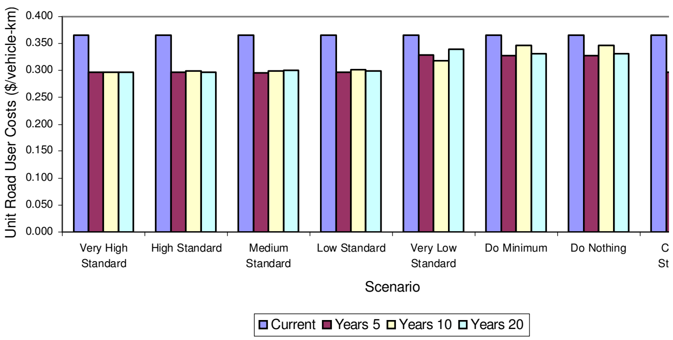
* Average: Comparison with Very High Standard

** Marginal: Incremental comparison with standard with lower agency deficit



Unit Road User Costs

Network	Standard	Unit Road User Costs ($/vehicle-km) Current	Years 5	Years 10	Years 20
Total Network	Very High Standard	0.365	0.296	0.297	0.296
	High Standard	0.365	0.296	0.298	0.297
	Medium Standard	0.365	0.295	0.299	0.300
	Low Standard	0.365	0.296	0.301	0.299
	Very Low Standard	0.365	0.328	0.318	0.339
	Do Minimum	0.365	0.327	0.346	0.330
	Do Nothing	0.365	0.327	0.346	0.330
	Custom Standard	0.365	0.296	0.298	0.297

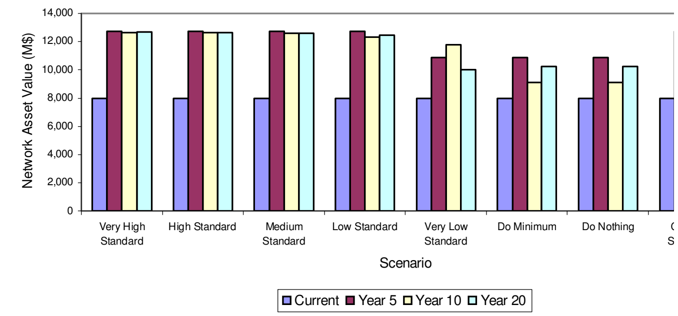


Nigeria FERMA

Consequences to Network Asset Value and Network Roughness

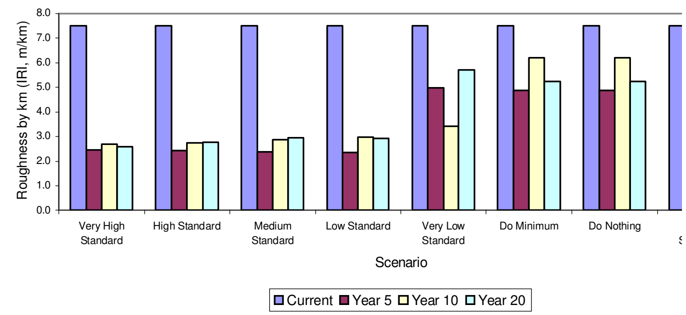
Network Asset Value

Network	Standard	Network Asset Value (M$)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	7,974	12,742	12,664	12,696
	High Standard	7,974	12,742	12,635	12,664
	Medium Standard	7,974	12,747	12,588	12,588
	Low Standard	7,974	12,721	12,307	12,468
	Very Low Standard	7,974	10,904	11,790	10,027
	Do Minimum	7,974	10,910	9,144	10,230
	Do Nothing	7,974	10,910	9,144	10,230
	Custom Standard	7,974	12,742	12,635	12,664



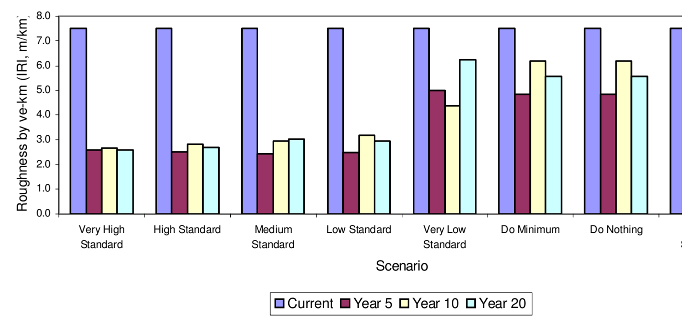
Roughness Weighted by Km

Network	Standard	Roughness by Km (IRI, mm/km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	7.5	2.5	2.7	2.6
	High Standard	7.5	2.4	2.7	2.8
	Medium Standard	7.5	2.4	2.9	3.0
	Low Standard	7.5	2.4	3.0	2.9
	Very Low Standard	7.5	5.0	3.4	5.7
	Do Minimum	7.5	4.9	6.2	5.3
	Do Nothing	7.5	4.9	6.2	5.3
	Custom Standard	7.5	2.4	2.7	2.8



Roughness Weighted by Vehicle-Km

Network	Standard	Roughness by Vehicle-Km (IRI, mm/km)			
		Current	Year 5	Year 10	Year 20
Total Roads	Very High Standard	7.5	2.6	2.7	2.6
	High Standard	7.5	2.5	2.8	2.7
	Medium Standard	7.5	2.4	3.0	3.0
	Low Standard	7.5	2.5	3.2	2.9
	Very Low Standard	7.5	5.0	4.4	6.2
	Do Minimum	7.5	4.8	6.2	5.6
	Do Nothing	7.5	4.8	6.2	5.6
	Custom Standard	7.5	2.5	2.8	2.7



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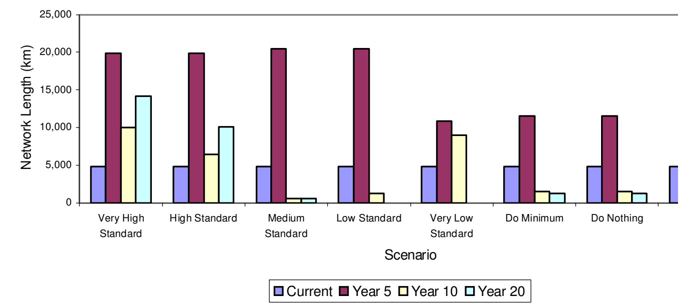
Consequences to Network Condition 1/2

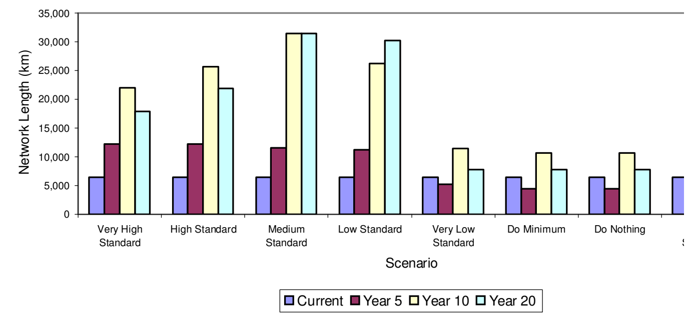
Network Length in Very Good Condition

Network	Standard	Network Length in Very Good Condition (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	4,815	19,830	10,044	14,134
	High Standard	4,815	19,830	6,420	10,148
	Medium Standard	4,815	20,451	621	621
	Low Standard	4,815	20,451	1,243	0
	Very Low Standard	4,815	10,821	9,009	0
	Do Minimum	4,815	11,546	1,450	1,243
	Do Nothing	4,815	11,546	1,450	1,243
	Custom Standard	4,815	0	272	43



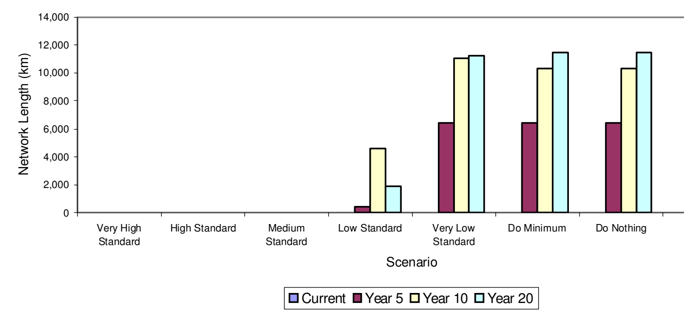
Network Length in Good Condition

Network	Standard	Network Length in Good Condition (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	6,420	12,271	22,056	17,966
	High Standard	6,420	12,271	25,680	21,952
	Medium Standard	6,420	11,649	31,479	31,479
	Low Standard	6,420	11,235	26,250	30,236
	Very Low Standard	6,420	5,229	11,442	7,766
	Do Minimum	6,420	4,504	10,717	7,766
	Do Nothing	6,420	4,504	10,717	7,766
	Custom Standard	6,420	12,271	25,680	21,952



Network Length in Fair Condition

Network	Standard	Network Length in Fair Condition (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	0	0	0	0
	High Standard	0	0	0	0
	Medium Standard	0	0	0	0
	Low Standard	0	414	4,608	1,864
	Very Low Standard	0	6,420	11,028	11,235
	Do Minimum	0	6,420	10,303	11,442
	Do Nothing	0	6,420	10,303	11,442
	Custom Standard	0	0	0	0



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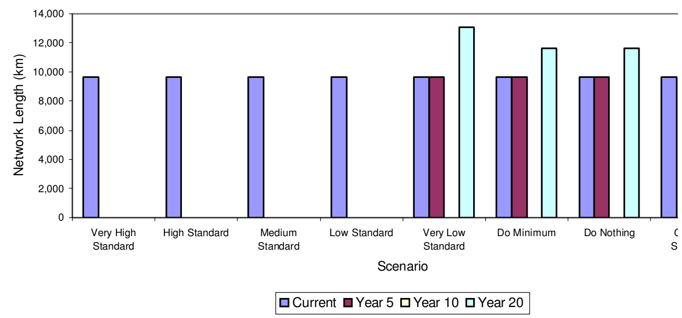
Consequences to Network Condition 2/2

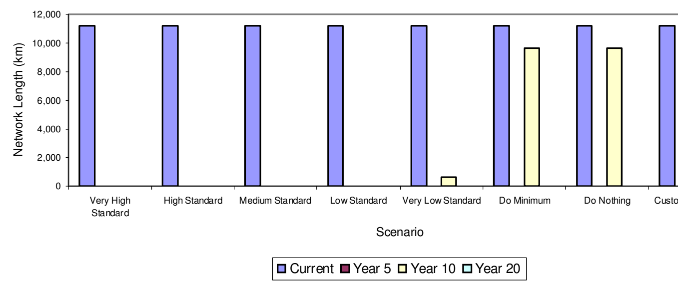
Network Length in Poor Condition

Network	Standard	Network Length in Poor Condition (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	9,630	0	0	0
	High Standard	9,630	0	0	0
	Medium Standard	9,630	0	0	0
	Low Standard	9,630	0	0	0
	Very Low Standard	9,630	9,630	0	13,099
	Do Minimum	9,630	9,630	0	11,649
	Do Nothing	9,630	9,630	0	11,649
	Custom Standard	9,630	0	0	0



Network Length in Very Poor Condition

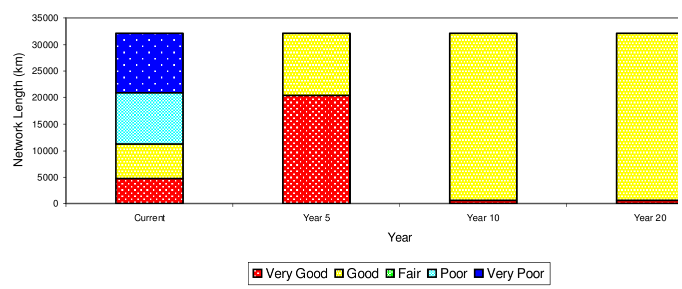
Network	Standard	Network Length in Very Poor Condition (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very High Standard	11,235	0	0	0
	High Standard	11,235	0	0	0
	Medium Standard	11,235	0	0	0
	Low Standard	11,235	0	0	0
	Very Low Standard	11,235	0	621	0
	Do Minimum	11,235	0	9,630	0
	Do Nothing	11,235	0	9,630	0
	Custom Standard	11,235	0	0	0



Network Length by Road Condition

Standard: Medium Standard

Network		Network Length (km)			
		Current	Year 5	Year 10	Year 20
Total Network	Very Good	4815	20451	621	621
	Good	6420	11649	31479	31479
	Fair	0	0	0	0
	Poor	9630	0	0	0
	Very Poor	11235	0	0	0
	Total	32100	32100	32100	32100
		Network Length (%)			
		Current	Year 5	Year 10	Year 20
	Very Good	15.0%	63.7%	1.9%	1.9%
	Good	20.0%	36.3%	98.1%	98.1%
	Fair	0.0%	0.0%	0.0%	0.0%
	Poor	30.0%	0.0%	0.0%	0.0%
	Very Poor	35.0%	0.0%	0.0%	0.0%
	Total	100.0%	100.0%	100.0%	100.0%



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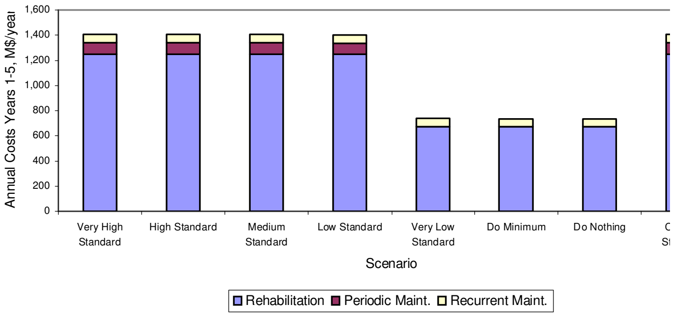
Consequences to Annual Road Agency Costs

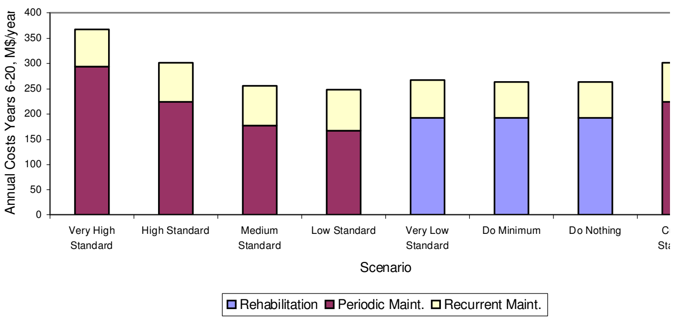
Annual Road Agency Costs Years 1-5 (Annual Costs Years 1-5)

		Annual Costs Years 1-5, M$/year			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	1,251.9	89.9	67.0	1,408.8
	High Standard	1,251.9	89.9	66.1	1,407.9
	Medium Standard	1,251.9	89.9	65.8	1,407.6
	Low Standard	1,251.9	84.1	66.3	1,402.2
	Very Low Standard	674.1	0.0	65.2	739.3
	Do Minimum	674.1	0.0	61.6	735.7
	Do Nothing	674.1	0.0	61.6	735.7
	Custom Standard	1,251.9	89.9	66.1	1,407.9



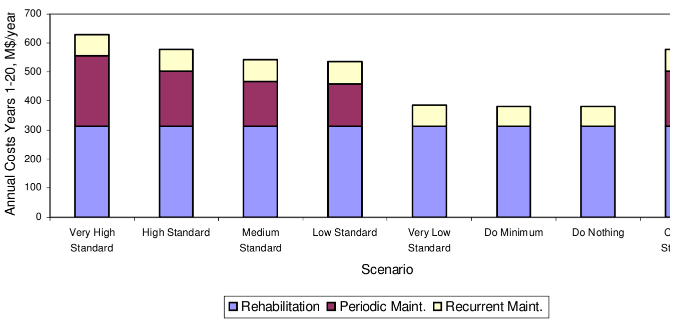
Annual Road Agency Costs Years 6-20 (Annual Costs Years 6-20)

		Annual Costs Years 6-20, M$/year			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	0.0	293.3	73.9	367.2
	High Standard	0.0	224.5	76.4	300.9
	Medium Standard	0.0	177.1	77.9	255.0
	Low Standard	0.0	167.4	80.4	247.9
	Very Low Standard	192.6	0.0	75.0	267.6
	Do Minimum	192.6	0.0	70.9	263.5
	Do Nothing	192.6	0.0	70.9	263.5
	Custom Standard	0.0	224.5	76.4	300.9



Annual Road Agency Costs Years 1-20 (Annual Costs Years 1-20)

		Annual Costs Years 1-20, M$/year			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	313.0	242.5	72.2	627.6
	High Standard	313.0	190.8	73.8	577.6
	Medium Standard	313.0	155.3	74.9	543.2
	Low Standard	313.0	146.6	76.9	536.4
	Very Low Standard	313.0	0.0	72.6	385.5
	Do Minimum	313.0	0.0	68.6	381.6
	Do Nothing	313.0	0.0	68.6	381.6
	Custom Standard	313.0	190.8	73.8	577.6



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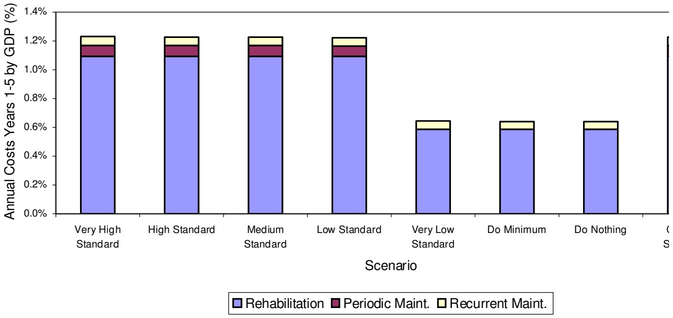
Consequences to Annual Road Agency Costs by GPD

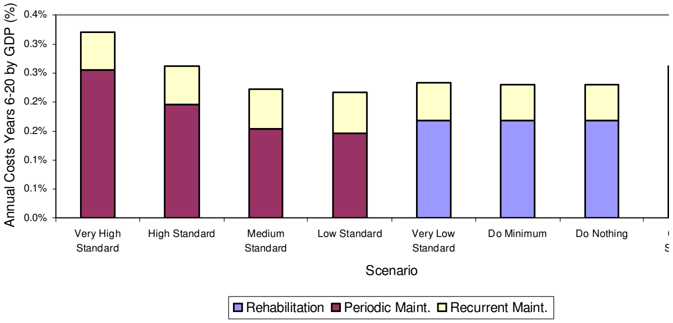
Annual Road Agency Costs Years 1-5 (Percentage of GDP)

		Annual Costs Years 1-5 by GDP (%)			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	1.1%	0.1%	0.1%	1.2%
	High Standard	1.1%	0.1%	0.1%	1.2%
	Medium Standard	1.1%	0.1%	0.1%	1.2%
	Low Standard	1.1%	0.1%	0.1%	1.2%
	Very Low Standard	0.6%	0.0%	0.1%	0.6%
	Do Minimum	0.6%	0.0%	0.1%	0.6%
	Do Nothing	0.6%	0.0%	0.1%	0.6%
	Custom Standard	1.1%	0.1%	0.1%	1.2%



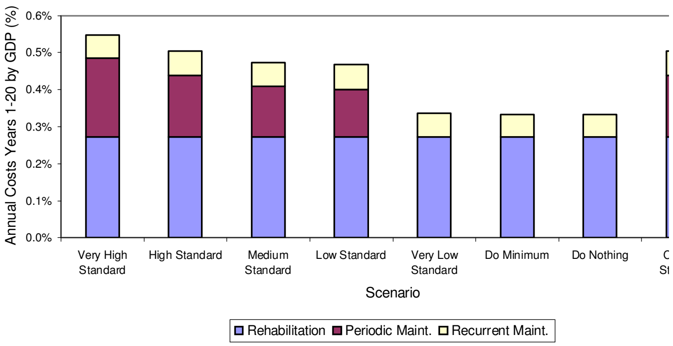
Annual Road Agency Costs Years 6-20 (Percentage of GDP)

		Annual Costs Years 6-20 by GDP (%)			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	0.0%	0.3%	0.1%	0.3%
	High Standard	0.0%	0.2%	0.1%	0.3%
	Medium Standard	0.0%	0.2%	0.1%	0.2%
	Low Standard	0.0%	0.1%	0.1%	0.2%
	Very Low Standard	0.2%	0.0%	0.1%	0.2%
	Do Minimum	0.2%	0.0%	0.1%	0.2%
	Do Nothing	0.2%	0.0%	0.1%	0.2%
	Custom Standard	0.0%	0.2%	0.1%	0.3%



Annual Road Agency Costs Years 1-20 (Percentage of GDP)

		Annual Costs Years 1-20 by GDP (%)			
Network	Standard	Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	0.3%	0.2%	0.1%	0.5%
	High Standard	0.3%	0.2%	0.1%	0.5%
	Medium Standard	0.3%	0.1%	0.1%	0.5%
	Low Standard	0.3%	0.1%	0.1%	0.5%
	Very Low Standard	0.3%	0.0%	0.1%	0.3%
	Do Minimum	0.3%	0.0%	0.1%	0.3%
	Do Nothing	0.3%	0.0%	0.1%	0.3%
	Custom Standard	0.3%	0.2%	0.1%	0.5%



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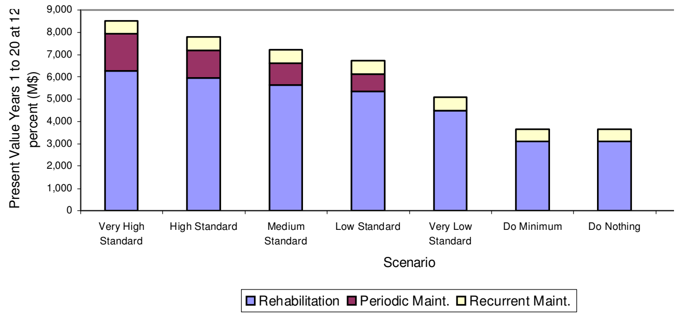
Consequences to Present Value Costs 1/2

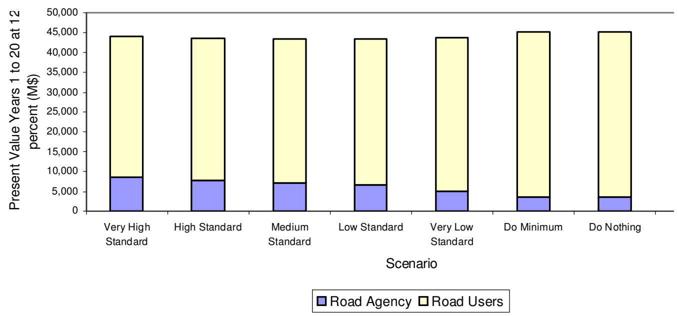
Present Value of Road Agency Costs

Network	Standard	Present Value Years 1 to 20 at 12 percent (M$)			
		Rehabilitation	Periodic Maint.	Recurrent Maint.	Road Agency
Total Network	Very High Standard	6,259.5	1,681.4	588.6	8,529.6
	High Standard	5,950.0	1,246.6	594.7	7,791.3
	Medium Standard	5,657.7	968.4	597.7	7,223.8
	Low Standard	5,355.8	764.9	606.6	6,727.3
	Very Low Standard	4,489.8	0.0	585.0	5,074.8
	Do Minimum	3,104.1	0.0	550.1	3,654.1
	Do Nothing	3,104.1	0.0	550.1	3,654.1
	Custom Standard	5,950.0	1,246.6	594.7	7,791.3



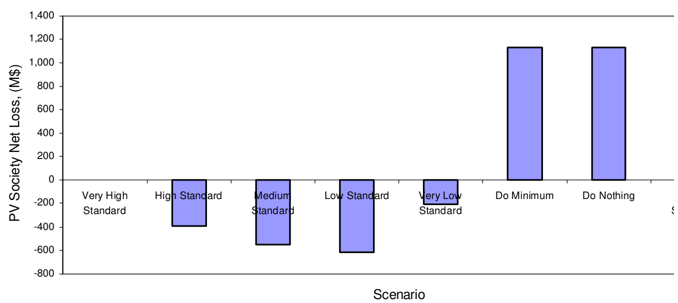
Present Value of Society Costs

Network	Standard	Present Value Years 1 to 20 at 12 percent (M$)		
		Road Agency	Road Users	Society
Total Network	Very High Standard	8,530	35,453	43,982
	High Standard	7,791	35,796	43,588
	Medium Standard	7,224	36,208	43,432
	Low Standard	6,727	36,640	43,368
	Very Low Standard	5,075	38,700	43,775
	Do Minimum	3,654	41,459	45,113
	Do Nothing	3,654	41,459	45,113
	Custom Standard	7,791	35,796	43,588



Present Value Society Net Loss Compared to Very High Standard

Network	Standard	Society Costs (M$)	Net Loss (M$)	Net Loss (M$/year)
Total Network	Very High Standard	43,982	0	0.0
	High Standard	43,588	-395	-19.7
	Medium Standard	43,432	-550	-27.5
	Low Standard	43,368	-615	-30.7
	Very Low Standard	43,775	-207	-10.4
	Do Minimum	45,113	1,131	56.6
	Do Nothing	45,113	1,131	56.6
	Custom Standard	43,588	-395	-19.7



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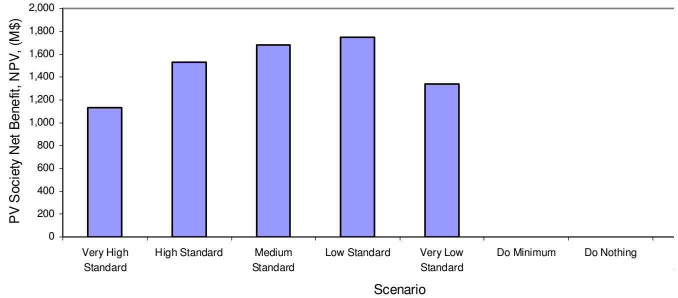
Consequences to Present Value Costs 2/2

Present Value Society Net Benefits Compared to Do Minimum Standard (NPV)

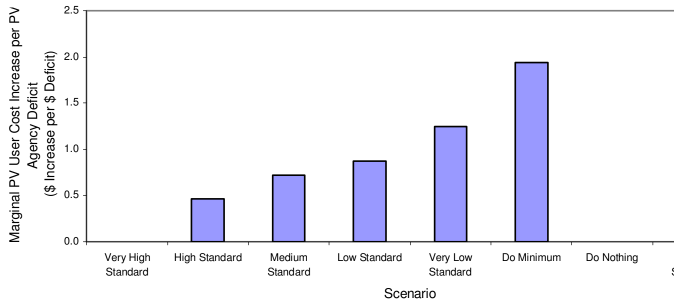
Network	Standard	Society Costs (M$)	Net Benefit (M$)	Net Benefit (M$/year)
Total Network	Very High Standard	43,982	1,131	56.6
	High Standard	43,588	1,526	76.3
	Medium Standard	43,432	1,681	84.1
	Low Standard	43,368	1,746	87.3
	Very Low Standard	43,775	1,338	66.9
	Do Minimum	45,113	0	0.0
	Do Nothing	45,113	0	0.0
	Custom Standard	43,588	1,526	76.3



Present Value Impact of Road Agency Deficit on Road User Costs

Network	Standard Scenario	Present Value Years 1 to 20 at 12 percent (M$) Agency Deficit	Users Costs Increase	Average* User Costs Increase per Agency Deficit	Marginal** User Costs Increase per Agency Deficit
Total Network	Very High Standard	0	0	0.0	0.0
	High Standard	738	343	0.5	0.5
	Medium Standard	1,306	755	0.6	0.7
	Low Standard	1,802	1,187	0.7	0.9
	Very Low Standard	3,455	3,247	0.9	1.2
	Do Minimum	4,875	6,006	1.2	1.9
	Do Nothing	4,875	6,006	1.2	#DIV/0!
	Custom Standard	738	343	0.5	#DIV/0!

* Average: Comparison with Very High Standard
** Marginal: Incremental comparison with standard with lower agency deficit



APPENDIX B: PWC TABLES

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Chipseal	14098	9686	12970			
1	64.7	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	63.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	61.2	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	58.0	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	53.8	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	48.7	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	42.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	35.4	Chipseal	14098	9686	12970	5693.945748	3912.012946	5238.365467
9	64.7	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	63.5	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	61.2	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	58.0	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	53.8	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	48.7	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	42.5	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	35.4	Chipseal	14098	9686	12970	2299.689189	1579.996417	2115.687954
17	64.7	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	63.5	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	61.2	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	58.0	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**97842**	**65742**	**80724**
Salvage value	7049	4843	6485
PWOC	**44123.31**	**29747.24**	**37030.70**

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Chipseal with stab base	20335	15923	19207			
1	74.8	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	73.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	71.2	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	67.9	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	63.5	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	58.0	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	51.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	44.0	Routine Maintenance	3086	2038	2323	5693.945748	3912.012946	5238.365467
9	35.4	Chipseal	14098	9686	12970	1112.842537	734.9232309	837.697088
10	64.7	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	63.5	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	61.2	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	58.0	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	53.8	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	48.7	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	42.5	Routine Maintenance	3086	2038	2323	2299.689189	1579.996417	2115.687954
17	35.4	Chipseal	14098	9686	12970	449.4584361	296.8231668	338.331804
18	64.7	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	63.5	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	61.2	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**104079**	**71979**	**86961**
Salvage value	8811.25	6053.75	8106.25
PWOC	**50542.99**	**36109.75**	**43435.77**

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Double surface	27186	19196	18767			
1	74.5	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	73.3	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	71.3	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	68.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	64.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	60.6	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	55.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	49.6	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	43.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	35.6	Chipseal	14098	9686	12970	4539.178689	3118.63277	4175.992879
11	64.3	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	62.6	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	59.9	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	56.3	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	51.6	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	46.0	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	39.4	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	31.8	Chipseal	14098	9686	12970	1833.298141	1259.56347	1686.613484
19	64.3	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	62.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**110930**	**75252**	**86521**
Salvage value	10573.5	7264.5	9727.5
PWOC	**56310.39**	**38628.81**	**41939.52**

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Double surface	27186	19196	18767			
1	74.5	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	73.3	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	71.3	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	68.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	64.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	60.6	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	55.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	49.6	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	43.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	35.6	Double surface	27186	19196	18767	8753.16441	6180.59825	6042.471731
11	74.5	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	73.3	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	71.3	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	68.5	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	64.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	60.6	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	55.5	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	49.6	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	43.0	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	35.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**113006**	**77114**	**81671**
Salvage value	0	0	0
PWOC	**57996.26**	**39943.14**	**41413.05**

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Chipseal with stab base	20335	15923	19207			
1	74.8	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	73.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	71.2	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	67.9	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	63.5	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	58.0	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	51.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	44.0	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	35.4	Double surface	27186	19196	18767	9803.544139	6922.27004	6767.568339
10	74.5	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	73.3	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	71.3	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	68.5	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	64.9	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	60.6	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	55.5	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	49.6	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	43.0	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	35.6	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	27.4	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**106155**	**73841**	**82111**
Salvage value	0	0	0
PWOC	**52076.40**	**37333.07**	**42488.39**

Low traffic, thin surface seal, 12% dicount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Chipseal	14098	9686	12970			
1	64.3	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	62.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	59.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	56.3	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	51.6	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	46.0	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	39.4	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	31.8	ouble surface with stab ba	33423	25433	25004	13498.98913	10271.96214	10098.69623
9	84.7	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	83.5	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	81.5	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	78.6	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	74.9	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	70.3	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	64.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	58.7	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	51.6	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	43.6	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	34.8	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	25.2	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**106155**	**73841**	**82111**
Salvage value	0	0	0
PWOC	**49401.31**	**34357.57**	**39481.99**

Low traffic, thin surface seal, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	64.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	62.0	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	57.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	52.0	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	44.3	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	34.8	Chipseal	14098	9686	12970	7142.485546	4907.22904	6571.005642
7	64.4	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	62.0	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	57.9	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	52.0	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	44.3	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	34.8	Chipseal	14098	9686	12970	3618.60546	2486.15495	3329.075956
13	64.4	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	62.0	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	57.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	52.0	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	44.3	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	34.8	Chipseal	14098	9686	12970	1833.298141	1259.56347	1686.613484
19	64.4	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	62.0	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**108854**	**73390**	**91371**
Salvage value	10573.5	7264.5	9727.5
PWOC	**48082.35**	**32494.12**	**40841.39**

Low traffic, thin surface seal, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	)ST(1/(1+12%)^Y	)ST(1/(1+12%)^Y	)ST(1/(1+12%)^Y
0	35.0	Chipseal with stab base	20335	15923	19207			
1	73.6	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	70.8	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	66.6	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	61.0	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	54.0	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	45.5	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	35.7	Chipseal	14098	9686	12970	6377.219238	4381.4545	5866.969323
8	64.4	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	62.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	57.9	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	52.0	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	44.3	Routine Maintenance	3086	2038	2323	3618.60546	2486.15495	3329.075956
13	34.8	Chipseal	14098	9686	12970	707.2315507	467.0569995	532.3716437
14	64.4	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	62.0	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	57.9	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	52.0	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	44.3	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	34.8	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	23.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**104079**	**71979**	**86961**
Salvage value	0	0	0
PWOC	**51193.48**	**36568.34**	**44107.50**

Low traffic, thin surface seal, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Double surface	27186	19196	18767			
1	74.1	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	72.1	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	68.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	64.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	58.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	52.2	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	44.3	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	35.2	Chipseal	14098	9686	12970	5693.945748	3912.012946	5238.365467
9	64.4	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	62.0	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	57.9	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	52.0	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	44.3	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	34.8	Chipseal	14098	9686	12970	2884.730118	1981.947505	2653.91897
15	64.4	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	62.0	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	57.9	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	52.0	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	44.3	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	34.8	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**110930**	**75252**	**86521**
Salvage value	0	0	0
PWOC	**56937.54**	**39072.56**	**42597.25**

Low traffic, thin surface seal, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	64.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	62.0	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	57.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	52.0	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	44.3	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	34.8	Chipseal	14098	9686	12970	7142.485546	4907.22904	6571.005642
7	64.4	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	62.0	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	57.9	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	52.0	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	44.3	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	34.8	Double surface	27186	19196	18767	6977.969077	4927.135084	4817.021469
13	74.1	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	72.1	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	68.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	64.5	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	58.9	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	52.2	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	44.3	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	35.2	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**110930**	**75252**	**86521**
Salvage value	0	0	0
PWOC	**48913.59**	**33187.47**	**39936.38**

Low traffic, thin surface seal, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Double seal with stab base	33423	25433	25004			
1	84.2	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	82.1	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	78.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	74.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	69.0	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	62.2	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	54.2	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	45.1	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	34.8	Chipseal	14098	9686	12970	5083.880132	3492.868702	4677.112024
10	64.4	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	62.0	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	57.9	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	52.0	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	44.3	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	34.8	Chipseal	14098	9686	12970	2575.651891	1769.595987	2369.570509
16	64.4	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	62.0	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	57.9	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	52.0	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	44.3	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**117167**	**81489**	**92758**
Salvage value	2349.6667	1614.3333	2161.666667
PWOC	**62700.17**	**44978.29**	**48364.19**

Low traffic, thin surface seal, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	62.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	56.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	47.3	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	34.9	Chipseal	14098	9686	12970	8959.533869	6155.628107	8242.669477
5	62.4	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	56.5	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	47.3	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	34.9	Chipseal	14098	9686	12970	5693.945748	3912.012946	5238.365467
9	62.4	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	52.0	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	44.3	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	34.8	Chipseal	14098	9686	12970	3618.60546	2486.15495	3329.075956
13	62.4	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	56.5	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	47.3	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	34.9	Chipseal	14098	9686	12970	2299.689189	1579.996417	2115.687954
17	62.4	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	56.5	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	47.3	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	34.9	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**119866**	**81038**	**102018**
Salvage value	0	0	0
PWOC	**53217.39**	**36068.67**	**45857.60**

Low traffic, thin surface seal, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Double surface seal	27186	19196	18767			
1	73.3	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	69.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	63.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	56.1	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	46.4	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	34.7	Double surface seal	27186	19196	18767	13773.27366	9725.291002	9507.946251
7	73.3	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	69.6	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	63.9	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	56.1	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	46.4	Routine Maintenance	3086	2038	2323	7815.325366	5518.391294	5395.064046
12	34.7	Double surface seal	27186	19196	18767	792.0993368	523.1038394	596.2562409
13	73.3	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	69.6	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	63.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	56.1	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	46.4	Routine Maintenance	3086	2038	2323	3959.487053	2795.788769	2733.307346
18	34.7	Double surface seal	27186	19196	18767	401.3021751	265.0206847	302.0819678
19	73.3	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	69.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**161206**	**111430**	**114559**
Salvage value	18124	12797.3333	12511.33333
PWOC	**74763.57**	**51869.64**	**52868.80**

Low traffic, thin surface seal, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Chipseal	14098	9686	12970			
1	62.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	56.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	47.3	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	34.9	Chipseal	14098	9686	12970	8959.533869	6155.628107	8242.669477
5	62.4	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	56.5	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	47.3	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	34.9	Double surface seal	27186	19196	18767	10979.96944	7752.942444	7579.676539
9	73.3	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	69.6	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	63.9	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	56.1	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	46.4	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	34.7	Double surface seal	27186	19196	18767	5562.794226	3927.881923	3840.100023
15	73.3	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	69.6	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	63.9	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	56.1	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	46.4	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	34.7	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**135030**	**92410**	**102965**
Salvage value	0	0	0
PWOC	**58811.95**	**40209.86**	**47094.10**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Chipseal	14098	9686	12970			
1	64.7	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	63.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	61.2	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	58.0	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	53.8	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	48.7	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	42.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	35.4	Chipseal	14098	9686	12970	8845.259611	6077.116229	8137.538456
9	64.7	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	63.5	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	61.2	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	58.0	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	53.8	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	48.7	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	42.5	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	35.4	Chipseal	14098	9686	12970	5549.625308	3812.857904	5105.5923
17	64.7	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	63.5	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	61.2	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	58.0	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**97842**	**65742**	**80724**
Salvage value	7049	4843	6485
PWOC	**61468.82**	**41372.81**	**51158.12**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Chipseal with stab base	20335	15923	19207			
1	74.8	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	73.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	71.2	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	67.9	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	63.5	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	58.0	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	51.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	44.0	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	35.4	Chipseal	14098	9686	12970	8344.584539	5733.128518	7676.923072
10	64.7	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	63.5	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	61.2	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	58.0	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	53.8	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	48.7	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	42.5	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	35.4	Chipseal	14098	9686	12970	5235.495573	3597.035759	4816.596509
18	64.7	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	63.5	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	61.2	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**104079**	**71979**	**86961**
Salvage value	8811.25	6053.75	8106.25
PWOC	**67252.06**	**47293.31**	**56947.84**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Double surface	27186	19196	18767			
1	74.5	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	73.3	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	71.3	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	68.5	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	64.9	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	60.6	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	55.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	49.6	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	43.0	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	35.6	Chipseal	14098	9686	12970	7872.249565	5408.611809	7242.380257
11	64.3	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	62.6	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	59.9	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	56.3	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	51.6	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	46.0	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	39.4	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	31.8	Chipseal	14098	9686	12970	4939.146767	3393.429961	4543.958971
19	64.3	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	62.6	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**110930**	**75252**	**86521**
Salvage value	10573.5	7264.5	9727.5
PWOC	**73685.33**	**50274.82**	**56095.38**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Double surface	27186	19196	18767			
1	74.5	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	73.3	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	71.3	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	68.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	64.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	60.6	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	55.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	49.6	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	43.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	35.6	Double surface	27186	19196	18767	8753.16441	6180.59825	6042.471731
11	74.5	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	73.3	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	71.3	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	68.5	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	64.9	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	60.6	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	55.5	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	49.6	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	43.0	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	35.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**113006**	**77114**	**81671**
Salvage value	0	0	0
PWOC	**57996.26**	**39943.14**	**41413.05**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Chipseal with stab base	20335	15923	19207			
1	74.8	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	73.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	71.2	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	67.9	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	63.5	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	58.0	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	51.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	44.0	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	35.4	Double surface	27186	19196	18767	16091.35163	11362.08291	11108.15847
10	74.5	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	73.3	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	71.3	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	68.5	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	64.9	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	60.6	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	55.5	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	49.6	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	43.0	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	35.6	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	27.4	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**106155**	**73841**	**82111**
Salvage value	0	0	0
PWOC	**69995.93**	**49454.49**	**55584.81**

Low traffic, thin surface seal, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Chipseal	14098	9686	12970			
1	64.3	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	62.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	59.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	56.3	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	51.6	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	46.0	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	39.4	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	31.8	ouble surface with stab ba	33423	25433	25004	20970.00369	15956.97884	15687.81893
9	84.7	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	83.5	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	81.5	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	78.6	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	74.9	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	70.3	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	64.9	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	58.7	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	51.6	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	43.6	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	34.8	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	25.2	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**106155**	**73841**	**82111**
Salvage value	0	0	0
PWOC	**68527.99**	**47740.01**	**53844.97**

Low traffic, thin surface seal, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	64.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	62.0	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	57.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	52.0	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	44.3	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	34.8	Chipseal	14098	9686	12970	9938.533699	6828.247795	9143.33821
7	64.4	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	62.0	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	57.9	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	52.0	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	44.3	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	34.8	Chipseal	14098	9686	12970	7006.274088	4813.645256	6445.692646
13	64.4	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	62.0	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	57.9	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	52.0	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	44.3	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	34.8	Chipseal	14098	9686	12970	4939.146767	3393.429961	4543.958971
19	64.4	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	62.0	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**108854**	**73390**	**91371**
Salvage value	10573.5	7264.5	9727.5
PWOC	**67683.94**	**45686.58**	**57150.10**

Low traffic, thin surface seal, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Chipseal with stab base	20335	15923	19207			
1	73.6	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	70.8	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	66.6	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	61.0	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	54.0	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	45.5	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	35.7	Chipseal	14098	9686	12970	9375.975188	6441.743203	8625.790764
8	64.4	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	62.0	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	57.9	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	52.0	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	44.3	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	34.8	Chipseal	14098	9686	12970	6609.692536	4541.174769	6080.842118
14	64.4	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	62.0	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	57.9	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	52.0	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	44.3	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	34.8	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	23.6	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**104079**	**71979**	**86961**
Salvage value	0	0	0
PWOC	**68217.64**	**47970.74**	**57924.22**

Low traffic, thin surface seal, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Double surface	27186	19196	18767			
1	74.1	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	72.1	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	68.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	64.5	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	58.9	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	52.2	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	44.3	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	35.2	Chipseal	14098	9686	12970	8845.259611	6077.116229	8137.538456
9	64.4	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	62.0	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	57.9	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	52.0	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	44.3	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	34.8	Chipseal	14098	9686	12970	6235.558996	4284.127141	5736.643508
15	64.4	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	62.0	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	57.9	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	52.0	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	44.3	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	34.8	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**110930**	**75252**	**86521**
Salvage value	0	0	0
PWOC	**74361.86**	**50752.87**	**56800.86**

Low traffic, thin surface seal, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	64.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	62.0	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	57.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	52.0	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	44.3	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	34.8	Chipseal	14098	9686	12970	9938.533699	6828.247795	9143.33821
7	64.4	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	62.0	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	57.9	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	52.0	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	44.3	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	34.8	Double surface	27186	19196	18767	13510.60912	9539.823903	9326.624046
13	74.1	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	72.1	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	68.9	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	64.5	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	58.9	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	52.2	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	44.3	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	35.2	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**110930**	**75252**	**86521**
Salvage value	0	0	0
PWOC	**69234.16**	**46980.24**	**55292.51**

Low traffic, thin surface seal, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Double seal with stab base	33423	25433	25004			
1	84.2	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	82.1	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	78.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	74.5	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	69.0	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	62.2	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	54.2	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	45.1	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	34.8	Chipseal	14098	9686	12970	8344.584539	5733.128518	7676.923072
10	64.4	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	62.0	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	57.9	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	52.0	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	44.3	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	34.8	Chipseal	14098	9686	12970	5882.602826	4041.629378	5411.927838
16	64.4	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	62.0	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	57.9	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	52.0	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	44.3	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**117167**	**81489**	**92758**
Salvage value	2349.66667	1614.33333	2161.666667
PWOC	**80175.67**	**56694.13**	**62617.28**

Low traffic, thin surface seal, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	62.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	56.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	47.3	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	34.9	Chipseal	14098	9686	12970	11166.93646	7672.219222	10273.45481
5	62.4	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	56.5	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	47.3	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	34.9	Chipseal	14098	9686	12970	8845.259611	6077.116229	8137.538456
9	62.4	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	52.0	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	44.3	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	34.8	Chipseal	14098	9686	12970	7006.274088	4813.645256	6445.692646
13	62.4	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	56.5	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	47.3	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	34.9	Chipseal	14098	9686	12970	5549.625308	3812.857904	5105.5923
17	62.4	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	56.5	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	47.3	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	34.9	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**119866**	**81038**	**102018**
Salvage value	0	0	0
PWOC	**74933.24**	**50729.51**	**64210.49**

Low traffic, thin surface seal, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Double surface seal	27186	19196	18767			
1	73.3	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	69.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	63.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	56.1	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	46.4	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	34.7	Double surface seal	27186	19196	18767	19165.05725	13532.42253	13229.99446
7	73.3	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	69.6	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	63.9	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	56.1	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	46.4	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	34.7	Double surface seal	27186	19196	18767	13510.60912	9539.823903	9326.624046
13	73.3	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	69.6	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	63.9	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	56.1	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	46.4	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	34.7	Double surface seal	27186	19196	18767	9524.446306	6725.199415	6574.901928
19	73.3	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	69.6	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**161206**	**111430**	**114559**
Salvage value	18124	12797.333	12511.33333
PWOC	**101870.83**	**70532.27**	**72234.23**

Low traffic, thin surface seal, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Chipseal	14098	9686	12970			
1	62.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	56.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	47.3	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	34.9	Chipseal	14098	9686	12970	11166.93646	7672.219222	10273.45481
5	62.4	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	56.5	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	47.3	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	34.9	Double surface seal	27186	19196	18767	17056.83273	12043.80788	11774.64797
9	73.3	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	69.6	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	63.9	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	56.1	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	46.4	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	34.7	Double surface seal	27186	19196	18767	12024.39402	8490.409312	8300.662199
15	73.3	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	69.6	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	63.9	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	56.1	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	46.4	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	34.7	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**135030**	**92410**	**102965**
Salvage value	0	0	0
PWOC	**83996.80**	**57473.77**	**65638.41**

High traffic, AC, 12% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.7	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	83.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	81.5	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	78.6	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	74.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	70.3	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	64.9	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	58.7	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	51.6	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	43.6	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	34.8	Asphalt 1 lift	55403	30228	41241	15927.0386	8689.827675	11855.80201
12	84.7	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	53.8	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	48.7	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	42.5	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	35.4	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	64.7	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	63.5	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	61.2	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	58.0	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**169440**	**99178**	**126619**
Salvage value	10073.273	5496	7498.363636
PWOC	**94537.85**	**54124.43**	**70557.84**

High traffic, AC, 12% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.7	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	83.5	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	81.5	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	78.6	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	74.9	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	70.3	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	64.9	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	58.7	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	51.6	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	43.6	Routine Maintenance	3086	2038	2323	21861.33882	15023.59319	16527.53018
11	34.8	Asphalt 2 lift	67898	46661	51332	887.1512572	585.8763002	667.8069898
12	89.7	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	89.7	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	88.6	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	86.8	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	84.1	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	80.7	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	76.5	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	71.5	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	65.7	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**181935**	**115611**	**136710**
Salvage value	16974.5	11665.25	12833
PWOC	**101081.12**	**61027.44**	**75702.46**

High traffic, AC, 12% discount rate, Max curve								
			Cost			High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Asphalt 2 lifts	67898	46661	51332			
1	89.7	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	88.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	86.8	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	84.1	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	80.7	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	76.5	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	71.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	65.7	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	59.2	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	51.8	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	43.7	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	34.8	Asphalt 1 lift	55403	30228	41241	14220.57017	7758.77471	10585.53751
13	84.7	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	83.5	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	81.5	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	78.6	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	74.9	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	70.3	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	64.9	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	58.7	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**181935**	**115611**	**136710**
Salvage value	15109.909	8244	11247.54545
PWOC	**105943.57**	**69974.03**	**79838.80**

High traffic, AC, 12% discount rate, Max curve								
			Cost			High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR	COST(1/(1+12%)^YR
0	35.0	Asphalt 1 lift with stab base	64758.5	39583.5	50596.5			
1	94.6	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	93.4	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	91.4	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	88.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	84.8	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	80.2	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	74.8	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	68.5	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	61.4	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	53.5	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	44.7	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	35.1	Asphalt 1 lift	55403	30228	41241	14220.57017	7758.77471	10585.53751
13	84.7	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	83.5	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	81.5	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	78.6	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	74.9	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	70.3	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	64.9	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	58.7	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**178795.5**	**108533.5**	**135974.5**
Salvage value	15109.909	8244	11247.54545
PWOC	**102804.07**	**62896.53**	**79103.30**

High traffic, AC, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.6	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	82.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	78.9	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	73.6	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	66.6	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	58.0	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	47.7	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	35.8	Asphalt 1 lift	55403	30228	41241	22376.34248	12208.58222	16656.54821
9	84.6	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	82.6	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	78.9	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	73.6	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	66.6	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	58.0	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	47.7	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	35.8	Asphalt 1 lift	55403	30228	41241	9037.429431	4930.841594	6727.300456
17	84.6	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	82.6	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	78.9	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	73.6	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**221757**	**127368**	**165537**
Salvage value	27701.5	15114	20620.5
PWOC	**110989.42**	**63001.41**	**82796.87**

High traffic, AC, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	)ST(1/(1+12%)^Y	)ST(1/(1+12%)^Y	)ST(1/(1+12%)^Y
0	35.0	Asphalt 2 lift	67898	46661	51332			
1	89.2	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	87.0	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	83.5	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	78.7	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	72.6	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	65.1	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	56.3	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	46.2	Routine Maintenance	3086	2038	2323	27422.86341	18845.5953	20732.13386
9	34.8	Asphalt 2 lift	67898	46661	51332	1112.842537	734.9232309	837.697088
10	89.2	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	87.0	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	83.5	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	78.7	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	72.6	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	65.1	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	56.3	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	46.2	Routine Maintenance	3086	2038	2323	9888.959461	6795.910592	7476.215309
18	34.8	Asphalt 2 lift	67898	46661	51332	401.3021751	265.0206847	302.0819678
19	89.2	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	87.0	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**259242**	**176667**	**195810**
Salvage value	52809.55556	36291.8889	39924.88889
PWOC	**132039.28**	**90167.56**	**99754.20**

High traffic, AC, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	\sphalt 1 lift with stab bas	64758.5	39583.5	50596.5			
1	93.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	90.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	86.5	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	81.1	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	74.5	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	66.6	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	57.5	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	47.1	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	35.4	Asphalt 1 lift	55403	30228	41241	19978.87721	10900.51984	14871.91804
10	84.6	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	82.6	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	78.9	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	73.6	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	66.6	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	58.0	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	47.7	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	35.8	Asphalt 1 lift	55403	30228	41241	8069.133421	4402.537138	6006.518264
18	84.6	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	82.6	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	78.9	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**231112.5**	**136723.5**	**174892.5**
Salvage value	34626.875	18892.5	25775.625
PWOC	**117884.57**	**71036.06**	**90322.50**

High traffic, AC, 12% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+12%)^YR)	
0	35.0	\sphalt 2 lift with stab bas	77253.5	56016.5	60687.5			
1	99.4	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	97.6	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	94.4	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	89.9	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	84.1	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	77.0	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	68.6	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	58.9	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	47.9	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	35.6	Asphalt 2 lift	67898	46661	51332	21861.33882	15023.59319	16527.53018
11	89.2	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	87.0	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	83.5	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	78.7	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	72.6	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	65.1	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	56.3	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	46.2	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	34.8	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	22.0	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**203785.5**	**141399.5**	**156156.5**
Salvage value	0	0	0
PWOC	**121171.93**	**85606.64**	**93818.60**

High traffic, AC, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	83.9	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	79.9	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	73.0	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	63.3	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	50.6	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	35.0	Asphalt 1 lift	55403	30228	41241	28068.88401	15314.44553	20893.97407
7	83.9	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	79.9	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	73.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	63.3	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	50.6	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	35.0	Asphalt 1 lift	55403	30228	41241	14220.57017	7758.77471	10585.53751
13	83.9	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	79.9	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	73.0	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	63.3	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	50.6	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	35.0	Asphalt 1 lift	55403	30228	41241	7204.583411	3930.83673	5362.962736
19	83.9	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	79.9	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**274074**	**155558**	**204455**
Salvage value	36935.33333	20152	27494
PWOC	**129019.84**	**72723.24**	**96209.96**

High traffic, AC, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Asphalt 2 lift	67898	46661	51332			
1	88.1	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	84.2	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	78.4	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	70.5	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	60.7	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	48.9	Routine Maintenance	3086	2038	2323	1563.46364	1032.514225	1176.904094
7	35.1	Asphalt 2 lift	67898	46661	51332	30713.60702	21107.06674	23219.98992
8	88.1	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	84.2	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	78.4	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	70.5	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	60.7	Routine Maintenance	3086	2038	2323	792.0993368	523.1038394	596.2562409
13	48.9	Routine Maintenance	3086	2038	2323	15560.46916	10693.49689	11763.96953
14	35.1	Asphalt 2 lift	67898	46661	51332	631.4567417	417.0151781	475.3318247
15	88.1	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	84.2	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	78.4	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	70.5	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	60.7	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	48.9	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**259242**	**176667**	**195810**
Salvage value	9699.714286	6665.85714	7333.142857
PWOC	**136125.14**	**92986.37**	**102844.50**

High traffic, AC, 12% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+12%)^YR)		
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	83.9	Routine Maintenance	3086	2038	2323	2755.357143	1819.642857	2074.107143
2	79.9	Routine Maintenance	3086	2038	2323	2460.140306	1624.681122	1851.881378
3	73.0	Routine Maintenance	3086	2038	2323	2196.553845	1450.608145	1653.465516
4	63.3	Routine Maintenance	3086	2038	2323	1961.20879	1295.185844	1476.308496
5	50.6	Routine Maintenance	3086	2038	2323	1751.079277	1156.415932	1318.132586
6	35.0	Asphalt 1 lift	55403	30228	41241	28068.88401	15314.44553	20893.97407
7	83.9	Routine Maintenance	3086	2038	2323	1395.949679	921.8877009	1050.807227
8	79.9	Routine Maintenance	3086	2038	2323	1246.383642	823.1140186	938.2207386
9	73.0	Routine Maintenance	3086	2038	2323	1112.842537	734.9232309	837.697088
10	63.3	Routine Maintenance	3086	2038	2323	993.6094081	656.1814562	747.9438286
11	50.6	Routine Maintenance	3086	2038	2323	887.1512572	585.8763002	667.8069898
12	35.0	Asphalt 2 lift	67898	46661	51332	17427.72546	11976.71651	13175.64587
13	88.1	Routine Maintenance	3086	2038	2323	707.2315507	467.0569995	532.3716437
14	84.2	Routine Maintenance	3086	2038	2323	631.4567417	417.0151781	475.3318247
15	78.4	Routine Maintenance	3086	2038	2323	563.8006623	372.3349805	424.4034149
16	70.5	Routine Maintenance	3086	2038	2323	503.3934484	332.4419468	378.9316205
17	60.7	Routine Maintenance	3086	2038	2323	449.4584361	296.8231668	338.331804
18	48.9	Routine Maintenance	3086	2038	2323	401.3021751	265.0206847	302.0819678
19	35.1	Routine Maintenance	3086	2038	2323	358.3055135	236.6256113	269.7160427
20	19.3	Routine Maintenance	3086	2038	2323	319.915637	211.2728672	240.8178953

TOTAL	**234252**	**143801**	**175628**
Salvage value	0	0	0
PWOC	**121594.75**	**71186.27**	**90888.98**

High traffic, AC, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.7	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	83.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	81.5	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	78.6	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	74.9	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	70.3	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	64.9	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	58.7	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	51.6	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	43.6	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	34.8	Asphalt 1 lift	55403	30228	41241	29185.60927	15923.73332	21725.24433
12	84.7	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	53.8	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	48.7	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	42.5	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	35.4	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	64.7	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	63.5	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	61.2	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	58.0	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**169440**	**99178**	**126619**
Salvage value	10073.273	5496	7498.363636
PWOC	**119403.38**	**69023.59**	**89164.48**

High traffic, AC, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.7	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	83.5	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	81.5	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	78.6	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	74.9	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	70.3	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	64.9	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	58.7	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	51.6	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	43.6	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	34.8	Asphalt 2 lift	67898	46661	51332	35767.8194	24580.43272	27041.05725
12	89.7	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	89.7	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	88.6	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	86.8	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	84.1	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	80.7	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	76.5	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	71.5	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	65.7	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**181935**	**115611**	**136710**
Salvage value	16974.5	11665.25	12833
PWOC	**126701.02**	**78319.84**	**95033.31**

High traffic, AC, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 2 lifts	67898	46661	51332			
1	89.7	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	88.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	86.8	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	84.1	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	80.7	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	76.5	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	71.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	65.7	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	59.2	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	51.8	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	43.7	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	34.8	Asphalt 1 lift	55403	30228	41241	27533.59365	15022.38992	20495.51352
13	84.7	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	83.5	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	81.5	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	78.6	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	74.9	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	70.3	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	64.9	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	58.7	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**181935**	**115611**	**136710**
Salvage value	15109.909	8244	11247.54545
PWOC	**130860.52**	**84900.89**	**98483.68**

High traffic, AC, 6% discount rate, Max curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 1 lift with stab bas	64758.5	39583.5	50596.5			
1	94.6	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	93.4	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	91.4	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	88.5	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	84.8	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	80.2	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	74.8	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	68.5	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	61.4	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	53.5	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	44.7	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	35.1	Asphalt 1 lift	55403	30228	41241	27533.59365	15022.38992	20495.51352
13	84.7	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	83.5	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	81.5	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	78.6	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	74.9	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	70.3	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	64.9	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	58.7	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**178795.5**	**108533.5**	**135974.5**
Salvage value	15109.909	8244	11247.54545
PWOC	**127721.02**	**77823.39**	**97748.18**

High traffic, AC, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	84.6	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	82.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	78.9	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	73.6	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	66.6	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	58.0	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	47.7	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	35.8	Asphalt 1 lift	55403	30228	41241	34760.52761	18965.42116	25875.11361
9	84.6	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	82.6	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	78.9	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	73.6	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	66.6	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	58.0	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	47.7	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	35.8	Asphalt 1 lift	55403	30228	41241	21809.18506	11899.13986	16234.36639
17	84.6	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	82.6	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	78.9	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	73.6	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**221757**	**127368**	**165537**
Salvage value	27701.5	15114	20620.5
PWOC	**147089.63**	**83954.16**	**109760.85**

High traffic, AC, 6% discount rate, Min curve								
			Cost			High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Asphalt 2 lift	67898	46661	51332			
1	89.2	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	87.0	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	83.5	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	78.7	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	72.6	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	65.1	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	56.3	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	46.2	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	34.8	Asphalt 2 lift	67898	46661	51332	40188.72188	27618.57421	30383.33193
10	89.2	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	87.0	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	83.5	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	78.7	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	72.6	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	65.1	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	56.3	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	46.2	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	34.8	Asphalt 2 lift	67898	46661	51332	23787.64273	16347.39164	17983.84749
19	89.2	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	87.0	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**259242**	**176667**	**195810**
Salvage value	52809.556	36291.889	39924.88889
PWOC	**169837.38**	**115844.64**	**128293.86**

High traffic, AC, 6% discount rate, Min curve								
			Cost			High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Asphalt 1 lift with stab base	64758.5	39583.5	50596.5			
1	93.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	90.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	86.5	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	81.1	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	74.5	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	66.6	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	57.5	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	47.1	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	35.4	Asphalt 1 lift	55403	30228	41241	32792.95057	17891.90676	24410.48453
10	84.6	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	82.6	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	78.9	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	73.6	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	66.6	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	58.0	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	47.7	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	35.8	Asphalt 1 lift	55403	30228	41241	20574.70288	11225.60365	15315.43999
18	84.6	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	82.6	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	78.9	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**231112.5**	**136723.5**	**174892.5**
Salvage value	34626.875	18892.5	25775.625
PWOC	**154139.36**	**92072.10**	**117401.47**

High traffic, AC, 6% discount rate, Min curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 2 lift with stab bas	77253.5	56016.5	60687.5			
1	99.4	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	97.6	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	94.4	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	89.9	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	84.1	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	77.0	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	68.6	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	58.9	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	47.9	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	35.6	Asphalt 2 lift	67898	46661	51332	37913.88856	26055.25869	28663.52069
11	89.2	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	87.0	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	83.5	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	78.7	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	72.6	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	65.1	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	56.3	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	46.2	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	34.8	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	22.0	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**203785.5**	**141399.5**	**156156.5**
Salvage value	0	0	0
PWOC	**148840.36**	**104309.45**	**114698.50**

High traffic, AC, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region		COST(1/(1+6%)^YR)	
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	83.9	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	79.9	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	73.0	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	63.3	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	50.6	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	35.0	Asphalt 1 lift	55403	30228	41241	39056.92882	21309.54722	29073.27765
7	83.9	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	79.9	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	73.0	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	63.3	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	50.6	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	35.0	Asphalt 1 lift	55403	30228	41241	27533.59365	15022.38992	20495.51352
13	83.9	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	79.9	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	73.0	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	63.3	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	50.6	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	35.0	Asphalt 1 lift	55403	30228	41241	19410.09706	10590.19212	14448.52829
19	83.9	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	79.9	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**274074**	**155558**	**204455**
Salvage value	36935.33333	20152	27494
PWOC	**175838.45**	**99451.39**	**131147.23**

High traffic, AC, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Asphalt 2 lift	67898	46661	51332			
1	88.1	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	84.2	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	78.4	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	70.5	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	60.7	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	48.9	Routine Maintenance	3086	2038	2323	2175.508228	1436.709581	1637.623335
7	35.1	Asphalt 2 lift	67898	46661	51332	45156.0479	31032.22998	34138.71176
8	88.1	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	84.2	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	78.4	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	70.5	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	60.7	Routine Maintenance	3086	2038	2323	1533.647456	1012.823563	1154.459832
13	48.9	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	35.1	Asphalt 2 lift	67898	46661	51332	30031.35088	20638.2053	22704.1931
15	88.1	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	84.2	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	78.4	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	70.5	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	60.7	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	48.9	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**259242**	**176667**	**195810**
Salvage value	9699.714286	6665.85714	7333.142857
PWOC	**176069.81**	**120141.37**	**133007.34**

High traffic, AC, 6% discount rate, Drastic curve								
				Cost		High	Low	Africa
Year	CR initial	Intervention	High	Low	Africa region	COST(1/(1+6%)^YR)		
0	35.0	Asphalt 1 lift	55403	30228	41241			
1	83.9	Routine Maintenance	3086	2038	2323	2911.320755	1922.641509	2191.509434
2	79.9	Routine Maintenance	3086	2038	2323	2746.529014	1813.812745	2067.46173
3	73.0	Routine Maintenance	3086	2038	2323	2591.065107	1711.144099	1950.435594
4	63.3	Routine Maintenance	3086	2038	2323	2444.401045	1614.286886	1840.03358
5	50.6	Routine Maintenance	3086	2038	2323	2306.038721	1522.912156	1735.880736
6	35.0	Asphalt 1 lift	55403	30228	41241	39056.92882	21309.54722	29073.27765
7	83.9	Routine Maintenance	3086	2038	2323	2052.366253	1355.386398	1544.927675
8	79.9	Routine Maintenance	3086	2038	2323	1936.194578	1278.666413	1457.478939
9	73.0	Routine Maintenance	3086	2038	2323	1826.598658	1206.289069	1374.980131
10	63.3	Routine Maintenance	3086	2038	2323	1723.206282	1138.008555	1297.151067
11	50.6	Routine Maintenance	3086	2038	2323	1625.666303	1073.592977	1223.727421
12	35.0	Asphalt 2 lift	67898	46661	51332	33743.22585	23189.08747	25510.43137
13	88.1	Routine Maintenance	3086	2038	2323	1446.837223	955.4939273	1089.113049
14	84.2	Routine Maintenance	3086	2038	2323	1364.940776	901.4093654	1027.46514
15	78.4	Routine Maintenance	3086	2038	2323	1287.679977	850.3861938	969.3067361
16	70.5	Routine Maintenance	3086	2038	2323	1214.792432	802.2511262	914.4403171
17	60.7	Routine Maintenance	3086	2038	2323	1146.030596	756.8406851	862.6795444
18	48.9	Routine Maintenance	3086	2038	2323	1081.160939	714.0006463	813.8486268
19	35.1	Routine Maintenance	3086	2038	2323	1019.96315	673.5855154	767.7817234
20	19.3	Routine Maintenance	3086	2038	2323	962.2293872	635.4580334	724.3223806

TOTAL	**234252**	**143801**	**175628**
Salvage value	0	0	0
PWOC	**159890.18**	**95652.80**	**119677.25**