DEVELOPMENT OF PAVEMENT MANAGEMENT SYSTEM FOR ROAD NETWORK MAINTENANCE

DAVID MAPIKITLA

DEVELOPMENT OF PAVEMENT MANAGEMENT SYSTEM FOR ROAD NETWORK MAINTENANCE

VAAL UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

MASTERS OF TECHNOLOGY RESEARCH DISSERTATION

Student Name: David Mapikitla
Student Number: 20129599
Student Signature:
Supervisor: Prof. Julius M. Ndambuki
Supervisor Signature:

DECLARATION

I, David Mapikitla, hereby declare that the work presented in this dissertation is my original work but where ideas and work of other people have been used, such persons have been acknowledged.

ACKNOWLEDGEMENTS

My special gratitude is expressed to my supervisor Prof. J.M. Ndambuki for his sincere guidance, support, advice and encouragement during my research.

I would also like to extend my appreciation to Mr G. Verwy of Kwezi V3 Engineers (Pty) Ltd and Mr L. Kannemeyer of the South African National Roads Agency Limited for their assistance in providing me with information.

Lastly, I thank my family and Vaal University of Technology for having afforded me the opportunity to continue and complete my studies.

TABLE OF CONTENTS

Appendices

LIST OF FIGURES

LIST OF PICTURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

Abbreviation	Definition
A.A.S.H.T.O.	The American Association of State Highway and Transportation Officials
A.D.T.	Average Daily Traffic
A.A.T.T.	Average Annual Daily Traffic
A.D.T.T.	Average Daily Truck Traffic
A.M.S.	Asset Management System
B.L.I.	Base Layer Index
C.B.R.	California Bearing Ratio
C.S.I.R.	Council for Scientific and Industrial Research
D_0	Maximum Deflection
D.B.P.	Deflection Bowl Parameters
D.C.P.	Dynamic Cone Penetrometer
D.P.L.G.	Department of Provincial and Local Government
d.T.I.M.S.	Deighton Transportation Infrastructure Management System
E.I.A.	Environmental Impact Assessment
F.W.D.	Falling Weight Deflectometer
G.P.S.	Global Positioning System
H.C.M.	Highway Capacity Manual
H.R.I.	Half-car Roughness Index
I.P.E.N.Z.	Institution of Professional Engineers New Zealand
I.T.S.	Intelligent Transport System
L.C.T.	Lobakeng Construction Technologies
L.L.I.	Lower Layer Index
L.O.S.	Level of Service
L.S.	Linear Shrinkage
M.R&R	Maintenance, Construction and Rehabilitation
M.L.I.	Middle Layer Index
N.D.o.T.	National Department of Transport

N.P.M.S.	National Pavement Management System
N.Z.	New Zealand
O&R.A.M.	Optimisation and Rehabilitation Allocation Model
P.D.M.	Pavement Deterioration Model
P.M.S.	Pavement Management System
P.S.I.	Present Serviceability Index
R.S.V.	Road Survey Vehicles
S.A.	South Africa
S.A.N.R.A.L.	South African National Roads Agency Limited
S.A.R.B.	South African Roads Board
T.M.H.	Technical Methods for Highways
T.R.H.	Technical Recommendations for Highways
T.S.M.	Treatment Selection Model
U.K.P.M.S.	United Kingdom Pavement Management System
U.T.G.	Urban Transport Guidelines
V.C.A.	Visual Condition Assessments
V.C.I.	Visual Condition Index
V.U.T.	Vaal University of Technology
W.I.M.	Warsim 2000 Intelligence Module
Ymax	Maximum Deflection

ABSTRACT

In the past thirty years there has been a rapid deterioration of the road network in South Africa. As an attempt to address this challenge, a study was conducted on R34 between Vrede and Bothmas Pass Border. The aim of the study was to develop a pavement management system for road network maintenance to serve as a decision support tool to assist to improve the efficiency of making decisions, provide feedback as to the consequences of these decisions, ensure consistency of decisions made at different levels and improve the effectiveness of all decisions in terms of efficiency of results.

The study focused on developing and testing pavement management system for road network maintenance. Consequently, visual condition inspections, non-destructive and semi-destructive tests were conducted on the field, data acquired, processed and analysed in accordance with guidelines stipulated in the Draft Technical Recommendations for Highways (TRH) 22 in order to draw conclusions.

The data acquired included the surfacing assessments, structural assessments, functional assessments, traffic surveys, riding quality, falling weight deflectometer, mechanical rutting, material investigations and dynamic cone penetration.

After analysis of the data, visual condition index was then calculated to be 40%. Visual condition index was then used to determine the action required towards rehabilitating the road. After consultation with guidelines contained in the TRH22, it was concluded that the pavement treatment needed for the road was Rehabilitation.

It was then concluded that PMS developed would provide key performance indicators to assist with decision support system and that it is also suitable for road network applications ranging from national roads, provincial roads, regional or district arterial and collector / distributor networks in SA.

The municipalities and other road maintenance agencies were then recommended to utilise the “easy to use” developed pavement management system as a decision support tool in their maintenance programmes.

1. CHAPTER 1: INTRODUCTION

1.1 Background

The first forms of road transport were horses, oxen and even humans carrying goods over tracks that often followed game trails, such as the Natchez Trace (John 1915). The first improved trails were at fords, mountain passes and through swamps. The first improvements consisted largely of clearing trees and big stones from the path. As commerce increased, the tracks were flattened and widened to accommodate human and animal traffic. Some of these dirt tracks were developed into fairly extensive networks, allowing communications, trade and governance over wide areas (John 1915).

Wheeled-transport were developed in ancient Sumer in Mesopotamia in 5000BC (John 1915), originally for the making of pottery. Wheeled-transport then created the need for better roads. Generally natural materials could not be both soft enough to form well-graded surfaces and strong enough to bear wheeled vehicles, especially when wet, and stay intact. It began to be worthwhile to build stone-paved roads and in fact, the first paved roads were built in Ur in 4000 BC (John 1915).

Since then, a strong need to have a system for management and maintenance of roads surfaced. Engineers throughout the world invested funding in developing a system that could solve the problem at hand, until Pavement Management System (PMS) was adopted as an effective solution to pavement management in the 1950s (The American Association of State Highway and Transport Officials 1985).

Prior to the development of PMS, countries typically established yearly road maintenance budgets that emphasised maintenance improvements on a worse-case first basis, or in response to citizen complaints and political priorities. This approach worked satisfactorily for most communities, as long as sufficient funding was available. However, while funding sources dried up and maintenance budgets decreased or stayed constant, the need for improvements increased due to greater traffic volumes, aging of pavements and inflated material costs.

Instead of providing preventative maintenance at an early stage, roads were left until much more expensive reconstruction was needed. Unfortunately, the short span of extra service years, during the delay of maintenance, was purchased at a very high price in terms of increased upgrade costs. It is for that reason that PMS was needed to orderly prioritize roads for maintenance at the earlier, cost-effective time.

1.1.1 Data for PMS

The effectiveness of any PMS is dependent upon the data being used (Nashville Department of Transport 2007). Primary types of data needed include pavement condition ratings, costs, roadway construction and maintenance history as well as traffic loading.

A major emphasis of any PMS is to identify and evaluate pavement conditions and determine the causes of deterioration. To accomplish this, a pavement evaluation system should be developed that is rapid, economical and easily repeatable. Pavement condition data must be collected periodically to document the changes of pavement condition.

Typically, condition inventories are input, stored and retrieved on a roadway segment basis. Segments are ideally defined as reasonable sized projects of 1 meter (m) to 250 meter in length, beginning and ending at intersections. Occasionally, varying traffic or construction history make shorter segments necessary.

The maintenance costs used in a PMS are dictated by the available information on the cost of activities conducted. Costs are typically shown as total unit cost per square meter (m^2) for activities. Cost information must be easily updated to reflect current cost values. The cost data is used to make estimates for maintaining a pavement at a given condition and for projecting long-range budget, based on the condition of the pavement.

1.1.2 Use of PMS

With an understanding of the database, an examination of the typical uses of a PMS can be undertaken. The following material briefly describes the main areas where a PMS is applied and the benefits achieved from each:

(a) Street Inventory

The most immediate use of the PMS is in having a complete and readily accessible inventory of country's road system including up-to-date conditions. This information is frequently very valuable for day-to-day use in tracking maintenance work and for reference in preparing reports or studies.

(b) Developing Maintenance Budgets

Rather than preparing the typical 1-year maintenance budget, a PMS allows a country to prepare a series of budgets. These budgets can be in the form of a multi-year program, identifying not only short-term (1 year) needs, but outlining needs over the course of many years. Further, alternatives can be prepared and presented to the budget decision makers.

(c) Prioritization

A PMS allows for the prioritization of maintenance projects based on cost and condition ratings and other factors such as traffic. It further can be used for selecting and ranking of projects for the upcoming budget year, as well as for long term financial planning.

1.1.3 PMS Software Components

The various components of a PMS are illustrated in Figure 1.1 and include:

(a) Road Inventory. This component defines the physical characteristics for each road; stored in road inventory files in the PMS database. Each road is divided into manageable sections called "road segments".

(b) Condition Survey. This is conducting of a windshield survey of each segment of road.

(c) Decision making information. In addition to inventory and condition data, decision making information is required and includes repair strategies, repair alternatives, repair costs and decision trees.

(d) Data Analysis. The PMS software contains analysis tools that identify potential repair alternatives for each segment, calculate the associated estimated repair costs, select the most cost-effective solution for each road segment and prioritise potential projects for budgeting.

(e) Reports. This component has variety of formats including pie charts, bar charts and tables.

(f) Querying capabilities, for determining districts, type of pavement and age or condition of pavement.

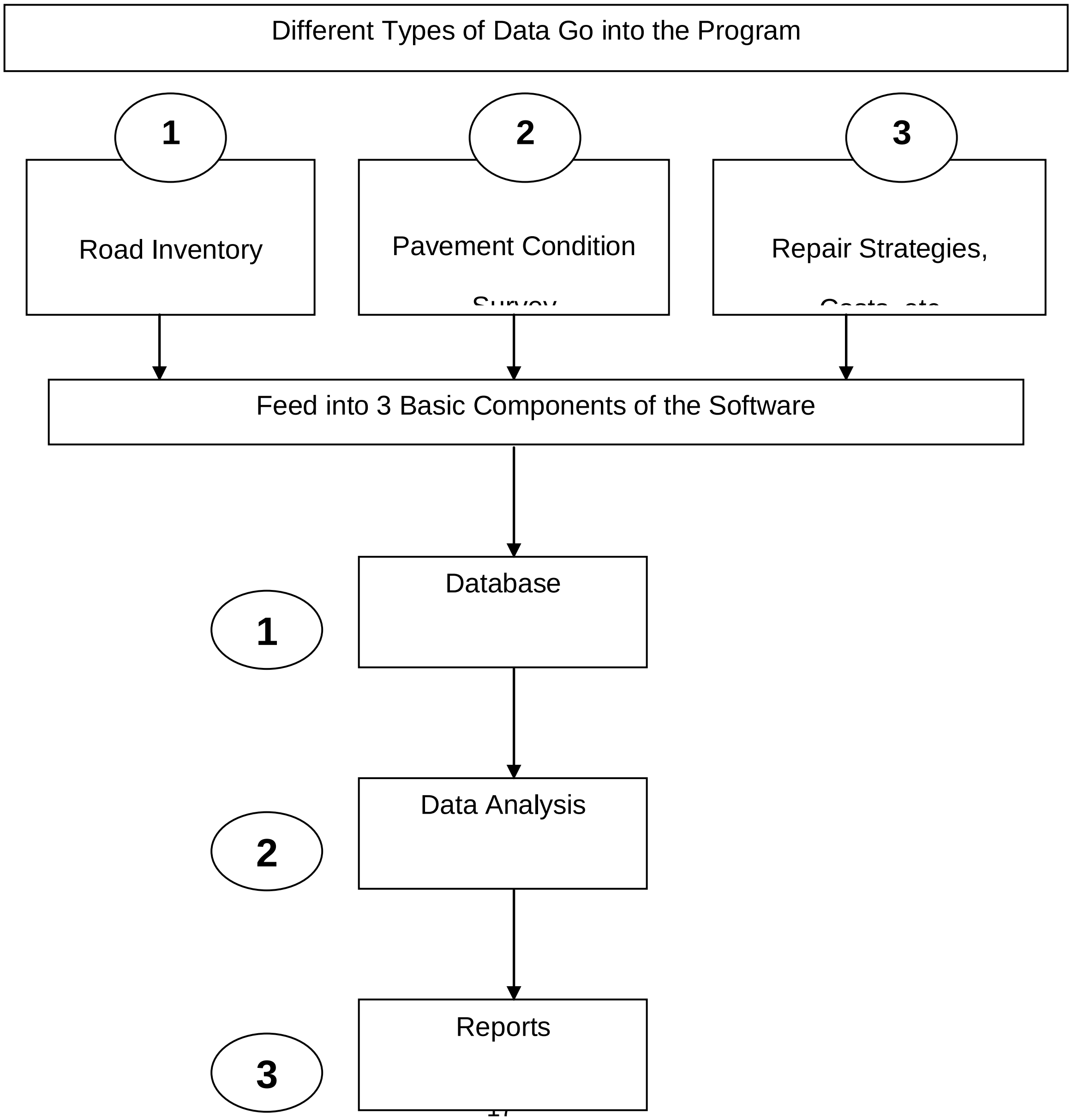


Figure 1.1: Diagrammatic illustration of PMS Program Data Components
(Source: Kercher 2001)

1.1.4 PMS in South Africa

In South Africa (SA), many roads were constructed more than fifty years ago and have been subjected to unanticipated increases in the weights and the numbers of the vehicles using them (National Department of Transport 1998). These increases have occurred during a time when governments at all levels have faced, and are facing, escalating demands on their financial resources (McQueen 2001). It is not surprising that the emphasis today is to plan and budget for their maintenance and rehabilitation. This can be attained by using modern management and engineering techniques (McQueen 2001).

The need for having a PMS in South Africa (SA) was identified by the South African Roads Board (SARB) through the South African Roads Agency Limited (SANRAL) (National Department of Transport 1996). SANRAL, as mandated by SARB, developed a PMS plan and the aim of the plan was to provide PMS Managers with the guidelines regarding the requirements of the PMS. Guided by the PMS plan, different road maintenance authorities (local, metropolitan and provincial) took a mandate of developing and managing their PMS.

1.2 Problem Statement

In 2005, a study was conducted by LCT Civils (a consultancy firm based in the Eastern Free State Province) into the pavement maintenance and management of the road network in Vrede (a town located in the Eastern Free State). One of the main aims of the research was to determine factors which gave rise to the deterioration of the road network in the area especially on the Provincial road R34. Findings of the research by LCT Civils indicated that a reactive maintenance approach was employed instead of pro-active preventative maintenance approach. These means that the quality of the road network in the area was not preserved but instead left to prematurely deteriorate due to deferring of maintenance requirements. However an alternative preventative maintenance approach was not provided to the authorities responsible for road network maintenance in that area. This research sought to address the latter problem.

1.3 **Objectives**

1.3.1 Overall objective

The main aim of the study was to develop a pavement management system for road network maintenance to serve as a decision support tool to assist to improve the efficiency of making decisions, provide feedback as to the consequences of these decisions, ensure consistency of decisions made at different levels and improve the effectiveness of all decisions in terms of efficiency of results.

1.3.2 Specific objectives

The specific objectives of the study were:

a) To identify the main contributory factors in the deterioration of the road,
b) Make recommendations based on these factors to develop best implementation applications,
c) From the implementation applications develop an effective pavement management system to be used as a decision support tool.

1.4 **Justification of the Study**

Pavement Management System is a planning tool that collects and monitors information on current pavement conditions, evaluates alternative repair strategies and prioritizes selected repairs. It serves as a preventative maintenance strategy that seeks to preserve the valuable road infrastructure assets at a reasonable cost to avoid premature total replacement of these assets at a much higher cost.

The implementation of PMS provides necessary information for decision-makers to be well informed and understands the long-term consequences of short-term budgeting decisions. It improves the efficiency of making decisions, provides feedback as to the consequences of these decisions, ensures consistency of decisions made at different levels within the same organisation and improves the effectiveness of all decisions in terms of efficiency of results (Merced County Association of Government 1548).

It also helps in the determination of four crucial factors to pavement maintenance and management namely the current condition of the roadway network, priority in the repair of roads, techniques to be used to achieve the best results and lastly the projected long-term consequences should repairs be delayed and differed.

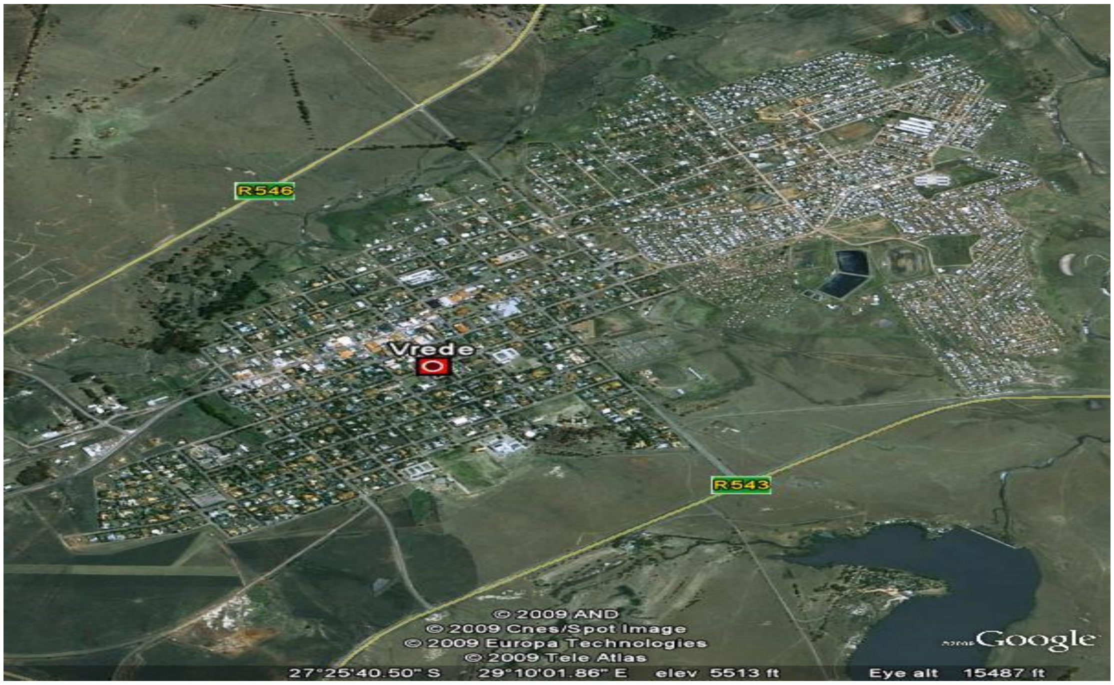
1.5 **Study Area**

The study was conducted on the provincial road called R34 between Vrede and Bothmas Pass (Free State / Kwazulu Natal Provincial Border). Vrede is a small town located in the eastern part of South Africa as shown on Pictures 1.1 and 1.2. Vrede is about 220 km from the Vaal University of Technology (VUT) towards Newcastle in Kwazulu Natal Province. Vrede and Memel form part of Phumelela Local Municipality and are situated on the north-eastern part of the Free State Province. The Free State / Kwazulu Natal border is known as Bothma’s Pass. Diagrammatic illustration of R34 is shown on Pictures 1.3 and 1.4.

Reasons for conducting studies on R34 were to determine the contributory factors to the deterioration of the road, determine the reactive action the relevant maintenance authority had taken to prevent further deterioration and lastly to develop a preventative maintenance strategy that could be used to prevent future deterioration.

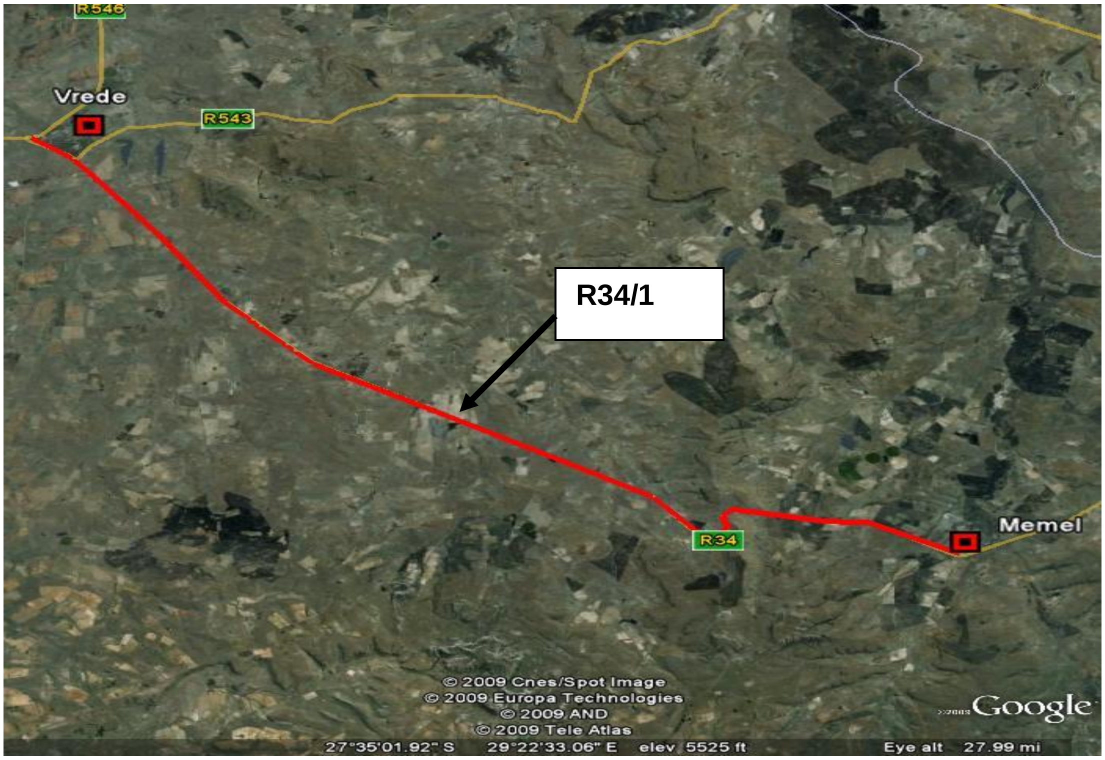
Picture 1.1: Location of the Study Area

(Source: Google Earth 2009)



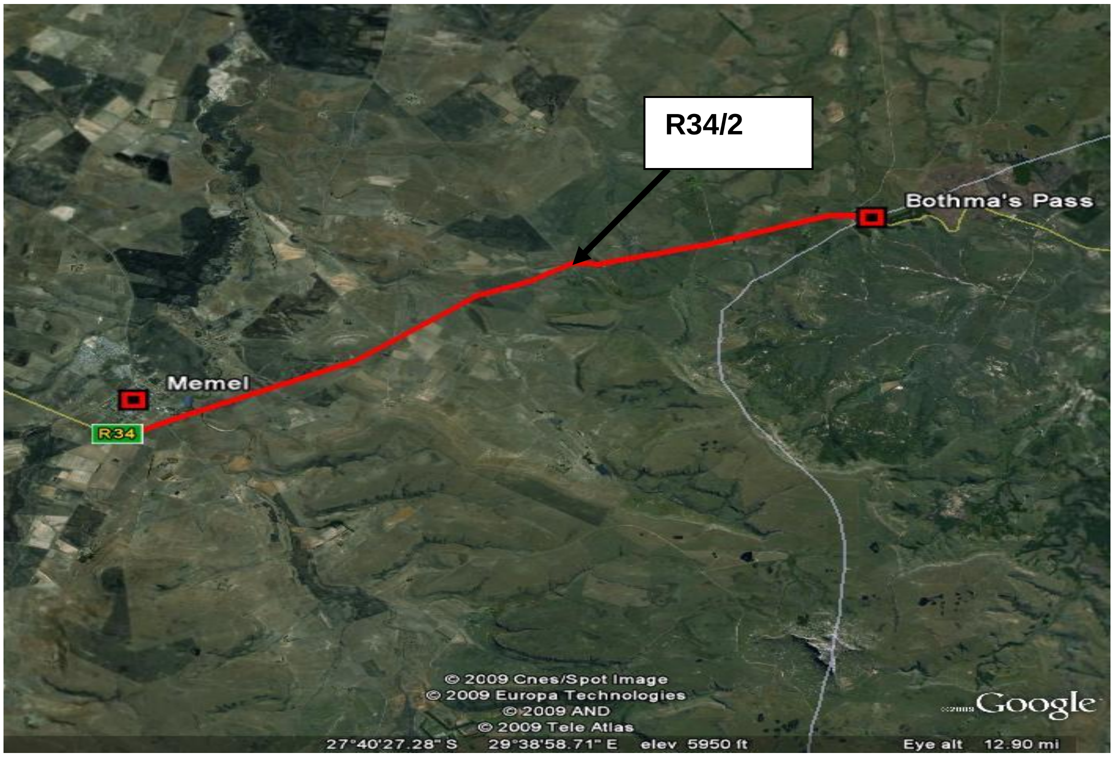
Picture 1.2: Regional Map of the Study Area (Vrede)

(Source: Google Earth 2009)



Picture 1.3: Location of Road R34/1 (Vrede to Memel)

(Source: Google Earth 2009)



Picture 1.4: Diagrammatic illustration of R34 (Memel to Bothmas Pass)

(Source: Google Earth 2009)

2 CHAPTER 2: LITERATURE REVIEW

2.1 Emergence of Pavement Management Systems

It is hard to say exactly when the idea of systematically managing pavement networks first started but it is believed to have started sometime after the building of the first stone-paved roads in Ur in 4000 BC (John 1915). The building of stone-paved roads developed a strong need for their management and maintenance, hence the belief.

Since then, Pavement Management System (PMS) progressed from a concept to current widespread and successful application in many countries around the world, and its implementation was initially achieved in 1960 (Hudson *et al.* 1979).

The initiation of PMS as a process began in about the mid 1960’s (Hudson *et al.* 1979). It was based on the integration of systems principles, engineering technologies and economic evaluation. Among the early published contributions were those involving a systems approach to pavement design, a management system for the Canadian Good Roads Association’s

Pavement Committee and a management system for highway pavements (Hudson *et al.* 1979). These were followed by major advances in developing the component technologies of pavement management, and by the mid 1970's much of the available knowledge was summarized in the first books on pavement management (Hudson *et al.* 1979).

Although perhaps arguable, the modern era began with the explosion of Post World War II road building in the late 1940's and continuing on for the next several decades, the AASHO Road Test, 1958-61, and researchers associated with it, made an enormous contribution to the technology base of PMS (Hudson *et al.* 1979).

The following years saw literally an explosion of interest in PMS and further implementation in many countries around the world. Much of that experience was summarized in the first two conferences on pavement management in Toronto in 1985 and 1987 (Hudson *et al.* 1979). The Third International Conference on Managing Pavements, in San Antonio in 1994 reported further major advances, as did the Fourth International Conference in 1998 in Durban, Republic of South Africa (Hudson *et al.* 1979). The Fifth Conference was held in Seattle in 2001 and illustrated in its many contributions that pavement management is dynamic and continually evolving with new and better technologies and real efforts to achieve integration with the broader spectrum of asset management (Hudson *et al.* 1979).

While there has often been a tendency to view pavement management as dealing primarily with data and data management, excluding design, construction and maintenance meant for administrators and not applicable to small agencies, the original definition and scope of PMS was comprehensive and has stood the test of time; i.e., "A pavement management system encompasses a wide spectrum of activities including the planning and programming of investments, design, construction, maintenance and the periodic evaluation of performance. The function of management at all levels involves comparing alternatives, coordinating activities, making decisions and seeing that they are implemented in an efficient and economical manner" (Hudson *et al.* 1979).

When the concept of PMS began to be formulated, no road agencies anywhere had a working PMS. Certainly many agencies had developed or adopted design methods, and built and maintained pavements according to those methods. In fact, maintenance management systems were well established in various agencies around the world, but the integration or coordination of all these activities into a working PMS, covering both the network and project levels, did not really occur until the mid to late 1970's (Hudson *et al.* 1979). In fact, the first two books on pavement management described design systems and the principles of network level pavement management, but they had no examples of an actual, implemented PMS (Hudson *et al.* 1979).

The initiatives (and risks) subsequently undertaken by a number of pioneering agencies were most instrumental towards expanded acceptance and further development of pavement management. Some of the first published records of implemented PMS began to appear about 1980, and by 1982, for example Session IV of the Fifth International Conference on the Structural Design of Asphalt Pavements was devoted to PMS. It provided descriptions of implemented, working systems in the Netherlands, United Kingdom and United States (Hudson *et al.* 1979).

The success of PMS is largely attributable to a number of key technology developments and/or applications including the following (Hudson *et al.* 1979):

(a) Automated surveillance or data capture equipment and methods, plus highly efficient and versatile database management procedures,
(b) Performance or deterioration model advances,
(c) Life-cycle economic analysis methodology,
(d) Vehicle operating cost (VOC) and user delay cost relationships,
(e) Network level prioritization methodologies,
(f) New and/or improved maintenance treatments and methods,
(g) New, more fundamentally based materials characterization methods for structural design and construction, and
(h) Computing capabilities with processing speed and capacity to make effective the foregoing technologies.

At the time the pavement management concept was first advanced, the available technology for data capture consisted of response type car road meters for roughness, manual condition survey methods for surface distress, locked wheel skid trailers (primarily) for surface friction and the Benkelman beam for deflection (Hudson *et al.* 1979).

Today, many thousands of kilometres (km) of network can be surveyed annually by multifunction data capture devices with the capability of measuring one or more of the following at travel speeds (Hudson *et al.* 1979):

i. Longitudinal profile (one or both wheel paths);
ii. Transverse profile;

iii. Surface distress through keyboard entries or image acquisition (video and CCD) and analysis;
iv. Surface texture;
v. Right-of-way features (video);
vi. Pavement layer thicknesses and other properties (ground penetrating radar), and
vii. Location identification through global positioning system (GPS) capability. Since the early 1960s, PMS has been adopted the world over as a solution to successful road network management.

2.2 Pavement Management Systems the World Over

a) PMS in Australia, like in other countries across the world, is managed at the district and state level, only. It was developed as an in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Other states use commercially available software for this purpose. All states use pavement data collection systems. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking, skid resistance and seal coat age (Anderson *et* al. 1994).

b) By 2005, 1,900,000 km roads had been constructed in China, among them 40,000 km roads were expressways, another 15,000 expressways would have been constructed by 2010 (Liu, 2006). By 2020, a national highway network would be completed with 85,000 expressways. Clearly, China needed a pavement management plan to address past and future pavements. In 1984, China initialised and developed a PMS and since its introduction significant progress, in terms of pavement management, has been made. The implementation of this PMS has not gone so well, due to less focus and acceptance. Most transportation departments in China, are more focused on road construction and not maintenance (Liu 2006).

c) Australia uses long-term (10-year) maintenance contracts to turn over total control and responsibility for roadway system maintenance, rehabilitation, and capital improvements to private contractors. In 1992 the managing authority of the French National Roads Network decided to modernize the means of evaluating the condition of its roads, i.e.

develop a PMS. The tool set up to do this was based primarily on a systematic survey of pavement surface damage, completed by skidding resistance measurements. For the evaluation tool to have the expected qualities, there had to be a special effort to make the damage survey a means of investigation as reliable as a measurement. The laboratories used a highly formalized method that precisely fixed the conditions in which the survey had to be performed, the type of information recorded, and its codification. Asset management programs for pavements have been used as effective methods for determining maintenance needs and increasing funding (Federal Highway Administration 2008).

d) In Germany the design of a new, complete pavement management system is under way. Major components are already operational. Meanwhile, data on road conditions have been collected with high-speed monitoring systems over the national road network, including the Autobahn. The data is assembled according to evenness, skid resistance, and surface damage and subsequently classified via a special grading system. By applying special algorithms, a service value, a structural value, and an overall condition value are being developed. The results of the survey are then presented in lists, route section graphs, and network graphs with different colours indicating where specific target, warning, and threshold values are exceeded. By means of continuous feedback, the information collected is used to improve and adjust the system's components and the plausibility of the output. There is an agreement that for an effective PMS application, repeated automated network monitoring is necessary. To minimize necessary monitoring and evaluation efforts, the use of multifunctional automated monitoring systems is used to collect all necessary data during a single pass (Burger *et al*. 1994).

e) The first experience of PMS in Italy was through the Province of Milano. Following the adoption of a new law in 2001, major portions of the interurban state road network had been transferred from the national road agency (ANAS) to the jurisdiction of the provincial governance. This transferral of competences brought up a number of consequences in the field of maintenance and management and in particular the need for the Provinces to optimise budget funds dedicated to the new additions to their road network. The latter situation led the Province of Milano to the adoption of a new approach for the task of pavement maintenance aiming at a more rational solution based on objective criteria for intervention planning (Crispino *et al* 2004).

f) In December 1998, New Zealand (NZ) embarked on an ambitious project to implement a National Pavement Management System (NPMS). A software called Deighton Transportation Infrastructure Management System (dTIMS) was chosen as the software application for multi-year programming road works. A pragmatic approach was selected and followed in the implementation of the NZ NPMS. The main aim or benefit of this approach was that it manifested an evolutionary progression for everyone rather than perfection of a system for a few and at much later date. In adopting this approach, a preliminary NZ dTIMS system was developed within a relatively short time-frame during the first seven months of the project using available information and systems (Phase I). This system was then further refined from feedback from the system users and the refined system was released in October 2000, marking the end of Phase II of the project. Phase II included further research and development. Phase III of the project was also developed and has brought about further refinements, operational research and enhancements, continued training and support for users. A year after the beginning of the NZ dTIMS project, more than 84 systems were being used by about 47 different RCAs throughout NZ. To date, the system is being used by all RCA's in NZ, with success. NZ has reported that its NPMS has been successful since its implementation. NZPMS has even awards at home and internationally and is recognised all engineering institutions in NZ, including the Institution of Professional Engineers New Zealand (IPENZ) (Wilson *et al*. 2002).

g) The Spanish Ministry of Public Works and Transport has implemented a PMS for its road network. Studying the experience of other authorities had been extremely important in selecting a method. The aim was to adapt the system to the circumstances of the network. The system was implemented in stages in order to produce results as soon as possible and to not lose the advantages of a rigorous approach. The existing requirements and resources available were considered in selecting the data to be collected. Some of the problems that had arose during the work had been successfully solved, and it is hoped that others would be solved in the future. The first stage has been implemented, and work is under way on the second stage (Gutierrez-Bolivar & Achutegui 1994).

h) The United Kingdom Pavement Management System (UKPMS) is a computer system that was designed for the economic management of the structural maintenance budget of a road network and dates back to the early 1980's. It incorporates a new system of visual data collection, data analysis, and budget allocation for all roads and has combined data from different types of condition surveys. Other significant features include the ability to project condition data into the future; this enables the user to take account of the economics of alternative maintenance treatments when deciding where and what treatments should occur. The core philosophy of UKPMS is to defer treatments where it is cost-effective and safe to do so and to give priority instead to preventive maintenance. The UKPMS provides standards for the assessment and recording of network condition and for the planning of investment and maintenance on roads, kerbs, footways and cycle-tracks within the UK. UKPMS provides a framework for combining the systematic collection of data with the decision-making processes necessary to optimise resources for the maintenance and renewal of pavements, including the generation of programmes of works and corresponding budgets. It is used by local authorities in the UK for the management of roads, and for the production of performance indicators that are used nationally (Scott Wilson Group OLC 2007).

2.3 Pavement Management Systems in the South African Context

PMS in SA occurs through the Asset Management System (AMS) and is maintained, with guidance from the SA PMS Plan, independently by different road network agencies, i.e. local and metropolitan levels (National Department of Transport 2006). By local level, it is referred to local and district municipalities.

AMS process (illustrated in Figure 3.3) refers to a systematic method of information collection and decision making support to permit the optimisation of resources for maintenance, rehabilitation and construction of new roads, generating a programme of works and corresponding budget which match a defined level of service (National Department of Transport 2006). AMS strategies in SA vary among different road authorities (local, metropolitan and provincial) as it is believed by National Department of Transport (2001) that there is no single "best" strategy, nor is there a universal set of criteria that can be applied to all road networks.

While in general terms there are undoubtedly budget programming strategies that are more appropriate than others, given specific conditions, the factors that influence the selection process are varied and complex (National Department of Transport 2001).

PMS in SA is a data-intensive system that uses state-of-the-art technology, computer programs and global positioning system (GPS) technology. The information is used for measuring system condition, predicting service life and selecting future projects. The program is used to validate cost benefits of pavement preservation and maintenance activities.

The SA PMS applies a two-step process of generating strategies and their optimisation. The optimisation process aids in selection of the most economical strategy within budget parameters. Even though the PMS determines optimum strategies, a field panel selects the final construction work program. This selection is then reviewed and final project selection may be modified to meet local needs and considerations.

A key component of SA PMS road condition analysis is the annual visual evaluation, which is based on the Technical Methods for Highways (TMH) 9 handbook. Rates are trained and certified to ensure consistency among the provinces. The annual evaluation is combined with mechanical measurements for use in the calculation of road condition indices. Mechanical measurements of the road, done every two to three years, include traverse and longitudinal profiling. The road indices are then used to formulate optimisation of preventative maintenance based on available funds.

2.3.1 Data Collection

Data collection is usually done through one of the following methods:

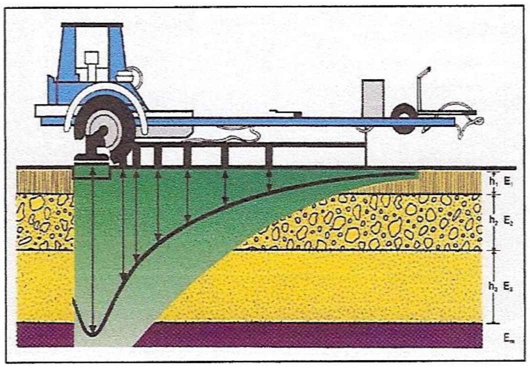
(a) Road Survey Vehicle (RSV)

RSV, as shown on Picture 3.1, uses the latest technology and records, traffic and weather permitting, various road characteristics (condition data) whilst moving along with the traffic stream at speeds between 20 to 120 kilometres per hour (km/h). Data can be collected on over 500 lane km per day per RSV. The digital electronic components used by the vehicle includes numerous lasers, accelerometers, gyro's, different GPS, Digital Video Systems (DVS), distance measuring instruments and power supply systems.

Picture 2.1: SANRAL Road Survey Vehicle
(Source: SANRAL 2006:5)

(b) Falling Weight Deflectometer (FWD)

FWD refers to a trailer mounted device as seen in Picture 3.2 and Figure 3.1 that simulates the effect of moving heavy vehicle wheel load (80 km/h) by applying a dynamic impulse load to the pavement, and then measuring the subsequent deflections that occur at various radial distances from the load centre to provide a deflection bowl.



Picture 2.2: Falling Weight Deflectometer (Source: SANRAL 2006:7)

Figure 2.1: Schematic Illustration of FWD (Source: SANRAL 2006:7)

(c) Traffic Monitoring Stations (TMS)

TMS are electronic monitoring equipment that makes use of induction loops and other sensors installed in the road surface to monitor the movement of vehicles. Depending on the sensors used this enables us to determine down to five minute intervals how many of which vehicle class past the measuring point, their speed, their following distance and even weight on each axle. TMS is shown on Figure 3.3.

Figure 2.3: Traffic Monitoring Station
(Source: SANRAL 2006:8)

(d) Incidents

Additional information is also collected with regard to all incidents that occur on the road network within the country.

(f) Routine Maintenance Costs

In addition to the above primary data items, information is also collected with regard to all routine maintenance expenditure that occur on our road network.

2.3.2 Data Analysis

Data analysis applies a two step operation. Step one is generating strategies and step two is optimisation. Briefly, step one, generates the life cycle costs and benefits for a list of Strategies using deterioration models and data which describe the network. Step two, selects one Strategy for each Uniform pavement section from the Strategy List so that the overall network objectives are met and the constraints are not violated.

(a) Generating Strategies

During this stage, each uniform road section is examined, one at a time. Based on observed historic performance it predicts the future condition over a time period of 20 plus (+) years, the Analysis Period. The costs and benefits for a list of feasible repair Strategies for that uniform road section gets generated by predicting how each Strategy would affect the condition over the Analysis Period. A repair Strategy consisting of one or more maintenance treatments in different years during the Analysis Period is then generated.

(b) Optimisation

Optimisation selects one Strategy from the list for each uniform pavement section so that the established network objectives are met while not violating the constraints. The constraint is usually the yearly budgets. For different sets of budget, different Strategies are selected. If zero budget is provided, the do-nothing Strategy for each uniform pavement section is selected. If infinite budget is provided, the best Strategy for each uniform pavement section is selected. Between these two extremes, optimisation uses the incremental benefit cost technique to find the most economic Strategy for each uniform road section without exceeding the budget. The incremental benefit cost technique determines the most incremental benefits on money invested.

(c) Decision-Making

Once the Strategy List for each uniform road section has been generated, the next challenge becomes which Strategy to choose. Optimisation selects the best Strategy for each uniform pavement section taking the objectives and constraints into consideration. The Selected Strategies form the Budget Programme recommended by optimisation. However, all of the other factors involved in developing a Budget Programme cannot possibly be considered. This is why the Budget Programme as generated, is then reviewed and adjusted by a Review Panel. The Review Panel involves the physical visit of each uniform road section and the review of recommendations by a panel consisting of experts from the Agencies involved.

2.4 Remarks

It is apparent from the literature review above that since PMS emergence in the early 1960s, road authorities throughout the world have adopted PMS as a solution to road network management. Its development and implementation has had successes and shortcomings to different extents.

There are a number of key problem areas with the existing PMS that are being used by the international road authorities namely the high establishment costs, high maintenance costs, complicated in terms of its format and in data collection, unreliable in pavement performance modelling, need for training and expensive. There is therefore a need for a cost effective and easy to use pavement management system.

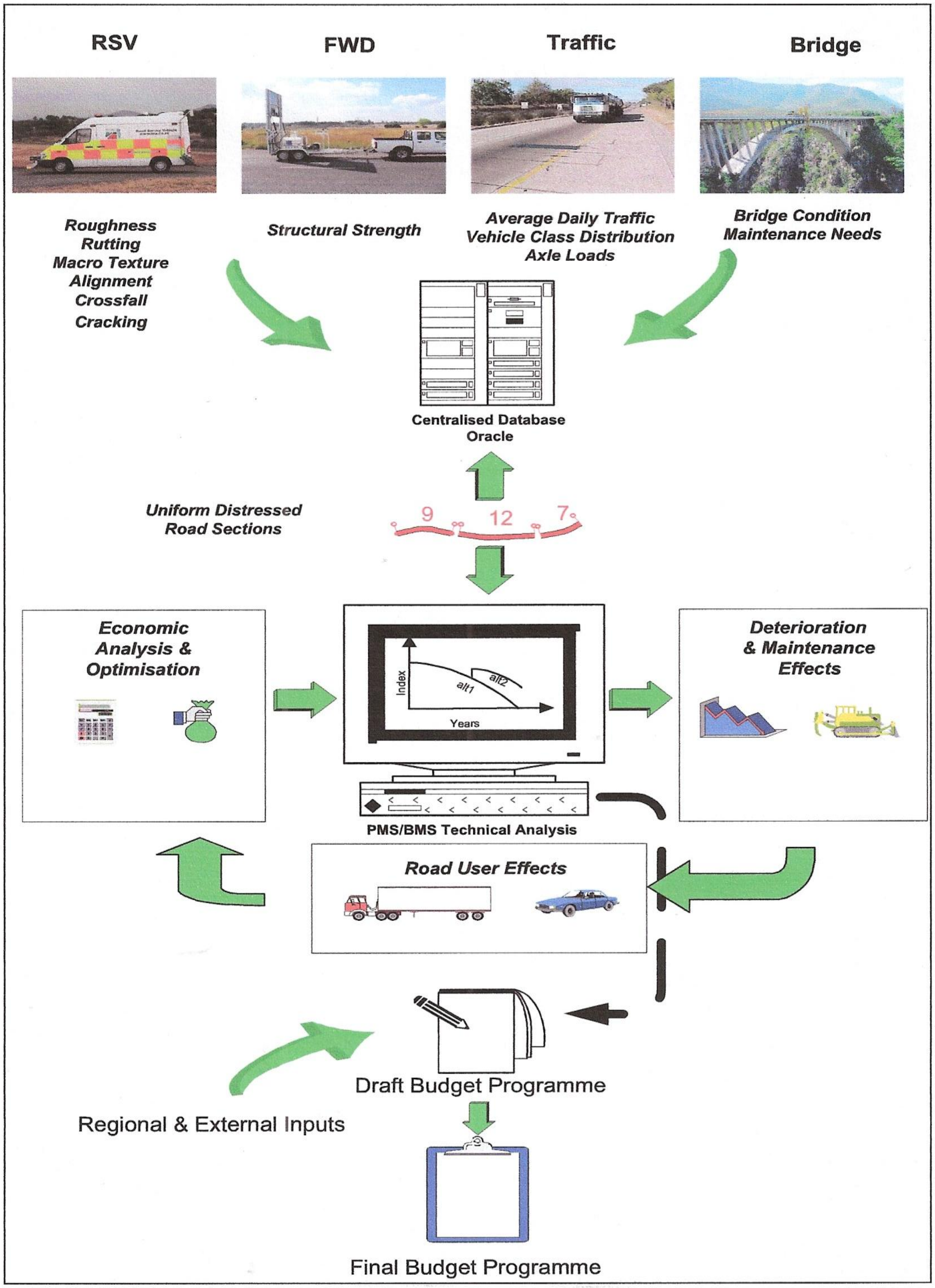


Figure 2.2: Asset Management Process in SA (Source: SANRAL 2006:10)

3 CHAPTER 3: METHODOLOGY

In order to achieve the overall objective of developing a pavement management system for road network maintenance to serve as a decision support tool to assist to improve the efficiency of making decisions; the following procedure was followed:

3.1 Literature Survey

Literature survey was conducted to acquire information regarding the PMS. Documents and reports available on, and related to, pavement management system were reviewed. Such documents and reports were acquired from various sources including libraries, the internet, journals and books.

The information acquired included the history and performance of existing PMS that are being managed by different road maintenance authorities in the country and throughout the world. The attributes and short comings of such PMS were also investigated.

Historical information of PMS that was investigated included the emergence of PMS, its past, present form and possible future based on its current status and the possible technological advancements that could be used to improve it.

Information regarding the global PMS status was acquired through investigations of PMS in all continents through studies conducted in different countries the world over. Those countries included Australia, Canada, China, France, Germany, Italy, New Zealand, Spain and the United Kingdom.

PMS of different South African road maintenance authorities was also acquired. Acquiring of such information was done through consultation with the relevant authorities from the South African National Roads Agency Limited (SANRAL), South African Roads Board (SARB), Council for Scientific and Industrial Research (CSIR), Provincial Road Departments, Local Municipalities, Consulting Engineers and Contractors.

3.2 Data Collection in the Study Area

In this study, three methods were used to collect data. The methods used were, (a) Visual Condition Assessments (VCA), (b) Non-destructive testing and (c) Semi-destructive testing. However, before these methods were employed to collect data, the evaluation of the environment of the study area was undertaken to determine the possible effects the environment might have on the road. The methods are discussed in detail below.

a) Visual Condition Assessments

Visual Condition Assessments (VCA) refers to the visual inspection of the condition of the pavement and is used to determine visual condition index, maintenance and rehabilitation needs and prioritisation at the network level of the road network.

The conduction of VCA in this study was performed in accordance with guidelines contained in the Urban Transport Guidelines (UTG) 12 for Standard Visual Assessment Manual for Flexible Pavements in Urban Areas, Technical and Recommendations for Highways (TRH) 22 for Pavement Management System and Technical Methods for Highways (TMH) 9 for Pavement Management Systems Standard Visual Assessment Manual for Flexible Pavements.

VCA was achieved through the conduction of assessments by trained assessors on site where visible distresses were recorded on inspection sheets. Distresses were defined by recording of their main characteristics, the so-called attributes of distresses, namely the type, degree and extent of the occurrence.

Type of distress refers to the different modes of distress for example cracking or pumping. The degree of a particular distress is a measure of its severity. The extent of distress refers to a measure of how widespread the distress occurs over the length of the road segment.

Visual assessments were carried out towards at the end of the rainy season, in May 2007, and the reason was to determine the effect the rainy season had had on the pavement structure. Data acquired included the following types of distress; the surfacing assessments (texture, voids, surfacing failures, aggregate loss, bleeding and polishing), structural assessments (traverse cracks, crocodile cracks, pumping, rutting, undulation, patching, potholing, depression and displacements), functional assessments (riding quality, skid resistance, drainage, shoulders and edge breaks.

The first step taken towards conduction of assessments involved breaking down of the road length into segments of 200 m in length. The reasons for dividing the road length into segments was to narrow down the road network for easy identification of the distress occurrence per specific location over the road length and also for easy prioritisation for maintenance and rehabilitation requirements.

Contained in each road segment were crucial items namely the road number, name of assessor, start and end kilometre distance, date, road category, road classification, road type, district, climate, terrain, road width, pavement structure, pavement age, shoulder width and traffic class.

Data was recorded onto field assessment forms on site. After conduction of assessments was completed, a representative sample of at least 10% of data acquired was checked on site to verify data recorded. The reason for checking the data for any faults is due to the fact that the key component to a quality PMS is quality data collection during the pavement evaluation process.

The functional features of the road were also investigated. Functional feature assessments were conducted to determine the influence of distress towards the function that the road sought to provide in regard to the standard of service being given to the road user. Those assessed were the riding quality, skid resistance, surface drainage, condition of the shoulders and edge breaking.

b) Non-destructive Testing Technique

Non-destructive testing technique was employed during data collection and was used to allow examination of a considerably broader expanse of pavement than is practical with physical sampling. Non-destructive testing techniques used were Traffic Investigations, Riding Quality, Falling Weight Deflectometer, Rutting and Material Investigations.

Electronic traffic counts were also conducted in October 2007 to determine the status quo traffic volumes utilising the road in order to analyse capacity and estimate the annual traffic growth of the road length.

The riding quality was measured in October 2007 as part of the assessment of serviceability of the road and the data acquired was to be analysed in terms of the International Road Index (IRI).

Falling Weight Deflectometer surveys were also conducted in October 2007. The deflection data acquired would be analysed in terms of the criteria published in TRH12 to determine uniform sections occurring in the alignment and to establish their bearing capacity and estimate remaining life.

Mechanical Rut surveys were conducted in November 2007 according to guidelines published by TRH12 and in conformance with the method called Cumulative Difference Method proposed by the American Association of State Highway and Transportation Officials (AASHTO) Design Manual for Flexible Pavements. Data acquired is shown on page 37.

Material investigations involved the investigation by the road prism into the centreline of the pavement including shoulders the cuts and fills of the geotechnical side of the pavement conditions. Test pits were excavated at selected positions and samples acquired as shown on page 40 for testing and analysis.

c) Semi-destructive Testing Technique

Semi-destructive testing methods that in general deploys a penetration device thorough a small diameter hole were conducted as they are typically faster, cheaper and provide detailed information into the condition of the layers of the pavement structure. Samples were from the field using a technique called Dynamic Cone Penetration (DCP). DCP field data was acquired through a process where DCP surroundings were done at excavated test pit positions on the existing alignment as well as between each test pit. In total, 55 DCP soundings were done and at each of the test pit position prior to excavation thereof as shown on Table 4.7.

3.3 Data Analysis

Data was analysed through five steps namely data management, pavement condition analysis, treatment recommendation, prioritisation and project implementation. The steps are discussed in detail below.

Step 1: Data Management:

In the office, a data base using a simple Microsoft excel software was developed. To make data input easier the data base was designed to look the same as the site data collection form. The data base is attached in Appendix B.

The PMS data base using Microsoft excel software was then developed. After the PMS development, data was imported from the initial data base into the PMS data base and checked for any errors and its validity, accuracy and integrity verified.

Step 2: Pavement Condition Analysis:

The visual condition analysis was performed on pavement distress data collected through visual condition assessments of the pavement surface. The main aim of the analysis was to determine the Visual Condition Index (VCI) which is used to determine the general condition of the pavement. VCI was calculated in accordance with the guidelines published in TRH22. The VCI results are attached in Appendix C .

The VCI determined was then compared to the condition categories table that is contained in TRH22 in order to determine the condition of the road in terms of how very poor, poor, fair, good or very good it is.

Traffic data was then analysed to determine the status quo in terms of traffic, the traffic growth rate on the road and lastly the capacity of the road in terms of its handling of traffic.

Riding quality data was used to determine the general extent to which road users, through the medium of their vehicles, experience the ride that is either smooth and comfortable or bumpy and therefore unpleasant or perhaps unsafe.

Data acquired through FWD was analysed and used to estimate the remaining life of the various sections of the road length in terms of maximum deflection (Ymax), base layer index (BLI), middle layer index (MLI) and lower layer index (LLI), for both the *Average* and *90th percentile* analyses.

Rut data was compared to determine if it conformed to the required standards for the similar pavement structure located within similar conditions.

Representative soil samples that were collected from the different soil horizons on site were subjected to laboratory testing to determine the Atterberg limits, grading, Mod AASHTO compaction and California Bearing Ratio (CBR) etc. for classification. The main aim of the exercise was to identify problems that required special attention, i.e. problematic soils and unfavourable subgrade conditions.

Capacity analysis in terms of DCP of the pavement structure was done to compare the existing structural capacity with the required standards for the similar pavement structure located within similar conditions.

Historical information was analysed to determine if the road had deteriorated or failed before its initial design life and the physiographical information to determine the climatical, topographical and geological status of the area where the road is located.

After consideration of all the results acquired, a holistic approach was taken in terms of the general condition of the road.

Step 3: Treatment Recommendation:

Based on the overall condition of the road determined in step 2 and with consultation with the guidelines published in TRH22, a decision was made in terms of what treatment is needed to address the deterioration of the road. The treatment recommendation is contained on page 52.

Step 4: Prioritisation and Ranking:

The priority and ranking of the treatment in terms of its urgency was then determined using the condition of the road with reference to the guidelines published in TMH9 and is shown on page 52.

Step 5: Project Implementation:

Recommendations are then made regarding the implementation of the project to avoid further deterioration and possible additional costs should the rehabilitation process be delayed.

With the results and information obtained from data analysis and consultations an easy to use pavement management system was developed, tested and recommendations were made towards overcoming the challenges experienced.

4 CHAPTER 4: ANALYSIS AND DISCUSSIONS OF THE RESULTS

In order to achieve the objective of the study, data was collected from the field and analysed in the laboratory. Data collected from the field included of visual condition assessments, traffic investigations, riding quality, falling weight deflectometer, rutting, material investigations and dynamic cone penetration analysis and is presented, analysed and discussed in this chapter.

4.1 Environmental Evaluation

The environment where the road is located was evaluated to determine the possible effects it might have on the road and it was found that the area had a Weinert N-value of between 2 and 5 and is therefore in the moderate part of the country. The Weinert's climatic N-value is an important parameter for predicting the mode of weathering and the general soil profile.

Precipitation or evaporation ratio is as important as the Weinert N value. Based on the Weignert N-value of between 2 to 5 and taking into account the status of the road, it can be concluded that the deterioration on the route is also due to chemical weathering and disintegration. The latter is based on the following facts where when N<5 (low) it means leaching is favoured over decomposition, N>5 (high) it means disintegration is favoured over decomposition, N<5 it means chemical weathering is favoured over mechanical and decomposition and lastly when N>5 it means that mechanical weathering is favoured over chemical and decomposition.

The rainfall of the area varies from 750 mm – 1,000 mm per annum, mainly during the summer months. The precipitation decreases from Botha's Pass on the edge of the escarpment towards Vrede. Hot summers and cold winters are typical of the interior plateau of Southern Africa.

It is therefore evident that the effects of the environment have had a negative effect and contributed towards the deterioration of the road.

4.2 Visual Conditions Assessments

Areas where severe deformation and pavement failures occurred were observed and recorded. It was noted that these failures were more pronounced in the outer wheel paths and especially in areas where the road traversed through cuttings. These failures were traffic induced and gave rise to cracking in the wheel paths. As a result of these cracks, moisture penetrated into the pavement layers resulting in a total loss of the pavement's structural capacity at selected positions. Failures were also found to have been caused by spalling of reseals or overlays around cracks, mechanical damage to the surfacing and localized loss of surfacing owing to poor bonding with the underlying layer. The degrees of surface failures in some areas were significantly visible and of "3" degree and appeared to have been caused by disintegration of weak aggregates. The condition survey data results are shown on Appendix B.

It was evident that large sections of the road network were extensively patched. Some of the existing patches were beginning to fail. Typical modes of failure observed in the distressed patches were cracking and deformation. The patchwork on specific localised areas on the road network indicated that the existing pavement structure could not accommodate the imposed traffic load. This implies that structural rehabilitation will be required if the road is expected to function to the required level of service for a design period similar to that of the life of the seal that would be needed for construction.

Furthermore, very little bleeding was noted on the road network. The condition of the existing surfacing appeared to be dry and brittle in general. Bleeding appeared to be rich in excess binder but with stones visible in the binder. It was also noted that severe crocodile cracks were observed in distressed areas. The occurrence of cracking conformed to areas where deformation and pavement failures had been noted. These cracks normally occur as a result of fatigue failure of the surfacing and base layer. This defect can be directly related to the inability of the pavement structure to carry the imposed traffic loading at selected positions. The dry and brittle condition of the surfacing in places was found to be a contributing factor. Cracking that occurred at drainage structures indicated to have been caused by poor compaction of the material during construction.

Aggregate loss was visible and had been caused by insufficient binder which resulted in texture surfacing being coarse in appearance. In the case of thin surface treatments, aggregate loss could eventually result in exposure of the underlying layer, and seeing that the unbound layers were present, potholing would occur; therefore aggregate loss should be repaired immediately. Small isolated surface failures from mechanical damage were also noted. Isolated failures also caused severe edge breaks in some streets. In those streets, this indicated that the streets in question were too narrow for traffic. The problems associated with edge breaking were found to have been caused also by lack of maintenance on the road shoulders.

During the condition survey, it was also observed that polishing was present and appeared to be severe in some areas. Where present, polishing caused the reduction in skid resistance. Visual assessments also indicated that rutting was present and was observed to be fairly wide and even shaped. It was measured and recorded as just discernible at “3” degree (i.e. between 10 – 15mm). There was however a section of the road where rutting was severe at “5” degrees. Further to that, undulation was observed and appeared to have been caused mainly by insufficient compaction during construction which led to potholing. Potholing appeared over large sections of the road network. It was noted to be worse in Vrede where a 140 mm deep pothole was noted.

In addition to defects mentioned above, a small area over the road network appeared to have a depression problem. It should be noted that depression causes ponding of water on the road network which in turn poses danger to road users and must therefore be repaired. Untreated depression on the road network leads to displacement which in turn reduces the riding quality of the road network and should therefore be maintained. The displacement resulted in the ride being fairly smooth and slightly uncomfortable, with intermittent moderate unevenness of the road profile, moderate rutting and ravelling. This in turn renders the surface texture to have excessive roughness, which is not acceptable.

4.3 Non-destructive Analysis

4.3.1 Traffic Analysis

Traffic analysis was conducted to determine its effect on the deterioration of the road. Base year traffic volumes were compared to the current traffic volumes and used to determine the traffic growth rate of the road.

The status quo traffic volumes information were obtained from Phumelela Local Municipality and are shown in Table 4.1.

Table 4.1: KM 14,0: ADT and ADTT (24 Hour)

DESCRIPTION	LIGHT	HEAVY			ADTT	ADT
		Short	Medium	Long		
East Direction	644	22	18	37	77	721
West Direction	648	23	23	45	91	739

It can be deduced from Table 4.1 that that the directional split on a daily basis is very close to 50/50 in the East and West directions. The surveyed ADT is 1,460, which can be assumed to be 1,500 vehicles per day after adjustments for the fact that the surveys were conducted outside school holiday time periods. The status quo volumes on other routes in the vicinity of R34 were also determined, and the volumes are indicated in Table 4.2. It should be noted that these routes were selected for the purposes of determining any possible deviation onto the R34 in future, especially with the upgrading of the Verkykerskop route (S18).

Table 4.2: Other Routes in Vicinity of R34 (24 Hour)

OTHER ROUTES	LIGHT VEHICLES	HEAVY VEHICLES	TOTAL
S18	71	6	77
S56	60	12	72
S57	55	4	59
S1204	23	18	41
S692	92	10	102
S803	40	1	41

From Table 4.2 it can be seen that the volumes are very low on the other routes, with the S18, S56 and S57 carrying in the order of 59 to 77 vehicles (two-way) per day.

The growth rate was calculated based on the historical data and determined to be 4,7% of total traffic. Taking the growth rate results, a sensitivity analysis for a 20-year design period was done based on the latest traffic data. Furthermore, traffic growth factors ranging between 3,5% and 5,5% per annum and factors for E80 per Heavy Vehicle ranging between 1,1 and 3,25 were selected for the analysis.

Capacity analyses were performed with application of the procedures prescribed in the Highway Capacity Manual (HCM) of 2000. For this purpose, two types of analyses were performed, namely a general rolling terrain analysis, which addresses the complete study area, and then also a more detailed analysis, where specific upgrades are considered. For the general terrain analysis, based on a Rolling Terrain analysis for the complete section, the results were that existing Level of Service (LOS) was found to be “C”, just exceeding LOS B, and years until LOS D is reached would be 21 at a 4% growth rate. For the specific upgrades, the HCM analyses were also conducted to determine the existing LOS (year 2007), as well as future years LOS. This was based on the 30th highest hour as a design scenario, with grades in excess of 3% and lengths of between 500 – 600 metres as minimum length. The approach followed was to determine the number of years (from an assumed opening date of 2010) before a LOS D is exceeded. The results are presented in this format in Table 4.3 (Vrede to Botha’s pass direction) and Table 4.4 (Botha’s pass to Vrede direction).

Traffic growth rate of 4.7% per annum on the project route indicates that traffic growth is significant taking into consideration the change in growth from the base year to the current state of traffic of the road.

Table 4.3: Level of Service (Vrede to Bothma’s Pass)

a) Vrede to Memel

Description	Chainage (begin)(m)	Chainage (end) (m)	Grade (%)	Length (m)	Percent time spent following	Avarage travel speed (km/h)	LOS Base year 2007	LOS Acceptable until (2% growth):	LOS future year 2030	LOS Acceptable until (4% growth)	LOS future year 2030	LOS Acceptable until (6% growth)	LOS future year 2030
U1	3097.63	3903.79	4.85	806.16	57.5	96.5	C	2030	D	2024	E	2018	E
UM1	5596.21	8171.33	3	2575.12	55.9	93.1	C	2030	D	2024	E	2018	E
UM2	11152.76	13649.27	3.22	2496.51	55.8	93.2	C	2030	D	2024	E	2018	E
U2	21450.45	22029.3	4.59	578.85	58.3	96.9	C	2030	D	2024	E	2018	E
UM3	35730.61	37776.8	3.53	2046.19	55.6	92.5	C	2030	D	2024	E	2018	E
U3	39311.71	39912.9	4.35	601.19	57.9	97.7	C	2030	D	2023	E	2017	E
UM4	41508.14	43924.7	4.26	2416.56	59.4	91.6	C	2030	D	2023	E	2017	E
U4	46909.69	47623.45	6.14	713.76	57.5	96.2	C	2030	D	2024	E	2018	E
U5	48268.78	49091.37	3.69	822.59	57.1	97.5	C	2030	D	2023	E	2018	E

b) Memel to Bothma's Pass

Description	Chainage (begin)(m)	Chainage (end) (m)	Grade (%)	Length (m)	Percent time spent following	Avarage travel speed (km/h)	LOS Base year 2007	LOS Acceptable until (2% growth):	LOS future year 2030	LOS Acceptable until (4% growth)	LOS future year 2030	LOS Acceptable until (6% growth)	LOS future year 2030
UM5	3950.98	5949.99	4	1999.01	57.4	92.1	C	2030	D	2024	E	2018	E
UM6	8652.41	10971.03	3.58	2318.62	57.4	92	C	2030	D	2024	E	2018	E
U6	12784.05	13468.13	5.01	684.08	56.7	97.1	C	2030	D	2024	E	2019	E

Table 4.4: Level of Service (Bothma's Pass to Vrede)

a) Memel to Vrede

Description	Chainage (begin)(m)	Chainage (end) (m)	Grade (%)	Length (m)	Percent time spent following	Avarage travel speed(km/h)	LOS Base year 2007	LOS Acceptable until (2% growth):	LOS future year 2030	LOS Acceptable until (4% growth)	LOS future year 2030	LOS Acceptable until (6% growth)	LOS future year 2030
U1	823.5	0	3.21	823.5	58.3	98.2	C	2030	D	2023	E	2018	E
U2	3097.63	2174.27	6.4	923.36	58.5	96.2	C	2030	D	2024	E	2018	E
U3	4650.64	3903.79	3.82	746.85	57.9	97.4	C	2030	D	2023	E	2018	E
U4	11152.76	10400.86	3.44	751.9	46.9	101.5	B	2030	C	2027	E	2020	E
UM1	25597.17	22802.38	3.37	2794.79	49.6	94.2	B	2030	C	2026	E	2020	E
UM2	47623.45	46909.69	6.14	713.76		90.8	C	2030	D	2023	E	2017	E
U5	51505.77	50619.6	4.36	886.17	59.3	96.8	C	2030	D	2023	E	2017	E

b) Bothma’s Pass to Memel

Description	Chainage (begin)(m)	Chainage (end) (m)	Grade (%)	Length (m)	Percent time spent following	Avarage travel speed(km/h)	LOS Base year 2007	LOS Acceptable until (2% growth):	LOS future year 2030	LOS Acceptable until (4% growth)	LOS future year 2030	LOS Acceptable until (6% growth)	LOS future year 2030
UM3	2199.63	852.98	3.42	1346.65	58.8	92.8	C	2030	D	2022	E	2017	E
UM4	7059.16	5949.99	4.97	1109.17	57.1	92	C	2030	D	2024	E	2018	E
UM5	12114.15	10971.03	3.33	1143.12	57.1	91.9	C	2030	D	2024	E	2018	E

From the results indicated in Tables 4.3 and 4.4 it can be seen that the LOS is C in the base year on all the major sections. With a 4% growth rate, the LOS is expected to deteriorate to an unacceptable level in 12 to 14 years from the opening date. With a 6% growth rate, the LOS is predicted to be unacceptable within 7 to 10 years from the opening date. Due to the predicted LOS, climbing lanes would be required on all the major upgrades indicated in Tables 4.3 and 4.4 within the capacity design life of the route, based on the historical growth rate of 4,7% per annum.

Based on the traffic engineering investigations shown on Tables 4.3 and 4.4, it can be seen that the Average Annual Daily Traffic (AADT) is 1,500 vehicles, with 12,4% heavy vehicles. The historical growth rate on R34 is in the order of 4,7% with the traffic volumes in the vicinity being very low. The LOS is C and the climbing lanes would be required on all the major road sections indicated in Tables 4.3 and 4.4 within the design life of the route, based on the historical growth rate of 4,7% per annum.

4.3.2 Riding Quality

The riding quality of a pavement refers to the general extent to which road users, through the medium of their vehicles, experience a ride that is smooth and comfortable, or bumpy and therefore unpleasant or perhaps safe.

It is evident due to the presence of deformations namely mechanical rutting, undulations, potholes and aggregate loss that the riding quality of the road was in a poor and uncomfortable state. This has been caused also by the frequent moderate unevenness of the road profile, ravelling and uneven patching that has rendered the road unsafe for use.

4.3.3 Falling Weight Deflectometer (FWD)

Falling Weight Deflectometer refers to a trailer mounted device that simulates the effect of moving heavy vehicle wheel load by applying a dynamic impulse load to the pavement, and then measuring the subsequent deflections that occur at various radial distances from the load centre to provide a deflection bowl.

Figure 4.1 and Table 4.5. presents the structural capacity and approximate remaining life for the various uniform sections in terms of maximum deflection (Ymax), base layer index (BLI), middle layer index (MLI) and lower layer index (LLI), for both the *Average* and *90th percentile* analyses of Road R34.

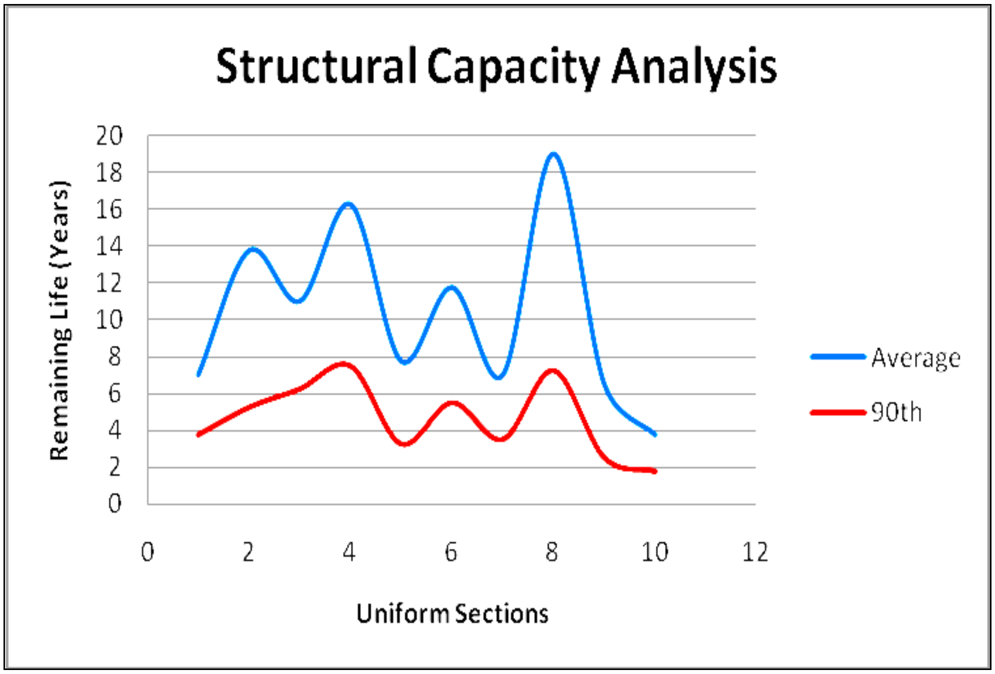


Figure 4.1: Structural Capacity Analysis

Table 4.5: Uniform Sections and Structural Capacity Analysis

Uniform Section	Start to End	Deflection Bowl Parameters (μm)			Structural Capacity (10^6 E80's)		Approximate Remaining Life (Years)	
(US)	(km)	(DBP)	Avg	90th	Avg	90th	Avg	90th
1	0.00	Ymax	824.1	1168.2	0.24	0.07	2	1
	to	BLI	490.5	812.0	0.26	0.07	3	1
	0.55	MLI	208.8	273.0	0.51	0.27	5	3
		LLI	57.2	78.2	2.52	1.22	18	10
2	0.55	Ymax	510.8	777.0	1.2	0.29	10	3
	to	BLI	270.6	449.0	1.31	0.33	11	3
	2.55	MLI	133.2	201.6	1.48	0.56	12	5
		LLI	50.1	77.2	3.44	1.26	22	10
3	2.55	Ymax	677.0	995.0	0.46	0.12	4	1
	to	BLI	434.6	665.0	0.37	0.12	4	1
	3.60	MLI	144.3	177.0	1.23	0.76	10	7
		LLI	44.6	60.0	4.5	2.26	26	16
4	3.60	Ymax	492.0	710.4	1.36	0.39	11	4
	to	BLI	278.0	449.4	1.22	0.33	10	3
	8.05	MLI	117.7	174.2	1.98	0.79	15	7
		LLI	41.9	60.2	5.18	2.24	29	16
5	8.05	Ymax	703.1	1028.0	0.4	0.11	4	1
	to	BLI	383.4	615.1	0.51	0.14	5	1
	17.00	MLI	182.3	271.0	0.71	0.28	7	3
		LLI	63.8	88.0	1.96	0.93	15	8
6	0.00	Ymax	583.9	822.0	0.76	0.24	7	2
	to	BLI	320.8	462.0	0.83	0.31	7	3
	17.50	MLI	161.4	246.0	0.94	0.35	8	3
		LLI	46.0	67.0	4.18	1.75	25	14
7	17.50	Ymax	790.2	1,056.1	0.27	0.10	3	1
	to	BLI	431.5	603.1	0.37	0.15	4	1
	19.00	MLI	228.3	310.3	0.42	0.20	4	2
		LLI	58.4	77.2	2.4	1.26	17	10
8	19.00	Ymax	437.0	691.0	2.03	0.43	15	4
	to	BLI	222.2	386.2	2.24	0.50	16	5
	32.70	MLI	115.9	192.0	2.05	0.63	15	6
		LLI	40.6	65.0	5.57	1.88	30	14
9	32.70	Ymax	716.4	1,060.3	0.38	0.10	4	1
	to	BLI	344.4	544.2	0.68	0.20	6	2
	42.15	MLI	215.9	318.3	0.48	0.19	5	2
		LLI	75.4	110.3	1.33	0.55	11	5
10	42.15	Ymax	1,015.0	1,498.7	0.12	0.03	1	0
	to	BLI	564.1	858.9	0.18	0.06	2	1
	55.20	MLI	291.9	440.0	0.23	0.09	2	1
		LLI	78.8	115.9	1.2	0.49	10	5

The LLI parameter contained in the table, particularly from km 0,0 to km 32,70, indicates that there are some remaining life in the pavement. From km 32,70 to km 55,0 indications are that the lower structural layers are overstressed and that major rehabilitation (addition of structural layers) is required to ensure functionality of the route over the design period, as the route appear to be prematurely failing due increased use by heavy vehicles on the route.

4.3.4 Mechanical Rutting

Rutting is a type of pavement deformation that occurs as a result of compaction and shear deformation through the action of traffic and is limited to the wheel paths of vehicles. In order to measure the compaction strength against traffic, mechanical rut tests are performed. In this study, rut sections where data was collected were determined based on the method proposed by the AASHTO Design Manual for Flexible Pavements and their results are reported in Table 4.6 and Figure 4.2.

Table 4.6: Rut Data Summary

From (km)	To (km)	90th
0	27.95	10
27.95	32.73	14.2
32.73	38.77	20.6
38.77	42.43	42.7
42.43	55	23.6

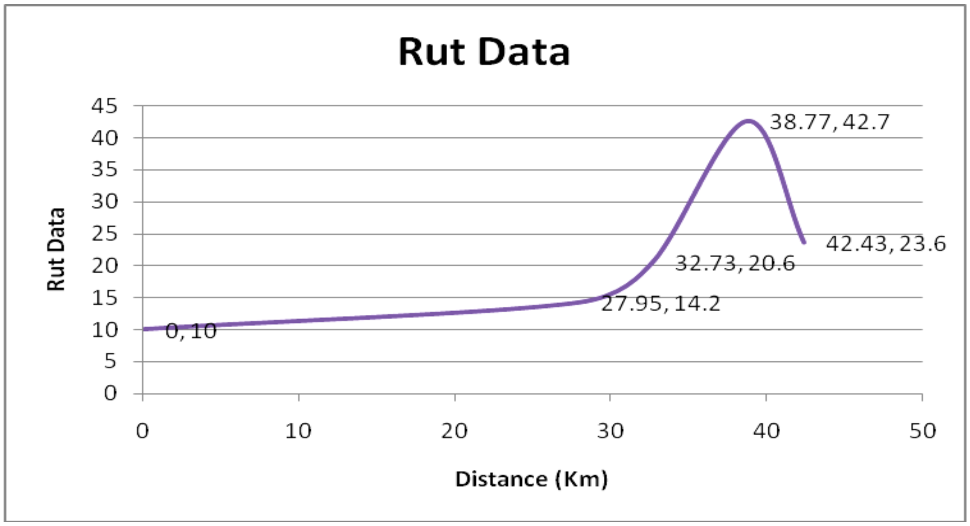


Figure 4.2: Rut Data Results

It is noted that a marked increase in the measured ruts occur from km 32,73 to km 42,7 and that approximately 14 % of the road (km 0,0 to km 32,73) has a warning rut level of greater than 10mm. However, from km 32,73 to km 55,0 the rutting is more significant with 69% of the measurements exceeding the rut "warning" criteria of 10mm. The uniform section from km 38.77 and km 42.43 exhibits the highest rut depths of 42,7 on the road. Approximately 71 % of the road investigated has a warning rut level of greater than 10mm and this means that the structural integrity of the road is in a poor condition.

4.3.5 Material Investigation

The investigation was aimed at identifying problems that required special attention, i.e. problematic soils and unfavourable subgrade conditions. Representative soil samples were collected from the different soil horizons and subjected to laboratory testing to determine the Atterberg limits, grading, Mod AASHTO compaction and California Bearing Ratio (CBR) for classification. For the purpose of the mechanistic analysis, the pavement layers were classified according to the TRH14.

Results from the test pit tests indicated a bituminous surfacing seal varying between 20mm and 50mm in thickness. The base layer (100mm – 250mm varying thickness) consists mainly of sand and weathered dolerite as well as sandstone. The plasticity index (PI) as well as the linear shrinkage (LS) indicates values ranging from NP to 12,0 and 0,0 to 6,0 respectively. The base layer materials were generally found to be of G5 to G7 quality while the subbase layer (100mm

– 300mm varying thickness) consists mainly of sand and weathered dolerite. The plasticity index (PI) as well as the linear shrinkage (LS) indicates values ranging from NP to 13,0 and 0,0 to 5,0 respectively. The sub base layer materials are of G5 to G7 quality. It was further determined that the in situ materials (600mm varying thickness) consist mainly of clayey sand, weathered dolerite, ferricrete, sandstone and stiff clay in places with the plasticity index (PI) as well as the linear shrinkage (LS) indicating values ranging from 5,0 to 22,0 and 2,5 to 11,0 respectively.

The in-situ shoulder materials were profiled and tested up to a depth of approximately 1000mm and were found to consist mainly of sand and weathered dolerite, ferricrete, stiff clay and dolerite boulders. The plasticity index (PI) as well as the linear shrinkage (LS) indicates values ranging from SP to 23,0 and 2,1 to 10,7 respectively. Their materials components were determined to be of “No Class” to “G5-G8 quality material with the in-situ cutting materials profiled and tested up to a depth of approximately 600mm to 1,500mm and found to consist mainly of sand and weathered dolerite, ferricrete and sandstone in places.

These material investigations revealed that the existing materials are generally good for pavement structures with life spans of more than 20 years and therefore their composition are acceptable and reusable but should be treated.

4.4 Semi-destructive Analysis

4.4.1 Dynamic Cone Penetration

Dynamic Cone Penetration (DCP) tests were conducted to measure the in-situ strength of the subgrade, subbase, base and surfacing materials of the road. DCP were done at excavated test pit positions on the existing alignment as well as between each test pit. In total, 55 DCP soundings were done on Road R34. DCP’s were done at each of the test pit positions prior to excavation thereof.

The results of the processed DCP’s were used to obtain the rate of penetration (DN value) in millimetres (mm)/blow through each defined pavement layer. The total number of blows required to penetrate the pavement to a depth of 800mm (DSN800) was used to evaluate the approximate bearing capacity of the pavement structure. Capacity analysis of the pavement structure was done to compare the existing structural capacity with DN-values resembling a pavement structure that can accommodate an imposed traffic loading of 3,03 million E80's.

A measured DN (mm/blow) value less than the required indicates that the specific pavement layer conforms to the strength requirements of the in situ material for a design traffic loading of 3,03 million ESAL's which falls within the ES10 traffic classification. The comparison between the in situ strength profile of the existing pavement and that of the designed pavement was used in addition to other tests to evaluate the current pavement situation. The DCP results are shown on Table 4.7 and Figures 4.3 and 4.4.

Table 4.7: DCP Analyses

	DCP Measurements 90th Percentile(mm/blow)				
Depth (mm)	0 - 150	150 - 300	300 - 450	450 - 600	600 - 800
Required	1.9	3.3	5.1	7.3	10.3
Distance (km)					
1.0	13.2	4.4	7.7	11.8	15.3
1.5	3.3	3.7	5.1	20.6	19.9
2.0	10.4	8.0	7.6	6.6	4.4
2.5	1.7	5.8	5.3	5.8	4.1
3.0	17.7	15.0	8.8	7.7	19.5
4.0	13.5	9.8	6.3	22.1	25.6
5.0	7.8	8.9	12.4	6.2	11.4
6.0	18.7	11.7	15.6	4.7	6.9

7.0	16.7	6.6	7.1	4.6	10.0
8.0	13.6	6.7	7.7	5.3	0.6
9.0	17.6	7.4	6.4	3.4	4.5
9.5	3.1	5.3	5.0	3.1	1.2
10.0	8.9	12.8	6.2	3.6	4.2
11.0	5.1	7.7	15.9	10.8	28.1
12.0	12.6	7.4	5.7	13.1	20.7
13.0	4.2	5.4	5.2	3.6	12.9
13.5	5.6	2.3	4.3	12.4	12.6
14.0	7.6	9.3	7.7	22.0	23.2
14.5	5.1	9.1	9.5	12.3	7.9
15.0	11.2	6.5	6.8	19.7	16.8
16.0	10.0	3.5	11.7	16.6	18.6
16.5	3.5	8.0	7.4	10.9	12.4
16.8	9.6	10.1	13.2	12.6	6.6
30.0	9.9	8.3	6.7	12.4	12.4
30.5	2.4	2.9	3.9	2.9	17.1
31.0	11.5	4.8	7.0	10.7	24.8
32.0	10.7	7.0	12.5	16.3	7.7

Table 4.7: DCP Analyses (continued)

DCP Measurements 90th Percentile(mm/blow)

Depth (mm)	0 - 150	150 - 300	300 - 450	450 - 600	600 - 800
Required	1.9	3.3	5.1	7.3	10.3
Distance (km)					
33.0	9.2	4.6	9.3	10.1	9.1
34.0	12.4	4.3	14.0	12.9	11.6
35.0	6.5	6.2	4.7	11.5	19.1
36.0	8.8	4.7	12.2	35.7	31.9
37.0	7.3	7.7	9.1	7.9	7.8
38.0	11.4	3.6	6.6	9.1	10.3
38.5	3.2	4.5	11.6	12.2	12.8
39.0	6.4	3.6	9.0	10.0	10.1
39.5	3.9	5.1	6.7	11.8	27.6
40.0	5.0	3.2	21.6	28.0	13.0
41.0	9.0	6.1	8.9	8.6	10.7
42.0	6.4	5.6	6.3	10.4	5.6
42.5	2.0	6.6	7.3	8.1	7.0
43.0	8.4	17.6	14.2	16.3	18.3
43.5	2.6	19.3	34.3	16.2	11.1
44.0	7.0	15.9	11.3	10.8	11.3
44.5	2.4	8.0	11.7	9.9	9.4
45.0	6.9	12.8	26.6	23.8	31.5
46.0	26.2	20.9	6.6	11.5	13.6
47.0	17.4	10.3	7.2	7.9	19.8

47.5	2.0	7.0	25.1	24.0	18.8
48.0	18.5	17.9	16.1	20.0	22.8
49.0	22.7	13.4	12.2	6.4	10.8
50.0	6.1	5.5	3.5	0.2	0.2
51.0	5.3	8.8	13.9	23.6	14.7
51.5	10.5	5.9	7.5	9.5	19.9
52.0	4.8	5.9	6.1	9.3	10.1
52.5	20.5	6.0	7.6	5.7	10.9

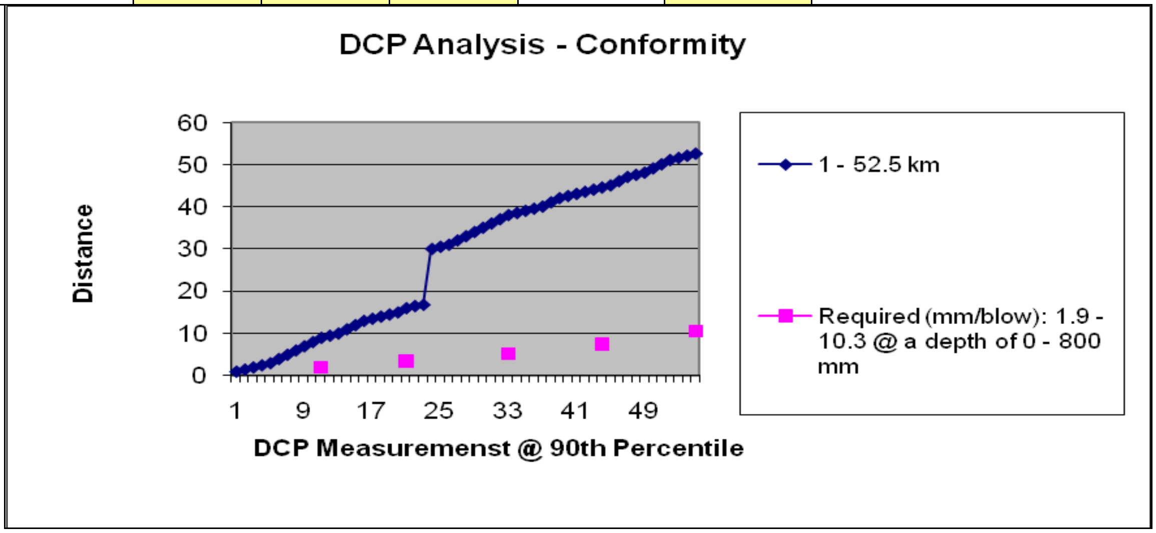


Figure 4.3: DCP Conformance Figures

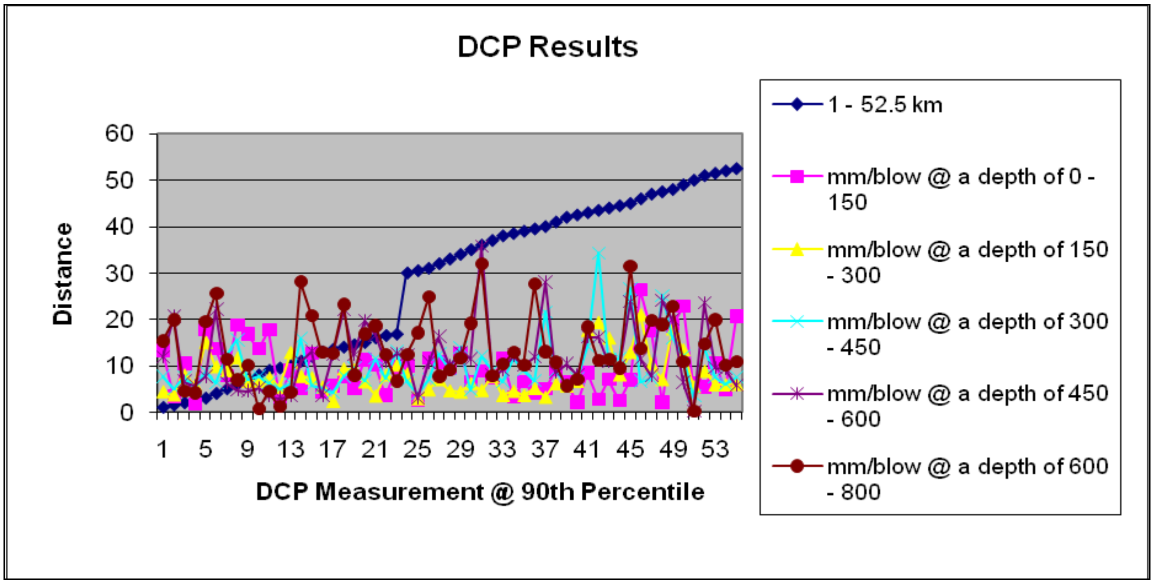


Figure 4.4: DCP Results

From the information in Table 4.7 and Figures 4.3 and 4.4 above, it is clear that the bearing capacities of the existing pavement structure are less than the anticipated traffic loading of 3.03 million E80s (guidelines of acceptability of the pavement strength). Therefore, strengthening the pavement is required and can either be obtained through the improvement of the quality of the material in the existing pavement modification or by adding good quality material to the pavement structure. A combination of these options is likely to provide the best solution in deriving an appropriate rehabilitation strategy. To achieve the best possible results, the in situ material properties and geometry should be considered when deriving a final rehabilitation strategy.

4.5 Development of Pavement Management System

4.5.1 Introduction

From results presented above, it is evident that the deterioration on the route is due to two factors namely environment and traffic effects. Environmental effects are borne by the climatical, topographical and geological effects while traffic effects are borne by increase in use of the road and in traffic loading.

According to Federal Lands Highway Program (2007) the combined effects of traffic loading and the environment will cause every pavement, no matter how well-designed or constructed to deteriorate over time. Therefore, in order to address the deterioration, maintenance and rehabilitation are used to slow down or reset this deterioration process.

Nowadays, road authorities are faced with the choice of preserving the roads at a reasonable cost or deferring maintenance and have to prematurely replace these assets at a much higher cost at a later stage. Therefore timing is crucial as it assists in saving money. Key performance indicators are therefore crucial as they assist with decision support system as to what is the current condition of the roadway network, which roads should be repaired first, what techniques should be used for best results and lastly what are the projected long-term consequences should the repairs be delayed or deferred?

In trying to assist the road authority responsible for the maintenance and rehabilitation of R34, PMS was developed as follows:

4.5.2 Systems Development

PMS in this study was developed as an integrated system with four major modules, i.e. Road Inventory, Conditions Survey, Analytical Models and Decision Making. The modules are described below:

(a) Road Inventory

The entire pavement system under study was broken down into branches and sections. A branch is an easily identifiable part of the pavement network that has distinct functions, i.e. national road, provincial road, secondary roads and local roads. Each branch was divided into uniform sections based on construction history, pavement condition and traffic volumes. A section is a subdivision of a branch and has consistent characteristics throughout its length and width. These characteristics include the structural composition, layer thickness, construction history, pavement condition and traffic volumes. A section can also be viewed as the smallest pavement area where the major maintenance and rehabilitation would be scheduled. Seeing that some sections did not have consistent characteristics throughout their entire area, it was decided that all sections be divided into even smaller components of 200m lengths called "sample units", for managerial purposes. Sample units should also have the same surface type throughout (for example, asphalt, brick paving and concrete).

The database, in Microsoft excel format, was then developed to capture the data acquired from the field. Before entry of data into the database, branches were given identities in the form of alphanumeric descriptive names called the "Branch Names" and alphanumeric codes called the "Branch IDs". The branch ID is a unique code that helped in storing and retrieving of data for specific branches. Sections and sample units were also given unique codes based on their location within their branches and sections respectively.

(b) Conditions Survey

Conditions surveys were conducted through the Visual Condition Assessment procedure whereby visual condition inspections were carried out and recorded on inspection sheets. The results thereof are shown in Appendix B. These assessments were then re-done for verification. This 'double' assessing is done to correct mistakes that might have been made in the first assessment to ensure that data acquired was accurate and correct.

Pavement distresses are classified using the degree and extent classification system, according to TMH9 (1990). The "degree" of a certain distress is a measure of its severity throughout the section of the pavement under investigation, and is indicated by numbers on a 0 to 5 scale (0 indicating non-visible distress, and 5 indicating severe condition). The "extent" of distress gives an indication of how widespread the distress is throughout the section of pavement under investigation.

VCA data acquired under this study included the surfacing assessments (texture, voids, surfacing failures, aggregate loss, bleeding and polishing), structural assessments (traverse cracks, crocodile cracks, pumping, rutting, undulation, patching, potholing, depression and displacements), functional assessments (riding quality, skid resistance, drainage, shoulders and edge breaks) and was categorised according to its nature, degree and extent. VCA was performed according to Standard Visual Assessment Manual UTG12, Technical and Recommendations for Highways (TRH) 22 Pavement Management System and TMH 9. Data on site was recorded on VCA recording forms (CSRA, 1992). These documents (TRH22, TMH9 and UTG12) provided guidelines for the visual assessment and pavement management system of the pavement network. In addition to VCA data collected, additional data (field works tests) were collected to detect conditions not identifiable by visual inspections. The tests included Mechanical Rut Tests (MRT), Dynamic Cone Penetrometer (DCP) and Falling Weight Deflectometer (FWD). Traffic Surveys, Material Investigations and E80 Measurements were also conducted.

To be able to handle the large amount of visual assessment data and convert it in such a manner that the data could be interpreted, a data management system (Microsoft excel) had to be incorporated.

Data processing and analysis was performed in accordance with guidelines stipulated in the Draft TRH22 (1994). Data acquired from VCA was used to determine the Visual Condition Index (VCI). VCI gives the combined effects of various distresses on the general pavement condition. Each distress is assigned to a weight factor which represents its influence on the overall pavement condition and can be adjusted accordingly. VCI ranges from 0 to 100, with 0 indicating severely damaged pavements, and 100 indicating pavements in an excellent condition. Refer to Figure 4.5 for the VCI illustratation.

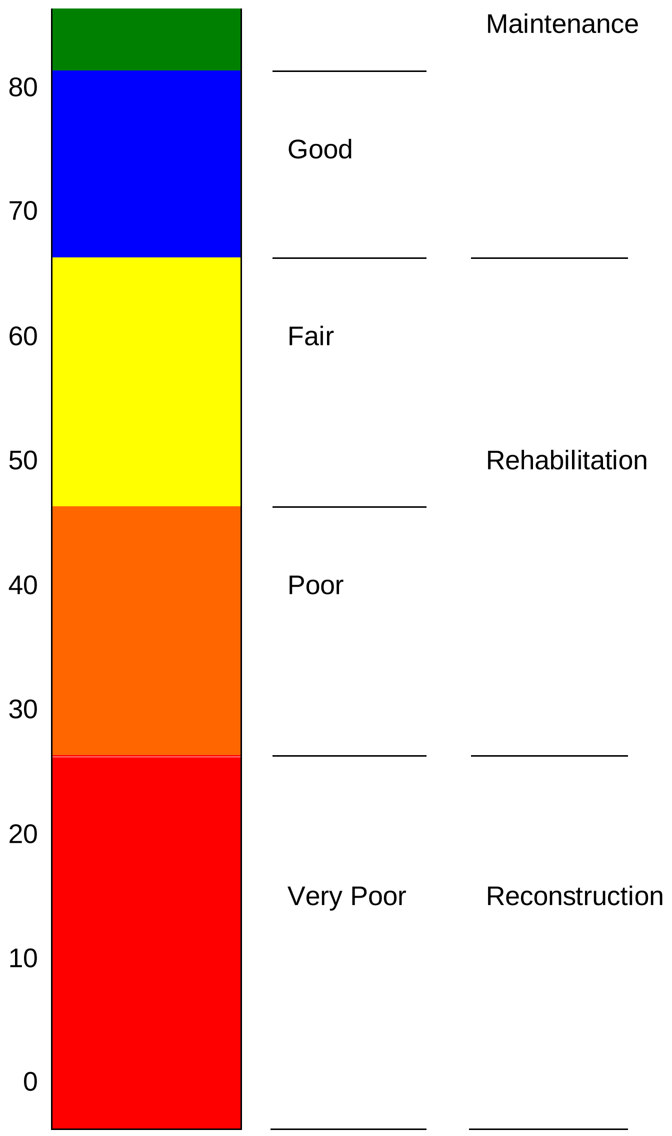


Figure 4.5: Condition Categories
(Source: TRH22 1994:58)

(c) Analytical Models

The analytical models used in the development of this pavement management system were the Pavement Deterioration Model (PDM), Treatment Selection Model (TSM) and Optimisation & Resource Allocation Model (O&RAM). These models interacted to form a comprehensive pavement management system that provides the basis for the systematic and consistent management of the pavement network.

The rate of deterioration and the nature of changes in the pavement condition were determined based on the results presented after analysis of the data. These assisted in estimation of the rehabilitation and or maintenance timing, type, and costs during the planning period. A summary of all appropriate maintenance and rehabilitation techniques required to improve each sample unit were drawn up. The treatment selection model was then employed to select the applicable remedial measures given a certain condition of road sample unit throughout the network. A prioritisation list was then developed, indicating the preferred order in which sample units should be rehabilitated. Prioritisation was determined according to the deterioration rate (financial consequence) of the sample unit in question. The O&RAM was then considered to determine and select the most economically viable alternative for each section, and finally, to establish priorities for the execution of different projects, taking into account resource constraints.

(d) Decision Making

Based on actions recommended by the analytical models and further data research, a decision is then made. After the decision-making process, budget is allocated to projects based on their prioritisation. The determination of when to do the maintenance and or rehabilitation is then done. After the execution of the project, the database is updated. Pavement performances are then monitored and improvements are made based on the long-term pavement performance.

A diagrammatic illustration of the modules is shown on Figure 4.6.

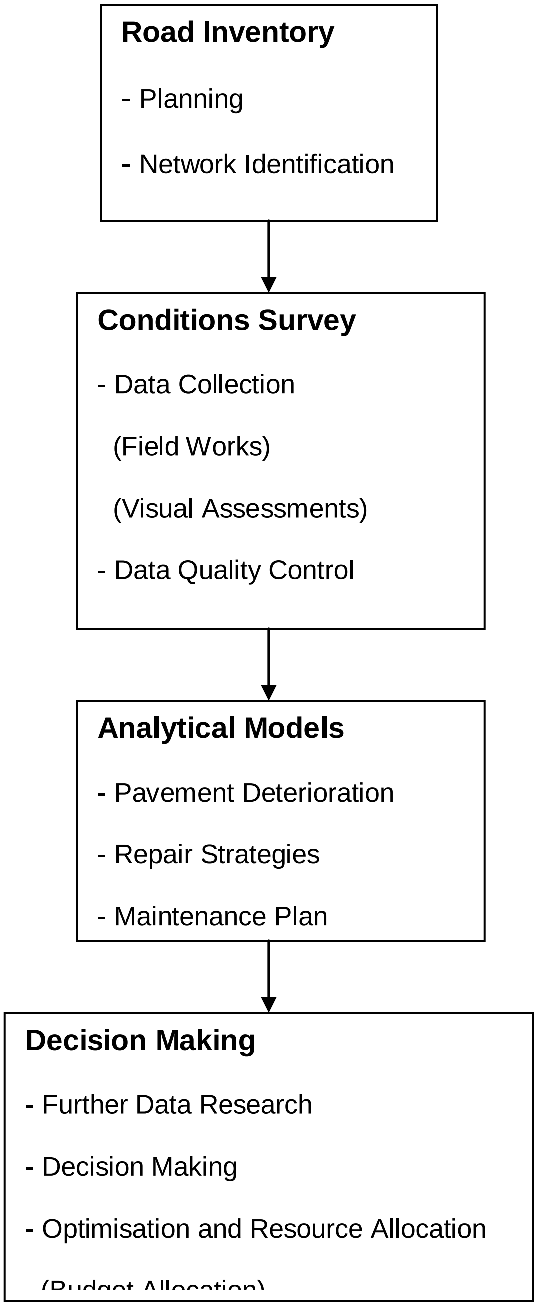


Figure 4.6: PMS Development Method

4.5.3 Application of the Developed PMS

To test the developed PMS, visual condition inspections were conducted on Kuhn Steet in Vrede. The inspections were conducted between 12th May and 17th June 2009. Data was acquired over 2km length of road. The 2km was divided into 200m long segments. The raw data acquired is attached in appendix B.

The pavement management system's Technical Recommendations for Highways (TRH) 22 of 1994 was then used as a guideline for analysis of the visual condition data as follows:

(a) Visual Condition Index

To determine the VCI, the following formula was used:

$$VCI_p = 100 \left\{ 1 - C * \left[\sum_{n=1}^{N} F_n \right] \right\}$$

and

$$VCI = (a * VCI_p + b * VCI_p^2)^2$$

Where:

VCI_p = Preliminary VCI

Fn = Dn * En * Wn

n = Visual assessment number

Dn = Degree rating of defect n

En = Extent rating of defect n

Wn = Weight for defect n

$C = 1 / \left[\sum_{n=1}^{N} F_n(\text{max}) \right]$

Fn (max) = Fn with degree and extent at maximum

VCI = Visual condition index (final)

Where:

a = 0,02509

b = 0,0007

VCImax = 100

VCImin = 0

(Source: TRH22 1994:55)

Factors a and b have been derived from processing condition data collected through an expert panel throughout South Africa (TRH22 1994:56). VCImax represents condition index range of a road in a very good condition while VCImin represents condition index range of a road in a very poor condition (TRH22 1994:58).

After calculations and analysis, VCI was determined to be 39,65 of which was rounded off to 40. Comparing the VCI rate of 40 to the VCI table shown on Figure 1, it was concluded that the pavement is in a poor condition. The VCI calculation data is provided on appendix B.

(b) Treatment Recommendations

Based on the VCI rate of 40, the pavement treatment required is Rehabilitation. Rehabilitation refers to restoring the road to acceptable structural capacity and level of service. Rehabilitation includes extensive reconstruction of existing layerworks, construction of additional layers, which may include the laying of asphalt overlay. Also, limited geometric improvements of existing road and drainage reinstatements where required could form part of the project.

(c) Prioritisation

Prioritisation is a process of determining the urgency for attention that a project requires. Prioritisation answers three questions, namely (a) which project should be selected first? (b) what measures should be applied? and (c) when should the measure be applied? (TRH22 1994:96).

From the visual condition data shown on Annexure A, it is evident that links 0-1, 1-2, 8-9 and 9-10 have high degrees and extents of distresses when compared to other links. The latter means that the mentioned links contain highly distressed road segments of which must be prioritised in terms the three questions that prioritisation answers. Therefore links 0-1, 1-2, 8-9 and 9-10 should be attended to first when the rehabilitation process starts.

Due to the severity of the degree of distresses, especially in the prioritised links, and the safety risk threat posed to road users an urgent attention is required in the rehabilitation of the road network. After the rehabilitation process has taken place, continuous maintenance activities should be applied to ensure that the life span of the road network is enhanced and increased.

(d) Ranking

As soon as projects have been prioritised it is important to rank them to determine the economical benefits they bring to the priority programme (TRH22 1994:97). Benefits obtained from repairing each selection of pavement are determined over a selected analysis period in monetary terms using, for example, vehicle operating costs.

The benefits are defined as the reduction in vehicle costs minus user costs, such as traffic delays during construction, and environmental costs, such as noise pollution (TRH22 1994:98). These costs, calculated over the same analysis period, include construction costs plus future maintenance and rehabilitation costs. Therefore, for the prioritised links, condition ranking proposed is condition-based, where worst-first approach method is applied as the links are all very close to one another and therefore having the same traffic and environmental dynamics.

(e) Project Execution, Future Monitoring Requirements and Feedback

The project is then executed based on the recommendations provided in terms of the type of the rehabilitation technique required including priority and ranking towards implementation.

As soon as the rehabilitation process is completed, the PMS software is updated to show the current condition of the road, i.e. its rehabilitated status.

The purpose of providing feedback to the system is to compare the actual conditions with those of projected by the PMS.

An annual maintenance programme would then have to be developed, adopted and implemented for the road maintenance. The road would also have to be rehabilitated every ten years in order to prolong the design life of the road.

It should be noted that in order to have an effective and efficient PMS visual assessments should be conducted every five years and data acquired compared with the data contained in the PMS software to ensure consistency.

4.6 Concluding Statement

An important component of the PMS is a comprehensive database capable of storing large quantities of data associated with each pavement section within the network. These data, which can be instantly retrieved and reported on a variety of media and formats, forms a solid base for subsequent analyses. The PMS database also contains pavement rehabilitation historical data which saves information on all types of previous treatments, their application date, and associated costs.

The successful development of this PMS is suitable for road network applications ranging from national roads, provincial roads, regional or district arterial and collector/distributor networks in SA. The system consists of an accurate and up-to-date locational reference system for the road network, automated pavement condition data collection techniques, data management, data access, and data presentation techniques based on an easy-to-use Microsoft excel software.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main aim of the study was to develop a pavement management system for road network maintenance to serve as a decision support tool to assist to improve the efficiency of making decisions, provide feedback as to the consequences of these decisions, ensure consistency of decisions made at different levels and improve the effectiveness of all decisions in terms of efficiency of results. The specific objectives were to identify the main contributory factors in the road deterioration, use these factors to develop best implementation applications and develop an effective pavement management system to be used as a decision support tool.

The environment has a Weinert's climatic N-value of between 2 and 5 which indicates that the deterioration on the route is due to chemical weathering and disintegration.

The traffic growth rate is 4,7% per annum which indicates that the growth of traffic on the road is significant taking into consideration the change in growth from the base year to the current state of traffic of the road. The traffic growth rate of 4.7% means that the LOS is expected to deteriorate to an unacceptable LOS E in 12 to 14 years. With a predicted a 6% growth rate, the LOS is would reach LOS E within 7 to 10 years. Therefore, due to the current growth rate of 4.7% and predicted rate of 6%, climbing lanes are required on all the major upgrades within the capacity design life of the route.

The riding quality of the road is in a poor and uncomfortable state. This is due to the presence of deformations namely mechanical rutting, undulations, potholes and aggregate loss.

The LLI parameter, particularly from km 0,0 to km 32,70, indicates that there are some remaining life in the pavement. From km 32,70 to km 55,0 indications are that the lower structural layers are overstressed and that major rehabilitation is required ensure functionality of the route over the design period, as the route appear to be prematurely failing due to increased traffic use and loading.

It is noted that a marked increase in the measured ruts occur from km 32,73 to km 42,7 and that between km 32,73 and km 55,0 the rutting is more significant with 69% of the measurements exceeding the rut "warning" criteria of 10mm. The uniform section from km 38.77 and km 42.43 exhibits the highest rut depths of 42,7 on the road. In general, 71 % of the road investigated has a warning rut level of greater than 10mm and this means that the structural integrity of the road is in a poor condition. This has occurred as a result of compaction and shear deformation through the action of traffic due to traffic loading.

Results of material investigations have indicated that surfacing seal varies between 20mm and 50mm in thickness, the base layer varies between 100mm and 250mm and consists mainly of sand and weathered dolerite as well as sandstone, the subbase layer consists of materials of G5 to G7 quality and that the subgrade consists mainly of clayey sand, weathered dolerite, ferricrete, sandstone and stiff clay and its width is 600mm. These means that the existing materials are generally good for pavement structures with life spans of more than 20 years and therefore their composition are acceptable and reusable.

The bearing capacities of the existing pavement structure between depth 0 – 300 mm conform to the required mm / blow of which indicated that the sub base was still strong. Between depth 450 – 800 mm, especially between km 5.0 and 10, the bearing capacities do not conform to the required strength. Causes for that were determined to be due to effects of increased traffic use and loading that have had a negative impact in the base structure of the pavement.

From results presented, it is evident that the contributory factors to the deterioration of the route understudy are environmental and traffic loading oriented.

Maintenance and rehabilitation techniques are used to slow down or reset the deterioration process but are their success are time dependent.

PMS developed addresses the timing effect of maintenance and rehabilitation requirements and provide key performance indicators to assist with decision support system.
PMS developed is suitable for road network applications ranging from national roads, provincial roads, regional or district arterial and collector / distributor networks in SA.

It is also easy to use, cheap and does not require specialised skills to operate it. This means that it can be used easily within road agencies for maintenance of road infrastructure.

5.2 Recommendations

i. The pavement should be rehabilitated to enable the road to function to the required level of service. It would also help to renew the pavement and increase its life span.

ii. Climbing lanes should be installed on all the major upgrades within the capacity design life of the route.

iii. The existing materials should be strengthened by stabilising the base layer with 3% cement and compacted to 102% AASHTO density and lastly subbase be replaced with G5 material and stabilised with 3% cement and compacted to at least 97% of modified AASHTO density.

iv. Considering the safety risk posed by the severity of the deterioration and to prevent further deterioration, the rehabilitation process should start immediately.

v. Municipalities and other road maintenance agencies throughout the country should use the “easy to use” developed PMS as a decision support tool in their maintenance programmes.

REFERENCES

ANDERSON, D., KOSKY, C., STEPHENS, G. & WALL, A.R. 1994. *Implementation of VIC Roads Pavement Management Systems.* Transportation Research Board, Washington DC 20001. USA.

BURGER, W., CANISIUS, P. & SULTEN, P. 1994. *Towards a New Pavement Management System in Germany: Organisation, Data Collection, Experience and Innovations.* Transportation Research Board, Washington DC 20001. USA.

CRISPINO, M., OLIVARI, G., POGGIOLI, M. & SCAZZIGA, I. 2004. *Development of Pavement Management System: The Validation of Pavement Performance of Curves* Available at: http://sed.siiv.it/documenti/63_2848_20080821110123.pdf. Assessed: 17/09/2007.

FEDERAL LANDS HIGHWAY PROGRAM. 2007. *Condition Evaluation of Existing Pavements.* Federal Highway Administration, Department of Transport, US.

FEDERAL HIGHWAY ADMINISTRATION. 2008. *Pavement Preservation Technology in France, SouthAfrica and Australia*. Federal Highway Administration, Department of Transport, US.

GUTIERREZ-BOLIVAR, O. & ACHUTEGUI, F. 1994. *Implementation of PMS in Spain State Road Network*. Transportation Research Board, Washington DC 20001. USA..

HUDSON, HAAS, & PETERSON. 1979. *Total Pavement Management Systems: Analysis Scheme.* New Orleans, LA. US Department of Transportation: Federal Highway Administration.

JOHN, A. 1915. *History of Road Transport. Union and Democracy*. Houghton Miffin Company, Massachusetts, Cambridge.

KERCHER, A.S. 2001. *Pavement Management System*. Kercher Engineering, Inc. 302.894.1533.

Liu, W. 2006. *Pavement Management Systems in China.* Available at: http://www.pavement.com.au/downloads/papers/PMS%20Development%20in%20China-Presentation%20in%2010th%20SPT)-.pdf. Assessed: 20/10/2007.

MCQUEEN, R.D. 2001. *Pavement Management Systems: Services*. McQueen & Associates Ltd. Virginia, USA.

MERCED COUNTY ASSOCIATION OF GOVERNMENT. 1548. *Pavement Management Systems.* California, USA.

NASHVILLE DEPARTMENT OF TRANSPORT. 2007. *Pavement Management Systems: Visual Condition Assessment.* Nashville Department of Transport, Nashville Metro.

NATIONAL DEPARTMENT OF TRANSPORT. 1996. *Annual Report*. South African National Roads Agency Limited (SANRAL), Pretoria, South Africa.

NATIONAL DEPARTMENT OF TRANSPORT. 1998. *Annual Report*. South African National Roads Agency Limited (SANRAL), Pretoria, South Africa.

NATIONAL DEPARTMENT OF TRANSPORT. 2001. *Assessment of Provincial Rural Road Infrastructure Strategic in South Africa.* CR-2001/9. South African National Roads Agency Limited (SANRAL), Pretoria, South Africa.

NATIONAL DEPARTMENT OF TRANSPORT. 2006. *Road Network Management. Asset Management: Version 2*. South African National Roads Agency Limited (SANRAL), Pretoria, South Africa.

SCOTT WILSON GROUP PLC. 2007. *Pavement Engineering: United Kingdom Pavement Management System.* Available at: http://www.scottwilson.com. Assessed: 15/09/2007.

TECHNICAL METHODS FOR HIGHWAYS (TMH) 9. 1992. *Pavement Management Systems: Visual Assessment Manual for Flexible Pavements.* Committee of State Road Authorities, Pretoria, South Africa.

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) 12. 1997. *Flexible Pavement Rehabilitation Investigation and Design*. Committee of State Road, Pretoria, South Africa.

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) 22. 1994. *Pavement Management Systems*. Committee of State Road Authorities, Pretoria, South Africa.

THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO).1985. *Pavement Management Systems.* Department of Transportation: Federal Highway Administration, New Orleans, LA. US.

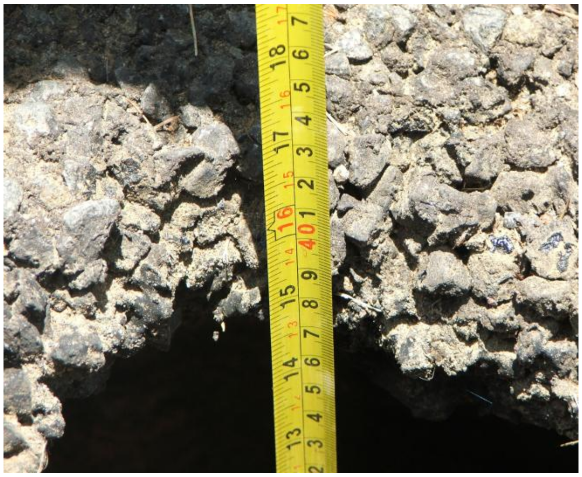
URBAN TRANSPORT GUIDELINES (UTG) 12. 1985. *Visual Assessment Manual.* Committee of State Road Authorities, Pretoria, South Africa.

WILSON, D.J., PRADHAN, N.K. & HENNING, T.J. 2002. *Appropriateness of Data in Pavement Management Systems: A New Zealand Experience.* Transportation Research Board, Washington DC 20001. USA.

PHOTOGRAPHS

A1: Crocodile Cracks

A2: Rutting



A3: 150mm Deep Pothole

A4: Potholes

A5: Surface Failure

A6: Patching

APPENDIX A (PHOTOGRAPHS)

APPENDIX B (CONDITION ASSESSMENT SURVEY)

APPENDIX C (VISUAL CONDITION INDEX RESULTS)

$VCI = ((a*VCIp)+(b*(VCIp)^2))^2$

where

a = 0.02509

b = 0.0007

VCImax = 100

VCI min = 0

VCIp = 78.60273973

$VCIp^2$ = 6178.390692

Fn = 5857.5

C = 3.65297E-05

C6: Calculation of VCI

6.297016224

39.65241333

f