# ASSESSMENT OF FACTORS AND MAINTENANCE STRATEGIES RELATED TO RECURRING POTHOLES IN BLOEMFONTEIN ROADS

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# DECLARATION

## WITH REGARD TO INDEPENDENT WORK

I, **SIPHO CLOUD KHOZA**, identity number and student number , do hereby declare that this research project submitted to the Central University of Technology, Free State, for MASTERS IN ENGINEERING: CIVIL, is my own independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State. It has not been submitted before to any institution or any other person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.

**SIGNATURE OF STUDENT**

**10 September 2020**

**DATE**

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# ABSTRACT

Roads play a major role in the everyday lives of people by connecting them to their respective destinations, carrying goods being transported to different locations, and creating spatial integration. The physical and structural conditions of the road infrastructure are crucial in ensuring an efficient flow of traffic, creating spatial integration and enhancing vital socio-economic activities. However, poor road pavement conditions, particularly potholes are a major barrier against efficient traffic movement, which also impact socio-economic activities.  It was observed that the occurrence of potholes is a serious challenge on the roads of South African cities.  Therefore,  using the roads of Bloemfontein city, in this study, the causes of the formation of potholes, the repair strategies and engineering methods adopted to repair potholes and maintain the roads were investigated. In other words, the study determined the reasons for the occurrence of potholes on the road surfaces and explored sustainable, engineering solutions to repair the potholes that recur on the roads of a South African city. A positivist ontological approach was followed to develop an empirical study of selected roads within the Mangaung Municipality, and within Bloemfontein City in particular. Based on this approach, both quantitative and qualitative methods were used. Several important roads were selected randomly from the Bloemfontein City road network as a case study. Data was collected through ,field observations and a questionnaire survey, direct interface interviews with various stakeholders, including the Government Municipality (Mangaung) and Department of Police, Roads and Transportation. Data from secondary sources were also collected from authentic sources. Various causes of potholes in the city were found to be, amongst others, the drainage system, heavy traffic loads, poor road designs, poor construction and lack of, or poor, maintenance of the existing roads. The findings of the study, according to surveys, revealed that 25% of potholes and road deterioration was associated with traffic volume and heavy loads, while 15% of the deterioration was associated with poor drainage. A linear regression model revealed a strong correlation between the formation of potholes, traffic volume, road layer thickness, and wheel load. Critical findings were made in terms of the correlation coefficient between the variables of traffic volume, traffic loads and road capacity and the formation of potholes. It was found that roads which had exceeded their design life-span had the most problems in terms of deterioration and prevalent recurrence of potholes, even after maintenance. This indicated that government should invest more funds in the rehabilitation of road

structures, particularly those which have exceeded their design life-span. This study can contribute to developing ways to analyse pothole-related problems on roads and to find solutions in other cities of South Africa

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F = Measurement of Bitumen Viscosity
ἡ = EquaCoefficient of viscosity
k = The Kinematic viscosity
logP = Softening Point, logP
A =Temperature sensitivity
VIF = Variation Inflation Factor
y = Correlation between Potholes and Traffic Volume
y = Correlation between Potholes and Layer Thickness
y = Correlation between Potholes and Traffic Speed
y = Correlation between Potholes and Wheel Load

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation officials |
| CBR | California Bearing Ratio |
| COLTO | Committee of Land Transport Officials |
| CST | Council for Scientific of Transport |
| CSIR | Council for Scientific and Industrial Research |
| COTO | Committee of Transportation Officials |
| CUTA | Committee Urban Transport Authorities |
| DCD | Department of Community Development |
| DoT | Department of Transport |
| EPWP | Expanded Public Works Programme |
| FHWA | Federal Highway Administration |
| IPTN | Integrated Public Transport Network |
| NAC | National Association of Counties |
| NACE | National Association of Country Engineers |
| NAPA | National Asphalt Pavement Association |
| NPV | Net Present Value |
| NITR | National Institute for Transport and Road |
| PMMS | Pavement Maintenance Management System |
| RISFSA | Road Infrastructure Strategic Framework for South Africa |
| RM | Road Maintenance |
| SANRAL | South African National Road agency Limited |
| SARF | South African Road Federation |
| TMH | Technical Methods For Highways |
| TRP | Transport Road Policy |
| TRH | Technical Recommendations for Highways |
| TRB | Transportation Research Board |
| UTG | Urban Transport Guidelines |

# CHAPTER ONE: INTRODUCTION

## 1.1 BACKGROUND

Roads play a central role in the everyday lives of people, connecting them to their respective destinations, carrying goods being transported to different parts of the country, and creating spatial integration. The condition of the roads is important in providing comfort and safety and, to some extent, in saving time and reducing the costs of travel. Potholes contribute largely to the poor quality conditions experienced on our road networks. Paved roads make up almost 80% of the value of the South African road infrastructure. At least 80% of the paved roads are bituminous roads. Bituminous roads are more vulnerable to potholing than concrete roads (Paige-Green, 2012), and this contributes to the large number of potholes on the roads.

A large number of potholes on road networks leads to a high cost of road maintenance. Governments spend a great deal of money every year maintaining road structures that deteriorate mostly because of potholes. In 2010, the UK estimated that more than R120bn was spent on pothole repairs, while Australia planned to increase its expenditure on pothole repairs by R9bn per annum for at least 15 years (Wilson, 2003).

The City of Cape Town reportedly spends over R110 million per year, repairing 250 potholes per week (Wheels24, 2016). In Johannesburg, an average of 1000 potholes are reported to the road authorities every week, although the City claims to repair up to 4500 potholes per month. (Wheels24, 2016). This was the rationale to undertake this research study to investigate and plan thoroughly to develop a sustainable solution.

Bloemfontein is the capital city of the Free State Province in South Africa. Bloemfontein is the seventh largest city in South Africa. It is situated at an altitude of 1,395m above sea level. The city falls under the Mangaung Metropolitan Municipality with a population of over 800 000 residents, which is 70% of Mangaung's total population (South African Tourism, 2018). Figure 1.1 shows part of the Central Business District (CBD) in Bloemfontein City.

*Source: South African Tourism, 2018*

**Figure 1.1: Bloemfontein City, Mangaung Province, South Africa**

The Mangaung Metropolitan Municipality is a Category A District. It is located in the Free State Province, in centre of South Africa. The Free State is bordered by the Gauteng, Eastern Cape, Northern Cape, KwaZulu-Natal and North West Provinces, and by the neighbouring nation of Lesotho (South African Tourism, 2018).

## 1.2 PROBLEM STATEMENT

Potholes are a serious problem on South African roads. They constitute the highest percentage of road deterioration and surface damage. There are several, on-going methods for repairing potholes, which are often found to be ineffective. Potholes are repaired on a monthly basis during the routine maintenance of the roads but, after a few weeks, or after heavy rains, the same sections of roads have potholes. In many cases, only the superficial aspects of the pothole problem are addressed without resolving the root cause, which then leads to ineffective maintenance on the same sections being repeated (Karoliny *et al*., 2015)

During the rainy season of 2009/2010, South Africa recorded an unprecedented occurrence of potholes, which continued into the 2010/2011 wet season. Maintenance projects were carried out throughout the country since then but the problem persists.
Mangaung Metropolitan Municipality (of which Bloemfontein City forms a major part) has a particular pothole repair strategy and procedure that is supposed to be followed but the

guidelines are not always adhered to, such as attendance to pothole complaints, which is supposed be within two days but there are delays generally in attending to such matters (Mangaung Metropolitan Municipality, 2017). Despite the availability of the guidelines and repair strategy, it has been observed that a large number of potholes still occurs and recurs on the roads of Bloemfontein City.

Therefore, the purpose of this study was to examine in detail what causes these potholes, how they are repaired, why they always recur after being repaired, and the cost implications for both motorists and government (Paige-Green, 2012). This study also included recommendations for sustainable solutions to general pothole repairs in Bloemfontein City.

## 1.3 RESEARCH AIM AND OBJECTIVES

### 1.3.1 Research Aim

The research aim is to assess factors and their impact on the occurrence and recurrence of potholes on Bloemfontein roads in order to find a possible effective and sustainable solution to the repair of recurring potholes.

### 1.3.2 Research Objectives

In order to achieve the aim of this research, the following specific objectives were set:

i. Assess potholes in terms of degree and extent of their occurrence on Bloemfontein roads.
ii. Investigate the engineering factors for recurring potholes in the study area.
iii. Evaluate the impact of pavement design technology and construction applicable on the city road structures.
iv. Examine the suitability of engineering methods and maintenance strategies adopted for the repair of potholes.
v. Determine the correlation strength between the formation of potholes and the examined cause factors.

## 1.4 METHODOLOGY

An ontological positivist approach was followed for this study in which both quantitative and qualitative methods were used (Zikmund *et al*., 2009). A few roads were selected randomly from the Bloemfontein City road network as a case study. The study was carried out to examine road conditions, traffic volume, road capacity, pavement designs, wheel loads and drainage. The study was conducted by means of data collection, questionnaires, an experiment, and direct interface interviews with various stakeholders, including the Government Municipality (Mangaung) and Department of Police, Roads and Transportation.

Information was collected initially from a review of literature relevant to the research topic. Data were collected from websites, journals, articles and other publications from various institutions locally and internationally, as cited in this dissertation and referenced on the bibliography.

Then, statistics were collected to identify trends in the repair of potholes and existing strategies and mechanisms currently used in Bloemfontein city. Statistics were collected from direct interviews with road authority institutions, including Mangaung Metropolitan Municipality and the Department of Police, Roads and Transport. Analyses were made of the pothole assessment, procedures and techniques, and their respective application.

A survey method was used to collect empirical data about roads in Bloemfontein and statistical methods were used to analyse the data. The survey was based on questionnaires administered to general public road users, including motorists and public transport users. Questionnaires were administered also to road authorities and people with technical experience in road maintenance. The outcome of the survey has been presented in Chapter Three and the findings in Chapter Four.

Finally, an experiment was conducted to evaluate the material currently being used and the respective procedures and techniques being applied. The experiment was conducted on a local road in Bloemfontein South. The complete procedure of pothole repair, from start to finish, was observed. Appropriate laboratory tests were conducted and examined, and the outcomes have been presented in Chapters Three and Four.

All the data collected and statistics gathered was assessed to ensure that only reliable and valid data, experiment methods and statistics were used. Finally, the data were tested rigorously for appropriate and relevant application. A detailed discussion of the research methods used has been documented in Chapter Three.

## 1.5 STRUCTURE OF THE REPORT

In Chapter One, the research, rationale, objectives and definitions of important terminology used in the thesis were introduced.

Chapter Two contains a comprehensive review of literature about pothole repairs. This chapter includes the concept of sustainable pothole repairs and a review of the factors and challenges affecting pothole repairs.

Chapter Three contains a detailed explanation of the methods used to collect and analyse data.

In Chapter Four, the results of the data analysis, findings and discussions have been presented.

Chapter Five contains the conclusions and recommendations based on the findings of this research. Recommendations for further research are made also in this chapter.

## 1.6 CONCLUSION

Since roads play a major role in the transportation of people and goods and create spatial integration, a holistic perspective of all aspects of road infrastructure and its maintenance in Bloemfontein City was essential for this study. The aim of the study was to examine the causes of the recurrence of potholes and to explore sustainable solutions to repairing them on the roads of Bloemfontein City

The study was conducted by means of data collection, a questionnaire, an experiment, and direct interface interviews with various stakeholders, including Mangaung Metropolitan Municipality and the Department of Police, Roads and Transportation. Findings were made concerning various causes of potholes in the city. Roads which had exceeded their design life-span had the most problems with deterioration and recurrence of potholes, even after maintenance.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 ROAD DETERIORATION

Deterioration occurs daily and rapidly on South African roads, which results ultimately in increased road accidents and vehicle damage (Automobile Association, 2016). Potholes are the main contributor to the deterioration of road networks and most money is spent globally constantly repairing them. The South African Government implemented a plan in 2011, with a R22bn budget for a 3-year period, dedicated to the repair of potholes. The budget still falls short as the actual estimate of potholes sits at R50bn per year. (Wheels24, 2016). In 2019, after delivering his State of the City address, Mayor Herman Mashaba said the City had been allocated a budget of R1.2bn for road repairs but said the city actually needed an estimated R11.8bn to address the road maintenance problem (Media24 News, 2019). Recurring potholes delay progress in development because they result in funds being used to resolve the same problem several times (Department of Transport SA, 2008).

Potholes not only cause inconvenience and costs for motorists and the government, but, in a worst case scenario, can cause fatal accidents. The South African Automobile Association (AA) stated that, if the South African roads were maintained properly, road deaths could be decreased by approximately 5% (Automobile Association, 2016).

## 2.2 DEFINITION OF ROAD TRANSPORT

Road transport refers to the transportation of merchandise and personnel from one location to the next on roads. A road is a course between two goals, which has been either cleared or dug away to enable transportation by means of mechanised and non-mechanised carriages (Bennett, Coleman & Co. Ltd, 2019). There are several advantages of road transport compared with different methods of transport. The investment required for road transport is less compared with railroads and air transport, for example. The expense of development, working expense and maintaining roads is less than that of railroads. (Berlin MD, 2012)

“Road transport” can be used to refer to the overland conveyance of either merchandise and materials or individuals (Eisele, *et al.*, 2000). The significant advantage of road transport is that it enables door-to-door conveyance of products and materials and offers significant financial savings for cartage, off-loading and stowage. Sometimes, road transport is the main method for conveying products and individuals to and from rustic areas which are not served by rail, water or air transport (Bennett, Coleman & Co. Ltd, 2019). Conveyance of products between urban communities, towns and small towns is made conceivable by road transport(Eisele *et al.,* 2000).

However, there are some disadvantages to road transport. For example, there is a greater likelihood of mishaps and breakdowns when using road transport (Oregon Department of Transport, 2009). Engines are not as protected as in different methods of transport. Road transport is less co-ordinated than other modes and can be unpredictable and unreliable (Berlin MD, 2012). Charge rates for road transportation are unstable and can be inconsistent, while the speed of road transport is moderate and constrained. Transporting massive products over long distances is expensive and can be inadmissible. In the present day, road transport also has a negative effect on nature. Building roads requires dissolving tar or laying other solids, which can damage the environment (El-Badawy & Valentin, 2018).

Furthermore, mechanised transport, made possible by roads, discharges vast quantities of air pollutants, such as nitrogen dioxide, unstable natural mixes, carbon monoxide and other harmful air toxins, including benzene, which have an unfavourable effect on respiratory well-being and pose a serious risk of dangerous atmospheric conditions (Eisele, *et al*, 2000). While the on-going existence of roads is a theme of research, the future of road transport includes innovations such as roads with solar-powered panels, where solar-powered cells replace black-top or tar, and there are vehicles with electric engines that reduce harmful discharges (Bennett, Coleman & Co. Ltd, 2019).

## 2.3 DESIGN AND QUALITY OF DIFFERENT TYPES OF ROADS

### 2.3.1 Road Design Procedures

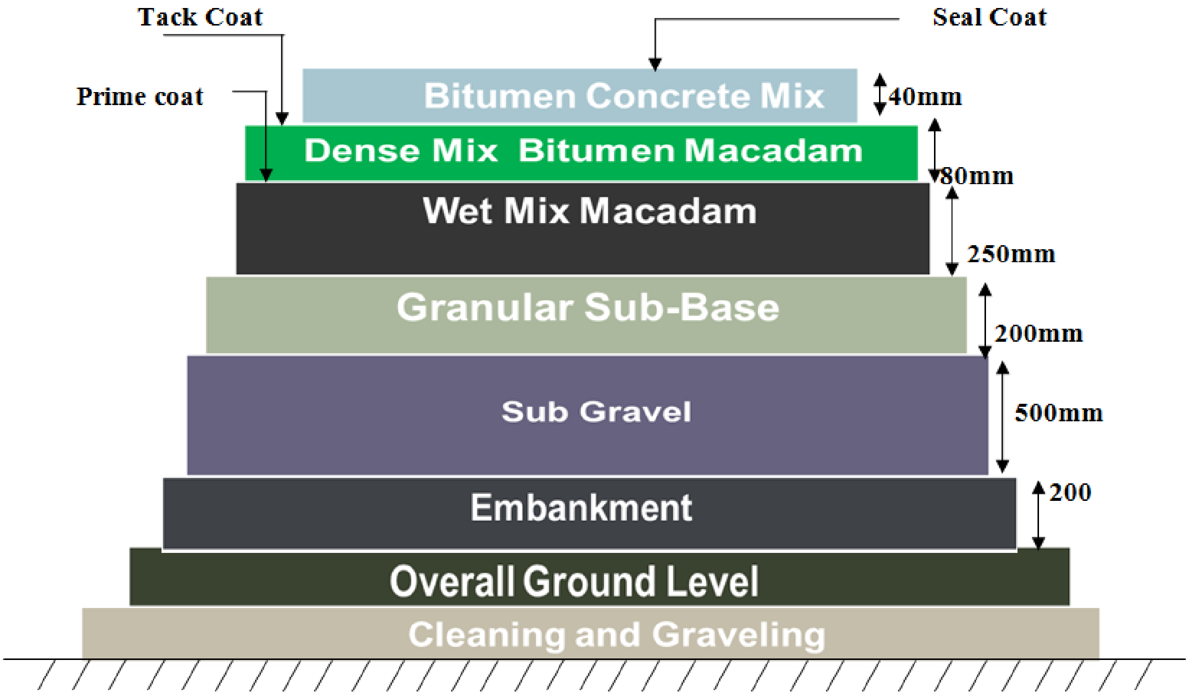
For flexible road-surfaces, structural design is concerned generally with determining appropriate layer thickness and composition. The main factors affecting design are stresses caused by traffic load and temperature variations. There are two common methods of designing the structure of flexible road-surfaces: empirical design and mechanistic empirical design (Nazarko & Vilutiene, 2015).

#### 2.3.1.1 Empirical design

An empirical approach is one that relies on the results of experimentation or expertise (COLTO, 1998). Several approaches use either a unit of supported physical properties or strength parameters of soil sub-grade (AASHTO, 2004). An empirical analysis of the flexible road design involves either a finished check or a soil strength check. An example of a design check is the Highway Research Board (HRB) soil system, within which soils are classified as units from A-1 to A-7 and a cluster index is used to differentiate soils among every group. Examples of soil strength checks are the McLeod Hveem Stabilometer, or California Bearing Ratio (CBR) check (Nazarko & Vilutiene, 2015).

#### 2.3.1.2 Mechanistic-empirical design

A mechanistic-empirical design technology relies on the properties of materials that relate input, such as vehicle weight, to an output or road-surface reaction. In road design, the responses are measured in units of stresses, strains, and defects in road structure, and the physical causes are measured in units of mass and material properties of the road structure (COLTO, 1998). The relationship between the road-surface responses and their physical causes is generally measured in units of mistreatment, using mathematical models. Together with this mechanistic approach, empirical components are used to determine what value of the calculated stresses, strains, and defects ends in road-surface failure. The relationship between physical phenomena and road-surface failure is determined by equations derived from empirical observation that are used to calculate the number of loading cycles before road-surface failure (Donev & Hoffman, 2018). Figure 2.1 illustrates flexible road-surface design (Rashid & Gupta, 2017).




*Source: (Rashid & Gupta, 2017)*

**Figure 2.1: Flexible road-surface design**

### 2.3.1.3 Road surface requirements

Road authorities are interested in the following characteristics of road surfaces:

a) Smoothness: the general public demands "swish" road-surfaces with a quiet ride. A studyt by (Ibraheem, 2014) found ride to be the foremost necessary feature for road-users.

b) Durability: agencies and private owners of roads need them to withstand the prejudicial effects of traffic load and atmosphere for their expected life span.

c) Safety: motorists and pedestrians expect safe roads. The road-surfaces must provide sensible skid resistance, with minimal surface defects, have distinct lane markings, minimise splash and spray and road-surface glare (Fetch, 2011).

d) Aesthetics: road-users are interested also in the appearance of the road-surface. Patches and different irregularities on the surface indicate that the road is not sturdy, which frequently leads to roughness/safety issues. Roads typically have asphalt or hydraulic cement, concrete surfaces (Enshassi & Kochendoerfer, 2016).

## 2.3.2 Vertical Alignment

Vertical alignment is the algorithmic mix of vertical bends and flat segments between them on a surface. Flat areas are referred to as elevations, and gradient is the estimation of their slant, usually expressed as a ratio e.g. a 5% gradient means an increase of five metres in elevation over a distance of one hundred metres. With the total economic life expectancy of the road as the highest priority, vertical alignment that is typical for the geographic area must be taken into consideration (TRH4, 1996).

Automobile speeds for travellers are determined by the quality of level surface as opposed to the vertical alignment, whereas the pace of transport by different, substantial vehicles is restricted by the vertical alignment. The recommended speed in relation to the vertical alignment ought to correspond appropriately with the even alignment and it can be contended that the next vertical alignment should define the speed (Chalke *et al*., 2018).

Given that the degree of vertical alignment must be satisfactory, consideration also must be given to the relationship between the ebb and flow of even and vertical alignment of a road. A vertical bend that corresponds with a grade bend ought to, if possible, be contained within the flat bend and, in a perfect world, have approximately the same length (Kannekanti, 2011).

Wherever a vertical bend falls within a grade bend, the overall rise created by the flat ebb and flow enhances visibility apart from that planned by the estimation of vertical ebb and flow. This enables the sighting profiles to take a better form than can be honed from the bottom. Be that as it may, the alignment is such that the driver's discernible pathway is contained within the dimension of the road. Thus, once the visible pathway goes past the road edge, the impact on visible distinction between parallel obstacles, for instance, safety barriers or high vegetation, should be checked (Pretorius, 2007). A smooth level line with continuous changes, suiting the category of road and the character of the geography, is preferable to a brief space with varied short lengths of level and vertical bends (COLTO, 1998).

#### 2.3.2.1 Slopes, camber and cross-fall

Camber refers to slants from a focal high point, as in a two-lane road, where the cross-section inclines down from the centre line to the shoulders of the road. Cross-fall refers to a single slant from shoulder to carriage-way. The slant, regardless of whether there is a camber or cross-fall, is constructed to enhance seepage off the road surface. The gradient of slant lies within 2% to 3%. In areas where high precipitation is common or wherever the most important, longitudinal angle is 0%, the higher slant gradient is favoured (CSIR, 2016).

Cambers that are steeper than 3% present operational problems, both in driving and in increased wear of vehicle parts. Anywhere that a load-bearing surface is constructed, the camber is taken to the external edge of the shoulder of the road. Unsurfaced road-shoulders must be designed with a cross-fall of 4% to ensure water run-off over this rougher surface that matches the run-off over a surfaced road (COTO, 2012). In the case of very narrow roads, on account of techniques or rare approaches, for example, where spatial limitations might block the arrangements for outdoor seepage, a negative or spin camber could be considered, i.e. the incline is to a focal low level. In this case, the centre-line of the road is the low point, thus making a cross-section V design. The whole surfaced width in that position serves as a drainage area (El-badawy & Valentin, 2018).

#### 2.3.2.2 Medians

Two specific conditions determine the steepness of the slant of the road: seepage and well-being. As mentioned above, the ordinary profile of a road would be a negative camber to encourage drainage (COLTO, 1998). The flattest incline that is suggested is 10%. Slants less than this might prompt ponding and might enable water to spill out of the middle onto the carriageway. Inclines more extreme than 25% (or 1:4) would make control of an errant vehicle more troublesome, resulting in a greater chance of cross-middle accidents. In the event that surface seepage requires a middle slant of more than 1:4, safety at this part of road would legitimise replacing surface drainage with an underground drainage framework (TRH4, 1996).

#### 2.3.2.3 Cut and fill hitters

Level roads that require cuts or fills so high that their hitters require particular consideration are exceptional in blended utilisation roads (COLTO, 1998). The expectation for these roads is that the grade line ought to be as close as possible to the common ground level and, ideally, marginally beneath it. This is important to guarantee straightforward entry to adjoining properties and furthermore to help the drainage of the surrounding area (Kannekanti, 2001).

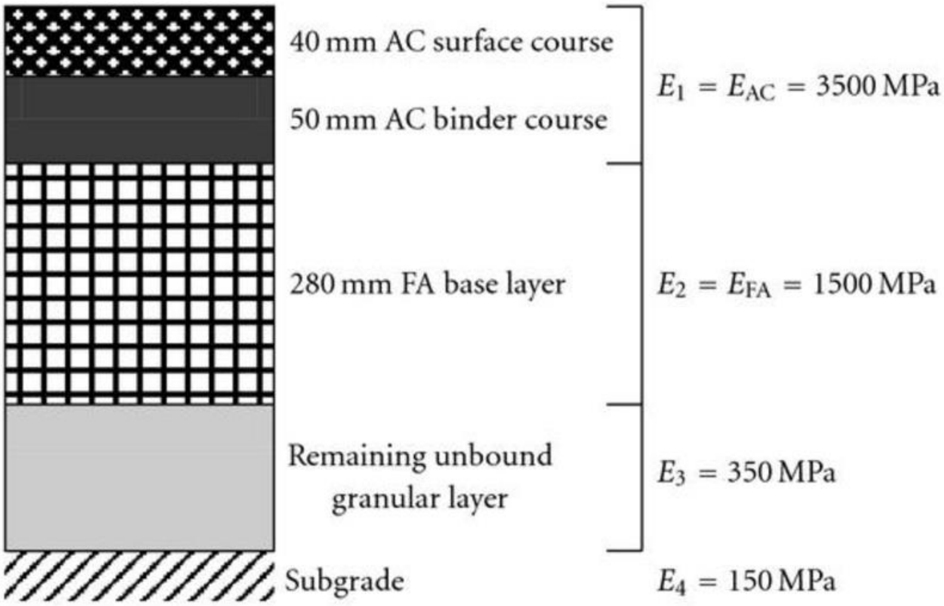
On vehicle only streets, the inclines of the sides of the street are determined, similar to medians, by two specific conditions. Shallow slants are required for safety, and a slant of

1:4 is the steepest required for this reason (KTH International Student Recruitment, 2000). An option would be to acknowledge the need for a steeper slant and accommodate safety by some other means, for example, guard-rails. For this situation, the steepest slant that can be used is determined by the common point of rest and erodibility of the development material (Shingloo, 2016).

### 2.3.3 Types of Road Surfacing

#### 2.3.3.1 Full-depth asphalt surface

Full-depth, asphalt, concrete road-surfaces are designed generally to account for fatigue and rutting (Boullbbibane, 2015). Design criteria, in terms of maximum allowable values for both the tensile strain on the underside of the asphalt concrete layer and vertical strain on top of the sub-grade, have been established and are used as the basis for selecting the design thickness (see Figure 2.2). Of particular importance is whether such roads will exhibit increased accumulation of plastic strains under long-term, repeated loading conditions that might lead to eventual collapse or whether the accumulation of plastic strains will cease and a shake-down condition will be reached (Rashid & Gupta, 2017)




*Source: (Eldin, 2002)*

**Figure 2.2: Full-depth asphalt**

#### 2.3.3.2 Conventional (flexible) asphalt concrete surface

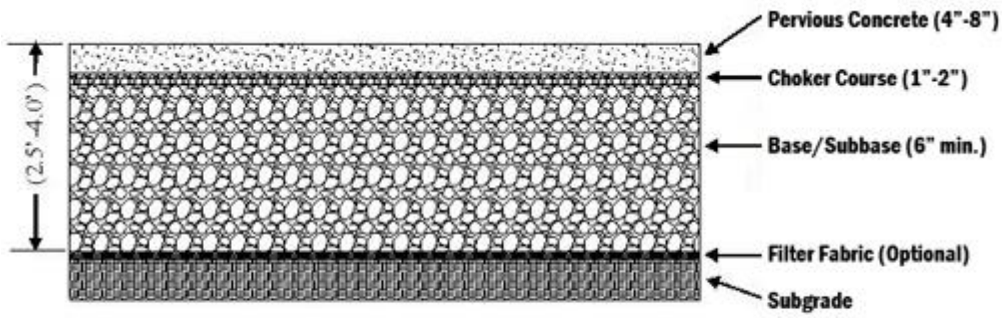
Flexible road-surfaces are so named because the total surface structure flexes or reflexes underneath a load. A flexible surface structure is generally composed of various layers of materials as illustrated in Figure 2.3 (Eldin, 2002). Each layer absorbs traffic loads from the layer above, spreads them out, and passes the excess load on to the next layer underneath. Thus, the stresses are reduced, being the greatest on the top layer and minimal above the sub-grade. In order to gain maximum benefit from this property, layers are usually organised in descending order of load-bearing capacity with material that has the best load-bearing capacity (and most expensive) above and material with the least load-bearing capacity (and least expensive) on the bottom (De Beer *et al*., 2012).


*Source: (Fetch, 2011)*

**Figure 2.3: Conventional asphalt concrete surface**

### 2.3.3.3 Porous asphalt design and function

Porous asphalt road-surfaces, illustrated in Figure 2.4, offer planners and constructors a new method for managing storm water. These surfaces, used frequently for parking lots, permit water to drain through the floor of the road-surface into a stone bed and filter into the soils below the road (Hezri, 2004). The worth of such road-surfaces has been proven since the mid-1970s, and recent changes in storm water guidelines have prompted many consulting engineers and public works officers to research statistics about them (Nazarko & Vilutiene, 2015).




*Source: (The Constructor, 2003)*

**Figure 2.4: Porous asphalt design**

With the appropriate design and construction, porous asphalt can be used to provide cost-effective, appealing road-surfaces with a life-span of at least 20 years and, at the same time, to have storm-water management structures that enhance filtration, water quality and, in many instances, reduce the need for a retention basin (The Constructor, 2003). The overall performance of porous asphalt road-surfaces is similar to that of other asphalt surfaces and, they can be designed for many situations (CSIR, 2016). It is important to channel the flow of water, usually into an underlying, open-graded, stone bed. When the surface water flows through the porous pavement and into the stone surface area, it slowly filters into the ground underneath. The size and depth of the stone bed must be designed to not disallow the water level from rising above the asphalt under any circumstances. The stone bed, often 18 to 36 inches in depth, provides an excellent sub-base for the asphalt paving (Lubbers & Bonner, 2002).

Special aspects of this road-surface, such as the underlying stone bed, are priced much higher than traditional construction methods, but these costs are more than off-set by removing the need for many aspects of standard storm-water management systems. On the jobs where construction costs have been assessed competitively, a porous asphalt road-surface is generally the less-expensive option (Wermeister *et al*., 2004).

### 2.3.4 Desirable Asphalt Properties.

Asphalt pavement must ensure a performance over a variety of temperature changes. During the warm summer season, pavement material must continue to be in a relatively solid state to withstand rutting (Komba *et al*., 2010). In the winter season the material must not become brittle to avoid cracking due thermal contraction of the roadway. Since temperatures fluctuate with geography, variable grades of asphalt binder are wildly available for various specific climates (Liu *et al*., 2014).

Generally, asphalt binders are categorized into two: unmodified (or neat) and modified binders. Most unmodified asphalt pavement performs efficiently over a 90°C range of road-surface temperature (as opposed to air temperature) between the summer and winter seasons. (The Asphalt Institute, 1997). However, there are many locations where the difference in high and low, road-surface temperatures exceeds the 90°C range. For these applications it is essential to regulate the asphalt binder to produce a “stretch” grade with an overall performance over an extended temperature range (Fetch, 2011).

The full-depth asphalt road-surface is one in which asphalt designs are used for all courses above the sub-grade. Such road surfaces are seldom affected by sub-grade moisture and are susceptible to underlying pavement construction. Full-depth asphalt is popular in all most highway construction and where high volumes of traffic, particularly trucks, are projected (El-Badawy & Valentin, 2018). Road-surfaces with untreated base layers can be used where local aggregates and drainage conditions are suitable. The untreated aggregate base is processed on a constructed sub-grade. A dense-graded asphalt layer and surfacing are used to complete the road-surface structure (AASHTO, 2004).

### 2.3.5 Historical Data: Design Aspects

Design aspects are all the items that are taken into consideration as factors contributing to a well-functioning road, with high service level and high performance, after construction. These factors determine the durability and design-life of any given road (AASHTO, 2004). These include all the road-paving design aspects, geometric design aspects and environmental factors that might affect the design-life and service of a road. Road quality, strength and durability depend entirely on the design, particularly the road-paving design. It was imperative to understand the design aspects of the roads in the area studied to assess their strength, longevity and durability under the existing traffic conditions.

Table 2.1 shows the details of the road-paving pavement design of each constructed layer underlying the roads selected for this study in Bloemfontein City. Since the study was focused on potholes, the main design element was the road-paving design.

**Table 2.1: Design of road-paving layers**

| Road | Description | | |
|---|---|---|---|
| | Prescribed design | Actual design | Remarks |
| **1. Nelson Mandela Drive** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: 150 lower selected G7<br>Layer 6: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: 150 lower selected G7<br>Layer 6: cut and fill | Actual design conforms to prescribed design |

| | | | |
|---|---|---|---|
| **2. Zastron Street** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: 150 lower selected G7<br>Layer 6: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: 150 lower selected G7<br>Layer 6: cut and fill | Actual design conforms to prescribed design |
| **3. Meadows Road** | Layer 1: 30mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 200mm sub-base<br>Layer 4: cut and fill | Layer 1: 30mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 180mm sub-base<br>Layer 4: cut and fill | 20% thickness deviation from the prescribed design |
| **4. Dewetsdorp Road** | Layer 1: 30mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 selected G7<br>Layer 5: cut and fill | Layer 1: 30mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 200mm sub-base<br>Layer 4: 130 selected G7<br>Layer 5: cut and fill | 25% Layer thickness deviation from the prescribed design |
| **5. Church Street** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 200mm sub-base<br>Layer 4: 150 selected G7<br>Layer 5: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 200mm sub-base<br>Layer 4: 150 selected G7<br>Layer 5: cut and fill | 10% Layer thickness deviation from the prescribed design |
| **6. M10 Street** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: 150 lower selected G7<br>Layer 6: cut and fill | Layer 1: 35mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 120 upper selected G7<br>Layer 5: 130 lower selected G7<br>Layer 6: cut and fill | 20% Layer thickness deviation from the prescribed design |
| **7. Moshoeshoe Street** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 150mm sub-base<br>Layer 4: 150 upper | Layer 1: 30mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 150mm sub-base<br>Layer 4: 150 upper | 25% deviation on surfacing from the prescribed design |

| | | | |
|---|---|---|---|
| | selected G7<br>Layer 5: cut and fill | selected G7<br>Layer 5: cut and fill | |
| **8. Walter Sisulu Road** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 250mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 200mm sub-base<br>Layer 4: 150 upper selected G7<br>Layer 5: cut and fill | 20% Layer thickness deviation from the prescribed design |
| **9. N1 to Bloemfontein** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 80mm BTB<br>Layer 3: 150mm base<br>Layer 4: 250mm sub-base<br>Layer 5: 200 upper selected G7<br>Layer 6: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm BTB<br>Layer 3: 150mm base<br>Layer 4: 250mm sub-base<br>Layer 5: 200 upper selected G7<br>Layer 6: cut and fill | Actual Design conforms to prescribed design |
| **10. N8 to Bloemfontein** | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 150mm upper sub-base<br>Layer 4: 150mm lower sub-base<br>Layer 5: 150 upper selected G7<br>Layer 6: cut and fill | Layer 1: 40mm asphalt surfacing<br>Layer 2: 150mm base<br>Layer 3: 120mm upper sub-base<br>Layer 3: 150mm lower sub-base<br>Layer 4: 150 upper selected G7<br>Layer 6: cut and fill | 20% Layer thickness deviation from the prescribed design |

*Source: (Mangaung Metropolitan Municipality, 2017- 2019)*

Deviations from road design prescriptions often occur, resulting in lower standards, as shown in Table 2.1. Of all the six prescribed road-paving layers, only 50% conformed to the required standards. Some of the layers that conformed to the thickness level and type of material were still not compacted to the required quality standards. This poor practice compromised the desired road quality and service level. Actual road design that is of a lower standard leads to poor road structure, which then forms part of the reasons that lead to rapid pothole development and, ultimately, road deterioration and failure

## 2.4 EFFECT OF ROAD CONSTRUCTION PARAMETERS

### 2.4.1 Soil Support

The capacity of the sub-grade to withstand the loads transmitted from the road-surface is one of the most necessary elements in designing road-surface thickness (COLTO, 1998). The sub-grade serves as a working platform to support construction equipment and as a foundation for the road-surface structure that helps to distribute traffic loads (CSIR, 2016).

Thus, it is essential to consider the structural functionality of the sub-grade. If the road-surface is not sufficiently thick, the loads imposed might cause extensive stress on the sub-grade than it can withstand. This may cause road-surface defects, cracking and, ultimately, failure (Matheba *et al*., 2015). Different kinds of soils have different load-bearing capacities. Sandy soil, for example, provide more stable support to heavy loads without deformation than a silty clay soil. As a result, for any given traffic volume and heavy loads using the roadway, a thicker road-surface will have to be constructed on clay soil than on sandy soil (TRH4, 1996).

### 2.4.2 Sub-Grade Classification

For the road designs discussed in Section 2.3 above, all soils can be categorized and classified into three classes: excellent (E), good (G), or fair (F). Resilient modulus (MR) design values are assigned to these different sub-grade classes. A fourth soil class, poor (P), is also covered in the following discussion. However, poor soil should undergo sub-grade treatment or replacement before laying aggregate and asphalt (Lubbers & Bonner, 2002).

#### 2.4.2.1 Excellent

Excellent sub-grade soils retain a substantial amount of their load-supporting capacity when wet. These include clean sands, sand-gravels, and those free of detrimental amounts of plastic materials (COTO, 2012). Excellent sub-grade soils are relatively unaffected by frost provided they contain less than 15% passing a 75 µm mesh sieve (No. 200). A soil classified as excellent will have an MR value of 20,000 psi or greater. (CBR > 17) (Das & Braja, 2002).

#### 2.4.2.2 Good

Good sub-grade soils are those that retain a moderate degree of firmness under adverse moisture conditions. These include soils such as loams, silty sands, and sand gravels containing moderate amounts of clays and fine silts (Das & Braja, 2002). A soil classified as good will have an MR value of at least 12,000 psi. (CBR > 8) (Jim Huddleston, 2003).

#### 2.4.2.3 Fair

Fair sub-grade soils are those that appear soft and plastic when wet. These include soils having large amounts fine silt (50% or more) and clay, passing a 75 μm sieve (No. 200) (TRH12, 1998). The sandy loams and coarse silts may also reflect poor bearing capacity in areas where frost penetration into the sub-grade may be encountered at different time intervals. This also applies in situations where the water table rises close to the ground surface during the course of the year. Soil classified as fair have an MR value of 7,500 psi. (CBR > 5) (Jim Huddleston, 2003).

#### 2.4.2.4 Poor

Poor soils often perform poorly as road-surface sub-grades. These include most clays and very fine silts. However, to improve their performance, these soils should be stabilised (AASHTO, 2004). Lime, fly ash, asphalt cement, Portland cement, and combinations of cement stabilisers can be added also to improve the sub-grade support. The selection of stabilising agent, the amount to use, and the application procedure depend on the soil classification and the sub-grade support value desired (Jim Huddleston, 2003). These should be determined through appropriate laboratory testing. A soil classification of poor will have an MR of 5,000 psi or lower (CBR < 3).

Soils can be categorised into one of the design classes using a variety of techniques ranging from past experience to detailed laboratory testing. These techniques are described below (Anderson & Steger, 2003). Regardless of the method used to characterise the soil, designers must be aware that, with increases in moisture content of all fine-grained soils, strength and modulus are reduced. Thus, a soil tested at moisture contents representative of summer conditions might have only half that strength in winter (AASHTO, 2004).

### 2.4.3 Soil Classifications

Soil is classified for road construction in order to determine overall performance of the sub-grade based on tests. AASHTO and Unified Soil Classification (USC) systems are mostly used in classification of soils (Dasgupta & Tam, 2005). After classified, the sub-grade category will be determined. AASHTO system classifies and categorize a soil's load-bearing capacity as A-1 to A-7. The best highway sub-grade soils are classified as A-1 and the worst are A-7 (AASHTO, 2004). The classification is informed by the sieve analysis, plasticity index, and liquid limit of the soil material tested (COLTO, 1998).

The USC system also depend on tests. With the USC system, classifies the most suitable sub-grade soils as well-graded gravel (GW), and plastic clays (CH) as the worst. Soil classification methods to estimate the soil's load-bearing capacity might also be adequate for projects where the instances of failure are minimal (AASHTO, 2004). Additionally, classification structures are also used to support the designer's experience with a given soil type. However, with projects of higher importance or, instances where the designer is not familiar with the soil types, additional testing is may be required (Jim Huddleston, 2003).

### 2.4.4 Sub-Grade Strength / Modulus Tests

The strength of soils underlying a road-surface is often determined by using the test procedures of either the Hveem Stabilometer (R-value) or California Bearing Ratio (CBR). Dynamic cone penetrometer (DCP) tests are also used to measure soil strength. The DCPs can be related to the CBR value using empirical relationships. These tests provide better characterisation of the sub-grade soil strength indication than the ones obtained simple soil classification. As the consequences of road-surface failure increase, the use of strength testing is warranted (COLTO, 1998).

Finally, for those road-surfaces where failure would affect the economics of the facility significantly, laboratory testing for the resilient modulus, MR, of the soil is required. Whether sub-grade soil was classified through simple classification, strength or modulus testing, soil properties will still vary and depend on moisture content. Soils sampled and tested under warm summer conditions might not represent the ordinary soil properties for the year, and average values of soil strength should be used. (de Beer *et al*., 2012)

### 2.4.5 Additional Soil Considerations

When poor sub-grade soils are identified, the designer can strengthen the quality of the sub-grade support by stabilising the soil or by replacing the unsuitable material with suitable imported material (Benatti & Miguel, 2013). Common stabilisation agents include cement and lime. The addition of any of the material improves the soil material workability by decreasing the plasticity of the soil. The use of cement and lime as stabilising agents increase the modulus and strength of soils. The use of lime to higher plastic clay (CH) can result in a satisfactory construction of base layers (COLTO, 1998). However, lime is not useful when used with non-plastic soil.

Construction on poor soils during the winter season can also be accomplished by removing soil thickness of between 12 to 24 and replace with coarse aggregates on a separation geo-textile (AASHTO, 2004). The aggregate performance is enhanced by the use of a separation layer. This separation layer reduces the intrusion of fine particles from the sub-grade into the subbase or base layer. When the intrusion of fines is reduced, the base strength is maintained with longer durability. However, some manufacturers claim that the use of a separation layer might reduce the desired base thickness (CSRA, 1994). Several classes of soils present various problems that may lead the retention of a road-surface engineering specialist. Existence of organic or expansive soils or a high water table requires special attention by a consultant (de Lima *et al*., 2019).

### 2.4.6 Aggregates

Asphalt mix designs require use of hard, inert aggregate materials such as processed gravel and crushed stone. The aggregates are specially and properly selected, graded and then combined with the asphalt cement to form asphalt mixes (De Beer *et al*., 2014). Aggregates play a major role as a load-bearing component of the mixture and they carry 90% to 95% of the weight of the total mixture (75% to 85% in terms of volume) (Jim Huddleston, 2003).

#### 2.4.6.1 Types of aggregates

Paving aggregates are often categorised according to source and method of preparation, such as the following (AASHTO, 2004):

a) **Pit or bank-run aggregates**. Both gravel and sand are pit or bank-run original aggregates. They are generally screened to acceptable size and washed before being used in road-surface construction (CSIR, 2016).
b) **Processed aggregates**. When natural or bank-run aggregate has been processed and screened to make it suitable for asphalt mixes, it is regarded as a processed aggregate (COLTO, 1998). Crushing generally improves the particle structure, by making the rounded particles more angular, and the surface texture, by making the

floor rougher.

c) **Quarry aggregates**. Paving aggregates are produced also by removing solid rock from the face of a quarry, by blasting or other means, and then crushing and sizing the materials to produce the required construction material (AASHTO, 2004). Quarry aggregates often result in more stable mixes because of their resilient texture and angular shape.

d) **Synthetic aggregates**. Aggregates produced by altering both the physical and chemical properties of the original material are known as artificial (or synthetic) aggregates. These aggregates are a by-product of manufacturing and burning process (e.g. blast furnace slag), and are specially produced for specific uses (e.g. expanded clays) (Eldin, 2002).

#### 2.4.6.2 Desirable aggregate properties

Selection of aggregate materials for asphalt concrete road-surfaces depends on the quality, cost and availability of material and the methodology to be used for construction. Suitable aggregates used in asphalt mix designs are evaluated and classified in terms of the following properties (Eldin, 2002):

a) **Size and grading.** The maximum dimension of an aggregate is the smallest sieve through which 100% of the material passes (COLTO, 1998). The purpose for which asphalt concrete is to be used determines not only the maximum aggregate size, but also the preferred gradation (distribution of sizes smaller than the maximum) (AASHTO, 2004).

b) **Durability.** Toughness or hardness is the potential of the aggregate to withstand crushing or disintegration during mixing, laying, compacting, and when bearing traffic load (Das & Braja, 2002).

c) **Soundness.** Soundness is the ability of the aggregate to resist deterioration caused by natural factors such as the unfavourable weather conditions (Jim Huddleston, 2003).

d) **Particle shape and texture.** The shape of aggregate particles influences the strength and workability of the asphalt mixture, as well as the density achieved during compaction. When compacted, irregular particles, such as processed stone, have a tendency to “lock” collectively and withstand displacement (Eldin, 2002). Surface texture have an effect on workability and road-surface strength. A rough, sand-papery texture provide more strength than as compared to smooth texture. Smooth faced aggregates are easy to coat with an asphalt layer, but not as suitable as rough surfaces (Jim Huddleston, 2003).

e) **Cleanliness.** Foreign or deleterious particles make some substances unsuitable for road-surface mixtures (COLTO, 1998).

f) **Absorption.** The porosity of an aggregate mixture permits the mixture to soak up asphalt and form a bond between the particles and the asphalt. A level of porosity is desired, however aggregates that are tremendously absorbent usually are not used (Scribd Inc, 2009).

g) **Moisture sensitivity.** Whenever the asphalt layer is separated from the mixture because of water action, it is referred to as stripping. Aggregates covered with a large amount of dirt also can cause poor bonding which leads to stripping (AASHTO, 2004). Aggregates that are susceptible to stripping normally are not suitable for asphalt road-surface mixtures unless an anti-stripping agent is used. (Liu *et al*., 2014)

### 2.4.7 Effect of Compaction

Degree of compaction has a direct impact on the life-span of a road-surface. Low base and surface compaction values will reduce the durability of a road-surface (de Lima *et al*., 2019). A larger numbers of air voids (or low density) reduces the strength and ability of the asphalt mix to resist deformation and cracking from repeated traffic loads. When asphalt is laid at lower densities than specified, permanent deformation might occur on the road structure during heavy traffic laods. (Pais *et al*., 2013).

### 2.4.8 Effect of Material Quality

Scope of work is usually accompanied by design specifications to ensure use of quality materials and to control gradation, fracture percentage, and durability of the road structure. Non- compliance with the specifications may reduce the strength and durability of a road structure and this, in turn, often results in payment adjustments (COLTO, 1998). As noted above, minor variations in thickness have a significant effect on the life-span of a road-surface. The use of thicker asphalt layers (>100 mm) offers several advantages over thin surface layers (The Asphalt Institute, 1997). For example, they are easier to compact because thicker sections retain heat longer and allow the contractor ample time to ensure that the specified density is met. Furthermore, minor variations in thickness are less harmful to the life-span of a road-surface when thicker sections are used (Galkin, 2015). Thicker sections can extend the construction season also, since thicker sections retain heat better, enabling contractors to meet density requirements in cooler weather (Pareira & Pais, 2017).

### 2.4.9 Construction Considerations

A number of construction factors have a major impact on work quality and the expected life-span of a road. These factors must be considered when developing the construction specifications for a particular design. (Jim Huddleston, 2003).

#### 2.4.9.1 Drainage

Civil engineers recognise the importance of good drainage in the design, construction, and maintenance of any road-surface. Probably no other single factor plays such an important role in determining the likelihood of a road-surface providing trouble-free use (TRH4, 1996). The accumulation of water in the sub-grade, or in an un-treated aggregate base course, usually causes problems. When the soil is saturated, it is weaker. Some soils swell when water is added, which causes differential heaving. These factors weaken the structure of a road-surface and its capacity to support traffic loads.

Water in the road's asphalt layers can strip or separate the asphalt layer from the aggregate (Saad, 2014). Clearly, it is important to consider the drainage of a roadway. There are two basic categories of drainage – surface and sub-surface (COLTO, 1998). Surface drainage includes the disposal of all water present on the road-surface, shoulder-surface, and the adjacent ground when sloped toward the road using different forms of culverts or similar drainage structures (see figure 2.5). Sub-surface drainage system removes water from the surrounding soil of the road structure. Lack of attention to either of these two drainage systems can lead to structural failure of road. (COTO, 2012)

*Source: (Saad, 2014)*

**Figure 2.5: Culvert to drain storm water from a road network**

### a) Surface drainage

Components of effective surface seepage are the crown, shoulders, slants, courses and deltas (COLTO, 1998). A road's crown ought to have an adequate incline from the asphalt centre-line to the edge to ensure that water will drain successfully off the roadway surface. At a point where the incline is too level, water can lake initially and filter through joints and splits into the asphalt or under the surface (Saad, 2014). This can cause asphalt breaks and potholes. Water that does not drain off the roadway also can pose a safety peril of drivers hydroplaning.

A crown within in the range of four to six percent is satisfactory for hard-surfaced streets. Shoulders ought to be flush with the nearby roadway, slant a marginal distance from the roadway, and have no signs of disintegration or auxiliary trench. Earth shoulders ought to be cut according to local office regulations and techniques (CSIR, 2016). Table 2.2 details and rate drainage efficiency on a road way based on duration of water removal from the road.

**Table 2.2: Quality of drainage determined by dissipation time**

| Drainage quality | Time for 50% dissipation |
|---|---|
| Excellent | 2 hours |
| Good | 1 day |
| Fair | 1 week |
| Poor | 1 month |
| Very poor | (Water will not drain) |

*Source: (Saad, 2014)*

For surface drainage, the road-surface and shoulders must be crowned or cross-sloped to facilitate the flow of water off the roadway. Normally, the cross-slope moves the water to a curbed or inverted, shaped gutter and then off the road into a storm sewer or flume to a ditch. In parking areas or playgrounds, the cross-slope or crown can be inverted toward a centre swale with a grated inlet for drainage (Jim Huddleston, 2003).

Construction of ditches is usually considered on edges of non-curbed road sections. Storm water from the road and shoulder surfaces to the ditch drainage area. The adjacent road shoulder is sloped frequently toward the ditch and can contribute significantly to the drainage flow. Comprehensive road design practices provide cross-slopes both on the surface and in the underlying road structure layers and sub-grade. Such designs will prevent accumulation of water on the road and enhance efficient drainage (Scribd Inc, 2009).

**b) Sub-surface drainage**

Sub-surface water is water that percolates through, or is contained in, the layers beneath the surface. It is present usually as water that flows under the force of gravity or as capillary water that moves under capillary action in the soil (Pareira & Pais, 2017).

Water might also rise from the underlying soil through the sub-grade and into the base course. This water will move readily into an untreated aggregate base to a low point on the profile (Enshassi & Kochendoerfer, 2016). If steep grades are present, and the sub-surface water flows into an untreated, aggregate base to the low spot and is not intercepted, failure of the road-surface structure will often result. Water in the road-surface courses also might contribute to the stripping of asphalt layers from the aggregate particles (Patel *et al*., 2018).

#### 2.4.9.2 Basic considerations

The user needs to consider a number of factors when selecting a type of mix for a given application (Shingloo, 2016). Factors that must be considered include the following.

**a) Surface appearance (texture)**

Depending on the application, the user might want a smooth textured surface (walkways, recreational areas) or a rough surface (streets, highways). The finer, dense-graded mixes will produce smooth and tighter surface texture. They will also be resistant to segregation caused by labour hand work (raking and shovelling). Where significant amounts of hard work is required, a fine mix is a preference (The Constructor, 2003).

**b) Rut resistance**

Some applications in commercial and industrial facilities require a much more stable mix to minimise deformation and rutting under heavy traffic loads. Mixtures containing coarse aggregates have greater performance for such applications. Other applications (e.g.

recreational structures and light trafficked driveways), only need minimal structural stability (Woods, 2004).

**c) Permeability**

It is a very critical performance aspect to select the most appropriate mix type, mix design and layer thickness (COLTO, 1998). Design, mixture type and layer thickness all have a major direct impact on a contractor's ability to achieve the utmost asphalt compaction quality to appropriate densities which, determines the performance of the road structure. Recent research has shown the relationship between poor mix designs, air voids and pavement permeability (Pareira & Pais, 2017).

### 2.4.10 Environmental Issues

Natural effects resulting from road development projects fall into three classes (Yang *et al.,* 2016):

i. direct impacts;
ii. indirect impacts; and
iii. cumulative effects.

#### 2.4.10.1 Direct impacts

Co-ordinate effects on the environment are related to the road itself, such as the road-building procedures, for example, site access, clearing of vegetation, and division of farmland. The extraction of rock material from a quarry for use in surfacing the road is a conspicuous, direct effect of road development. In this case, the terrain in which the quarry is situated would be influenced by activities related to the road project. For the most part, co-ordinate effects are less demanding to monitor, evaluate, and control than aberrant effects, because their impact is generally self-evident (Yang *et al.,* 2015).

#### 2.4.10.2 Indirect impacts

Generally, back-handed effects are connected intimately with the development, and might have more significant results on the environment than co-ordinate effects. Back-hand effects are more difficult to quantify, but can be more far-reaching. After some time, they can influence larger topographical areas of nature than anticipated. Cases include reduction of surface water quality by the disintegration of land cleared for an urban development close to a new road. Another basic, aberrant effect related to new roads is increased deforestation of a zone, caused by easier access to logs or the convergence of new settlements (Byzyka & Chamberlain, 2017):

Effects on nature ought to be considered because they are related not only to the convenience of road access, but also to destinations associated with a road project, which include storage and retrieval sites, materials treatment areas, quarries, access roads, and project offices on site. Comprehensive documentation of the assumptions used in the assurance of effects is essential. Tolerances and the nature of essential data must be demonstrated while evaluating any effects that are difficult to measure (Hong *et al*., 2014).

#### 2.4.10.3 Cumulative impacts

The process of total natural change can emerge from any of the four types of occasions (Bennett, Coleman & Co. Ltd, 2019) as follows:

(i) Single vast occasions, i.e. an extensive undertaking;
(ii) Multiple, inter-related occasions, i.e. road extensions within a district;
(iii) Catastrophic, sudden occasions, i.e. a significant land-fall into a stream confluence; and
(iv) Incremental, broad, moderate change, for example, an inadequately composed duct or seepage framework along a lengthy, difficult terrain stretching out from a watershed (Thube *et al*., 2005)

These occasions can be substantive, multiplicative or synergistic, which then could result in harm to the capacity of one or more biological communities, or the structure of an environment. The total effect of a road improvement, might be the de-vegetation and possible disintegration of a roadside pull-out. The situation could develop as follows: a road cutting through a mountain offers some spectacular views and, without assigned rest zones, drivers pull over randomly. (Woods & Adcox, 2005) Roadside vegetation is harmed by vehicle and pedestrian activity, and the dirt is left unprotected. Ensuing precipitation causes disintegration and silting of adjacent waterways. The vegetation never has enough time to recuperate as a result of high activity volume, and the situation deteriorates over time (Cepas, 2012).

As the example above shows, appraisal of aggregate impacts (CEA) is a complex process which requires broad knowledge of biological standards and environment reaction systems (Hezri, 2004). The success of a CEA depends strongly on the system that is set up before the evaluation is attempted. The assessment can start once spatial limits for the evaluation have been defined; quantifiable factors have been selected; and the connections between the selected factors have been established (Thube *et al.,* 2005).

The overall effect of the proposed road project on the neighbouring environment can then be assessed by: compiling a breakdown of activities that are part of the proposed project; evaluating the progressions that will happen in the quantifiable factors caused by these activities; and evaluating the impacts that the adjustments in each of the quantifiable factors will have within the area defined by the spatial limits. CEA is valuable but must be completed appropriately with a specific end goal to create dependable outcomes (Chalke *et al*., 2018)

#### 2.4.10.4 Ecosystem function impacts

The effects of sub-set or variation of aggregate, that impact biological community functions, which incapacitate or destabilise entire environments, are the most hazardous and, frequently, are the least likely to become evident over a brief time-frame. Managing numerous road-related cases requires navigating watersheds in which developments affecting surface and sub-surface water are unpredictable (Dasgupta & Tam, 2005). One notable example was a roadway built over a mangrove timberland along the Caribbean drift.

At the planning stage, the extent to which the expected blending of fresh and ocean water would affect the survival of the sound timberland on both sides of the road was not comprehended fully (Agreement SA, 2010). Thus, the vast majority of the woodland ceased to exist. On one side, the waters were not sufficiently saline and, on the other, there was insufficient blending with fresh water. The impact was to annihilate the biological system and the effect on the nearby populace, which utilized the mangrove woods territory, was extreme. It was most likely that there was no indication of this effect until a few years after the road was constructed. A similar situation could arise in circumstances where streets separate courses of natural life movement, which can incur pressure (Fetch, 2011)

Finally, there is the effect on the social condition. Having had their traditional grazing areas cut off by new or re-developed roads, even with negotiated arrangements, cattle ranchers might be compelled to move their herds onto the backwoods or fallow lands, which would result in quick exhaustion of the undergrowth (Hezri, 2004). This would deplete the fringe of the backwoods eco-zone and the essential woodland environment, disrupting the existing fauna with the intrusion of a species better adjusted to the biological system of the recently made "grazing forest". The invaded woodland biological community is affected further, dependents on the biological community are influenced, and a chain response occurs through the system, with consequences for the social condition in the form of network aggravations and hardships (Matheba *et al*., 2015).

#### 2.4.10.5 Positive and negative impacts

The emphasis in all road projects should on be avoiding and mitigating negative effects. Ecological effects can have both constructive and destructive impacts; a few effects can affect a few people significantly and adversely affect others in a similar domain (Hezri, 2004). For instance, rechannelling streams as part of road development might enhance seepage for a road-side agriculturist, yet ruin the livelihood of other people who rely upon the aquatic species disrupted by the rechannelling (Hong *et al*., 2014).

Positive results of completed projects usually include improved access, reduced travel time and cost, and fewer accidents. Other positive results of a project could include enhanced water maintenance for nearby use, storm water control, or providing better access to offices for people on foot and bicycles. Occasionally, positive results occur without being anticipated by the road constructor, for example, the use of watering points for domesticated animals in dry territories (Kandhal, 2008).

### 2.4.11 Bitumen Pavement Materials

Bitumen is a dark shapeless, cementitious material that can be strong, semi-strong or gooey, and is found in various structures, such us shake black-top, normal bitumen, tar and bitumen obtained from oil, which is referred to as oil bitumen (Eldin, 2002).

A large portion of roads, generally, are constructed with bitumen (COTO, 2012). The global interest in bitumen represents in excess of 100 million tons each year, which is approximately 700 million barrels of bitumen used every year. Oil bitumen is regularly referred to as bitumen or black-top. In Europe, for example, bitumen implies the fluid cover. In North America, the fluid layer is referred to as black-top, or black-top bond (Scribd Inc, 2009).

#### 2.4.11.1 Origin of bitumen

Generally, the expression "bituminous materials" is used to indicate substances in which bitumen is available or in which it can be traced. Bituminous substances include basic bitumen and tars. Bitumen occurs in nature in various forms: hard, which effectively is disintegrated bitumen in shake black-top; and milder, which is available in tar sands and black-top lakes (Paige-Green, 2012). Bitumen can be obtained also from the build-up yielded through an oil refining process. Although tars do occur in nature, the world has depended on bitumen obtained from oil for over a hundred years for various reasons (CSIR, 2016).

Tars are obtained as condensates from the processing coal (at high temperatures), oil, oil-shale, wood or other natural materials. Pitch is produce when a tar is partly refined so that unpredictable segments have dissipated. Coal tar is mistaken often for bitumen but they are two, completely unique, synthetic products and should not be confused (Monismisth *et al.,* 1970). Known for its cement and strong attributes, bitumen is used widely in the development business. Bitumen is used in road construction because it is thick when hot, but strong once it has cooled. In this way bitumen works as the cover or adhesive for parts of the whole (Scribd Inc, 2009).

#### 2.4.11.2 Viscosity and rheology of bituminous materials

The resistance of a fluid when streaming characterises the consistency of that liquid. Under the influence of power, a liquid displays higher resistance when the consistency is high (Galkin, 2015). The two factors that characterise the thickness of bitumen are:

- Chemical composition of bitumen
- Structure of bitumen

The structure of bitumen comprises two variables: asphaltenes micelles and maltenes. In bitumen sol, the asphaltenes micelles are scattered in a maltenes continuum. As the asphaltenes content lessens, the thickness of bitumen also diminishes. Collection is the factor that determines the thickness of bitumen gel. Bitumen gel has a higher thickness (The Asphalt Institute, 1997).

The influence of asphaltenes on viscosity of bitumen can be summarised as: the increments in consistency are related to the increments in the quantity of asphaltenes

(Galkin, 2015):

- The change in consistency is determined by the asphaltenes particles;
- The asphaltenes have absolute. The more prominent the accumulation, the greater the thickness.

#### 2.4.11.3 Measurement of bitumen viscosity

Bitumen viscosity can be expressed as the proportion of shear pressure in relation to the rate of shear strain. It is estimated in Pascal Seconds. The dynamic thickness can be computed also in terms of kinematic consistency in units of $m^2/s$ or $mm^2/s$. 1 $mm^2/s$ = 1 cSt (Centistoke) (Eldin, 2002).

In view of high necessity for kinematic consistency, various instruments can be used to estimate the bitumen thickness. The details needed for estimation are the overall consistency at 60°c and a kinematic thickness at 135°c. The vacuum fine tube viscometer is used to determine overall consistency. A barometrical slim tube viscometer is used to quantify the kinematic thickness (Galkin, 2015).

The displacement occurring in a thin layer of bitumen can be determined by using a sliding plate test. The strength in the layer can be calculated also. The test involves keeping the bitumen layer between metal plates for various combinations of stacking time and temperature (The Asphalt Institue, 1997).

The opposition of power is represented by F in Equation 1 where:

F = Opposition of power
A = Zone of the surfaces
D = Separation between the surfaces
V = Relative speed of development of one plate in relation to the other

$$F = \eta\frac{AV}{d}$$

**Equation 1**

The coefficient of viscosity is represented by η. This is also called the absolute viscosity is calculated by using Equation 2:

$$\eta = \frac{Fd}{AV} = \frac{Shear\ Stress}{Rate\ of\ Strain}$$

**Equation 2**

Kinematic viscosity is calculated by using Equation 3:

$$\text{The kinematic viscosity} = \frac{Dynamic\ Viscosity}{Mass\ Density}$$

**Equation 3**

The most pragmatic method to gauge the consistency of bitumen is by using a rotational viscometer test (ASTM D4402 - 02). The Brookfield and Thermocel rotational viscometer makes it possible to estimate the consistency of bitumen at different temperatures (The Asphalt Institute, 1997).

#### 2.4.11.4 Influence of temperature on the viscosity of bitumen

Bitumen has a tendency to melt when subjected to a temperature rise and will solidify when the temperature falls. The consistency of various types of bitumen also changes with variations in temperature (Galkin, 2015).

It is essential to know the variations of thickness with temperature of the bitumen used in the development procedure. This is the main factor that determines the suitability of introducing bitumen to open conditions (The Asphalt Institute, 1997). The bitumen used for an area having high temperatures is different from that used in cooler areas. The workability, solidness and load-bearing factor are based on the thickness of the bitumen composition used (Kandhal *et al*., 2008).

The changes in thickness of bitumen in relation to temperature are expressed by the estimation of the temperature sensitivity of bitumen. It is dictated by the infiltration worth, P and softening point temperature, T (Kannekanti, 2001). The exact relation can be given as:

**Log P = AT +k** **Equation 4**

Where:

P = Softening point

A = Temperature sensitivity

T = Temperature

k = Temperature coefficient

"AT" is assigned to temperature sensitivity of the logarithm of infiltration worth. The estimation of A fluctuates from 0.0015 to 0.06. This variation itself appears to vary with the reaction of bitumen to temperature. "k" is a constant (Workmeister *et al*., 2004).

From the above explanation, a connection was made by (Wilson *et al*., 2010) as expressed in Equation 5. This new connection related A to an index named the penetration index, PI. The connection states that, for road bitumen, the infiltration worth index PI = 0.

$$A = \frac{d(\log P)}{dT} = \frac{20 - PI}{50(10 + PI)}$$

**Equation 5**

Where:

A = Temperature sensitivity

P = Softening point

PI = Penetration index

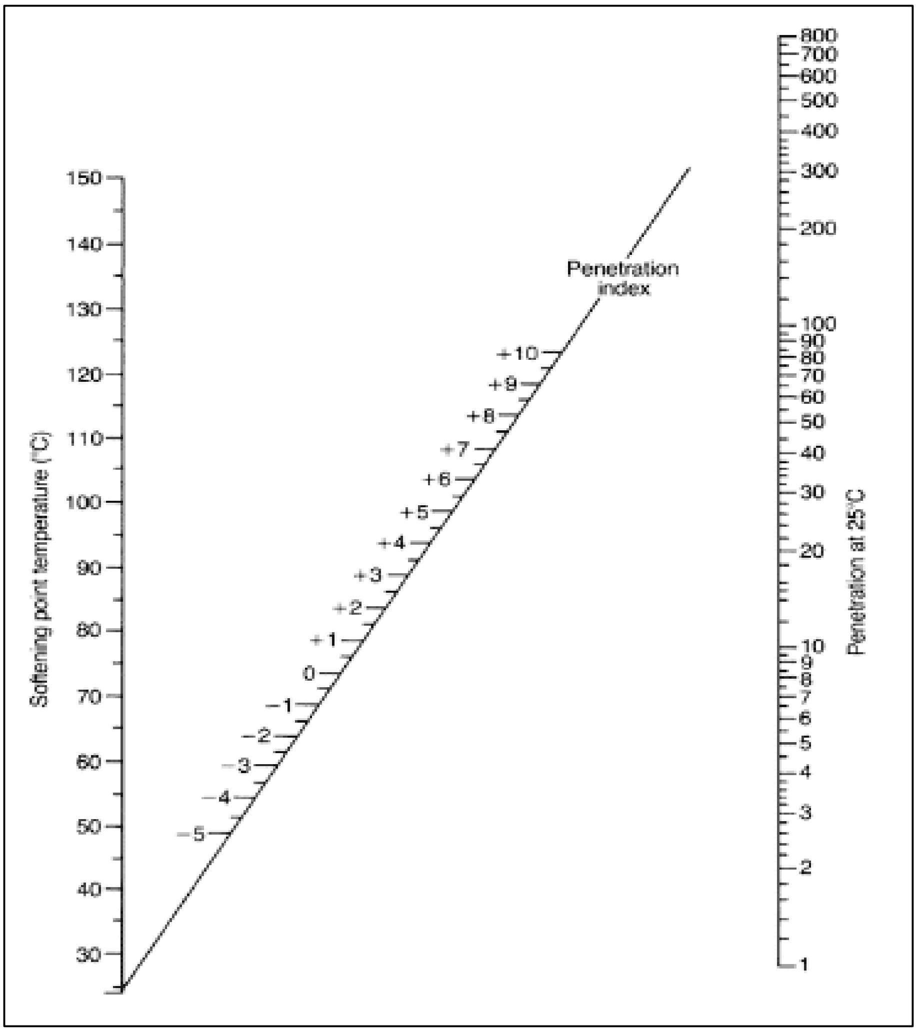
It has been observed that most varieties of bitumen have an infiltration worth of approximately 800, at their softening point temperature. Therefore, the PI can be assessed, if the infiltration at 25°c and softening point temperature are known (Lubbers & Bonner, 2002) as shown in Equation 6.

$$\frac{d(\log P)}{dT} = \frac{\log 800 - \log P}{SP - 25} = \frac{20 - PI}{50(10 + PI)}$$

$$\text{i.e. } 0.0523 = \frac{20 - PI}{50(10 + PI)}$$

**Equation 6**

Figure 2.6shows the Nomograph to prove the validity of the expression by (Lubbers & Bonner, 2002) stated above.



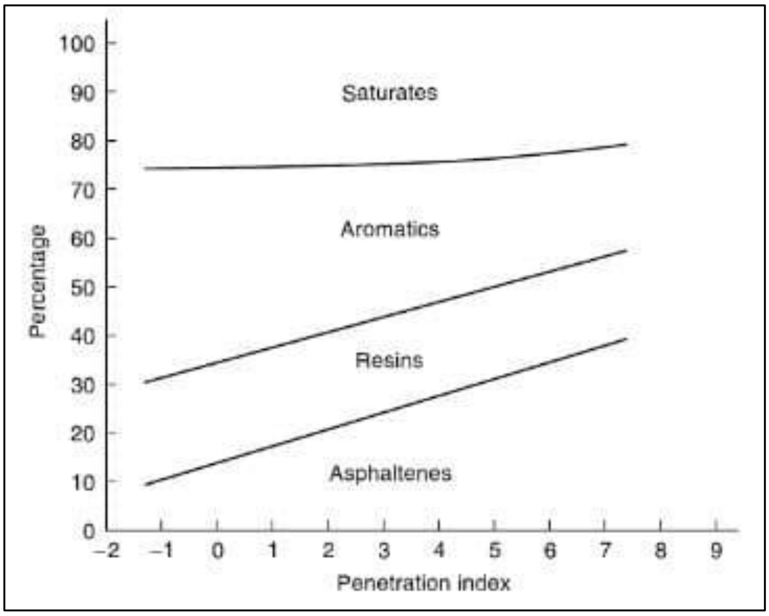

*Source: (Lubbers & Bonner, 2002)*

**Figure 2.6: Nomograph to evaluate the penetration index of bitumen, with the known values of softening point temperature and penetration value at 25°c**

A quantitative measure of the reaction of bitumen material to a given temperature is expressed by a penetration index value (PI). The PI index for bitumen that is used for roads has a value between - 2 and +2.

At the point where the PI reading is low, the bitumen behaves the same as Newtonian liquids in that they are exceptionally fragile at reduced temperatures. At the point where the bitumen has a higher estimated PI (Figure 2.7), protection from lasting rutting is enhanced (Shingloo, 2016).

PI increases with an increase in asphaltenes, to the detriment of aromatics. Thus, the PI is influenced by the bitumen compound composition to a larger degree. The figure below illustrates the range of PI with every compound portion of bitumen (The Asphalt Institute, 1997).




*Source: (Lubbers & Bonner, 2002)*

**Figure 2.7: Variation of penetration index in relation to chemical composition**

Bituminous materials or surfaces are used widely for roadway development, essentially because of their significant protective and water-sealing properties available generally with minimal effort. Bituminous materials consist of bitumen, which is a dark, thick, cementitious substance comprising predominantly high atomic weight hydro-carbons obtained from refining oil or common black-top. It has adhesive properties and is dissolvable in carbon di-sulphide (Das & Braja, 2002). Tars are deposits from the reductive refining of natural substances, for example, coal, wood, or oil, and are more sensitive to temperature than bitumen. Bitumen obtained for refining oil is dissimilar to tar (Lubbers & Bonner, 2002).

#### 2.4.11.6 Production of bitumen

Bitumen is the residue deposited when crude oil is refined. A range of refinery methods can be used to produce bitumen of varied consistency and other useful properties, for example, the conventional refining process or the dissolvable extraction process (Scribd Inc, 2009). Contingent upon the sources and qualities of the unrefined oils and the properties of bitumen required, more than one processing might be used to produce different forms of bitumen as follows (Ibraheem, 2014).

a) **Cutback bitumen:** Typical practice is to heat bitumen to reduce its thickness. In some cases, the preference is to use fluid binders, for example, reduction bitumen.

For reduction bitumen, an appropriate solvent is used to break down the consistency of the bitumen. From an ecological perspective, reduction bitumen is favoured (Fetch, 2011). The solvent for the bituminous material will dissipate and the bitumen will bind the residue (Jim Huddleston, 2003). Reduction bitumen is used for bituminous road development and maintenance in a cool climate. The distillates used to prepare reduction bitumen are naphtha, lamp oil, diesel oil, and heater oil. There are different types of reduction bitumen such as fast-restoring (RC), medium-restoring (MC), and moderate-restoring (SC). RC is recommended for surface dressing and inter-mixing. MC is recommended for pre-mix with less fine residue. SC is used for pre-mix with an apparent amount of fine residue (Lubbers & Bonner, 2002).

b) **Bitumen emulsion:** Bitumen emulsion is a fluid item in which bitumen is suspended in a finely isolated state in a watery medium and stabilised by appropriate material. Ordinarily, emulsions with cationic composition are used in India. (Parmer *et al*., 2017). The bitumen content in the emulsion is approximately 60% and the remainder is water. At the point where the emulsion is applied, it separates, exuding water and the blend begins to set. The duration of setting depends on the type of bitumen. (Kandhal *et al*., 2008). Three types of bituminous emulsions are available: quick-setting (RS), medium-setting (MS), and moderate-setting (SC). Bitumen emulsions are ideal binders for sloping road development. Where warming of bitumen is troublesome, fast-setting emulsions are used for surface-dressing work. Medium-setting emulsions are favoured for pre-mix application and repair-work. Moderate-setting emulsions are favoured in blustery weather (Lubbers & Bonner, 2002).

c) **Bituminous primers:** In bituminous groundwork the distillate is consumed by the road surface on which it is spread. The retention in this manner depends on the porosity of the surface (Kandhal *et al*., 2008). Bitumen preliminaries are helpful on stabilised surfaces and water-bound, macadam, base courses. Bituminous groundworks are laid generally on road sites by blending infiltration bitumen with oil distillate (Yang *et al.,* 2015).

d) **Modified bitumen:** Certain added substances or mix of added substances, known as bitumen modifiers, can enhance properties of bitumen and bituminous blends (Yang *et al.,* 2015). Bitumen treated with these modifiers is known as adjusted bitumen. Polymer-changed bitumen (PMB) or morsel-elastic adjusted bitumen (CRMB) should be used only in the outer course, depending on the pre-requisites of extraordinary climatic variations (Shukla *et al*., 2014). Details for using changed bitumen have been issued by IRC: SP: 53-1999. It is noted that the use of PMB and CRMB is subject to strict control of temperature during development. The advantages of using changed bitumen are as follows (Lubbers & Bonner, 2002):

- Lower sensitivity to day-by-day and regular temperature variations;
- Higher protection against deformation at high asphalt temperatures;
- Better age-resistant properties;
- Higher fault-resistant life for blends;
- Better bonding between residues and binder;
- Prevention of splitting and disintegration.

#### 2.4.11.7 Requirements of Bitumen

The attractive properties of bitumen depend on the composition blend and development. Generally, bitumen should have the following desired properties:

- The bitumen should not be highly sensitive to temperature: in the hottest climate, the blend should not be too delicate or unstable and, in a cool climate, the blend should not be excessively weak and cause breaks (Jim Huddleston, 2003).
- The consistency of the bitumen during blending and compacting should be satisfactory. This can be accomplished by using reductions or emulsions of appropriate quantities or by warming the bitumen and residues before blending.
- There should be sufficient proclivity and adhesion between the bitumen and residues used in the blend (Komba *et al*, 2010).

#### 2.4.11.8 Multi-grade bitumen

Multi-grade bitumen is a synthetically changed bitumen that has properties that vary from a hard clearing grade bitumen at high temperatures of application, to a delicate clearing grade bitumen at low temperatures. Multi-grade bitumen gives enhanced protection from deformation and decreases the adverse effects of high temperatures of application, while giving less solidness at low temperatures of application than a comparable, ordinary clearing grade bitumen (Nazarko & Vilutiene, 2015).

Multi-grade bitumen has the following properties (Wilson *et al*., 2010):

- a positive PI;
- a less asphalt temperature-sensitive binder;
- a higher modulus at raised temperatures;

- less vulnerable to harsh elements;
- Frequently performs like a PMB without the expansion of polymers;
- Subsequently it has no versatile recuperation;
- Used in Australia, France and Poland;
- Product example: Multi-phalt from Shell.

## 2.5 CHALLENGES TO QUALITY OF ROADS

The critical factor in maintaining asphalt road-surfaces is to understand the underlying causes of the road surface and the actions needed for repairs before any repair work is executed. To maximize maintenance budgets, reliable working technology must be applied to correct failures and prevent any possible recurrence (Bennett, Coleman & Co. Ltd, 2019). The section below provides basic information about the common types of road pavement failures, including the usually common causes and the measures recommended to make effective corrections (El-Maaty *et al*., 2016). Adequate advice and training must be provided to personnel involved in road maintenance. Operations carried out with due diligence will lead to an efficient, effective and consistent system of asphalt road-surface maintenance (Khaing & Tinhtwe, 2014).

### 2.5.1 Types of Road Failures

The types of road-surface failures most commonly encountered in asphalt roads are explained below, including a classification of the type of failure, possible cause of the failure, and appropriate correction approach (Khaing & Tinhtwe, 2014).

a) **Bleeding or flushing:** A defect usually caused by excess and low density asphalt in the surface layer. The contributing factors are: inadequate coarse stone, excessive rolling at some stage in placement, stripping of the asphalt from the aggregate, or low air voids (CSIR, 2016). Some minor bleeding can be corrected by applying coarse sand or stone screenings to form extra asphalt layer. Major bleeding can be corrected by cutting off excess asphalt and replacing with new material (Yongjoo *et al*., 2013).
b) **Corrugations and shoving**: Corrugations and shoving are a result of unstable mixture in the asphalt layers owing to rich asphalt, with a high proportion of fine aggregates, coarse or fine aggregate with a very smooth texture or too rounded, or very soft asphalt cement for the traffic load conditions (Anderson & Steger, 2003). Corrugations and shoving can also be triggered by excessive moisture,

contamination caused by oil spillage, or lack of surface curing (Scribd Inc, 2009). To repair corrugations in an aggregate base overlain with a thin surface treatment, mill the pavement, add aggregate as needed, mix well, re-compact, prime and then re-surface. Where the surface has 50mm or more of asphalt plant mix, corrugations can be eliminated with a "heater planer" or by using cold planning. When corrugations have been eliminated, cover with a new floor cure or new asphalt overlay (KTH International Student Recruitment, 2000). To repair shoved areas, re-construct the base and surface accordingly, and replace unsuitable material to prevent a recurrence (Jim Huddleston, 2003).

c) **Alligator cracking:** Inter-connected cracks forming a sequence of small polygons, resembling an alligator's skin, are called alligator cracks. In-situ investigations must be conducted to determine the most possible cause of alligator cracking (Khaing & Tinhtwe, 2014). If poor drainage is a contributing factor, corrections have to be made swiftly. Should the road be poorly drained, in all likelihood the base is inadequate, and the road-surface will require reconstruction or heavy re-surfacing (Saad, 2014). Major re-surfacing will be required if cracking occurs due to repetitive, heavy traffic loads. If the cause of deformation cannot be rectified, urgent repairs may be required. (The Asphalt Institute, 1997). This distress should be repaired as follows:
   - Cut out road-surface and wet material.
   - If the base or surface is wet from underneath, install necessary underdrains to prevent future saturation.

### 2.5.2 Repairing of Roads

Several maintenance/rehabilitation methods are established for managing and protecting roads against various failures, including the following.

#### 2.5.2.1 Preventive maintenance

The purpose of preventive maintenance is to keep the road-surface in good condition and include some of the following treatment methods (Agreement SA, 2010):

a) crack sealants,
b) fog seals,
c) chip seals.
d) slurry seals and micro-surfacing,
e) thin hot-mix overlays.

**Table 2.3: Surface treatment and life expectancy**

| Treatment | Pavement Age (Years) |
|---|---|
| Fog Seal | 1 – 2 |
| Emulsion Seal Coats | 1 – 3 |
| Chip Seals | 4 – 7 |
| Slurry Seals | 4 – 7 |
| Thin Overlays ( < 25 mm) | 8 – 12 |
| Thick Overlay ( 100 mm) | 10 – 18 |

*Source: (The Asphalt Institute, 1997)*

Table 2.3 shows the timing and efficiency for the various treatments with dependence to traffic level and surrounding environment. The authority (or owner) to the facility should be advised to attain optimal timing when applying treatments for maintenance, in order to minimise life-cycle costs. To achieve best results with treatments, the surface must be well prepared, best techniques must be applied, correct standard mixing and application methods must be adhered to (The Asphalt Institute, 1997).

#### 2.5.2.2 Corrective maintenance or rehabilitation

Corrective maintenance is used when a road-surface is substandard in terms of load-bearing capacity (excessive deflection), water-proofing (cracks), surface deformation (rutting), surface friction (too slick), or ride quality (bumps) (Agreement SA, 2010). Environmental factors, such as frost, thermal cycles, and ultra-violet light also can cause road-surface deterioration that requires maintenance.

Techniques used for corrective maintenance or rehabilitation should include those used for preventive maintenance and also hot mix asphalt overlays, profiling, mill and fill, and recycling (COLTO, 1998). The timing of corrective maintenance or rehabilitation is very crucial, as it has a major impact on the maintenance budget. Since the rates of road deterioration can be predicted and their life-span is influenced by climate and the range variety of traffic loads, it is possible to determine the most effective time to carry out road maintenance(Donev & Hoffman, 2018).

#### 2.5.2.3 Maintenance treatments

Several maintenance treatments are available to the owner (agency) for preventive or corrective maintenance. They include the following (Kandhal , 2008).

a) **Crack sealants:** The materials, which usually consist of a modified asphalt, are applied to cracked road-surfaces to prevent water entering the cracks. Most of these materials have an effective life of only 1 to 2 years. Furthermore, if crack sealants are applied too thickly on the surface adjacent to the crack, they tend to bleed through subsequent overlays. It is important to clean the cracks prior to applying the sealant (El-Badawy & Valentin, 2018).

b) **Fog (or flush) seals:** This is a light application of an asphalt emulsion (usually a CSS-1) with no aggregate cover to restore asphalt mix durability. It is an effective method, but the material must be applied moderately to avoid slippery of road-surface (Jim Huddleston, 2003).

c) **Asphalt emulsion seal coats***:* These consist of a mixture of asphalt emulsion and inert fillers. The mixture is approximately 80-85% emulsion and 20-15% filler, depending on the manufacturer. Often 30mm mesh sand is added to the seal coat material immediately prior to application. One or two coat applications are common. Most emulsion seal coats are machine applied either by spraying or with a sponge (Al-Busaltan, 2014).

d) **Chip seals:** It is an application of asphalt together with an aggregate cover. The technique consists of single or multiple layers, ranging from 9.5mm to 25mm in thickness. The process consists of an application of a rapid setting emulsion followed by an overlay application of aggregate, with a size of 9mm x 2mm (Agreement SA, 2010).

e) **Slurry seals**: This treatment is a mixture of a well-graded sand-size aggregate, mineral filler, and asphalt emulsion. A single course is usually applied with a thickness of 3mm to 9mm (Cepas, 2012). Slurry seals are normally used in road sections affected by road-surface distress due to excessive oxidation and hardening of the existing road surface. They are normally used to repair and fill minor surface cracks and voids, retarding surface ravelling and, sometimes to improve road surface friction (Agreement SA, 2010).

f) **Micro-surfacing:** This is a polymer-modified slurry seal system developed originally in Europe. Its most common uses are rut filling, minor levelling, and restoration of skid resistant surfaces (COTO, 2012). The polymer-modified slurry cures and gains strength faster. Therefore, it can be laid with greater thickness. For example, it has been used to fill ruts in excess of 25mm, but is normally used on projects with rut depths of up to 19.0mm. Micro-surfacing re-quires special paving equipment with a more powerful and faster mixer than that used for slurry seals. An experienced contractor is also recommended if this product is used (CSIR, 2016).

g) **Thin hot mix overlays:** Both open-graded and dense-graded mixes have been used with thicknesses of 25.0mm to 37.5mm. These materials make use of aggregates with a top size of 9.5mm to 12.5mm. The expected life of thin hot mix overlays is normally 8 - 12 years, depending on the condition of the road-surface on which it is placed, the traffic, and climate. This maintenance treatment is best for improving the ride quality and the only treatment that adds to the structural strength of the road-surface. Details of these maintenance treatments can be found in the publications of the Asphalt Institute (MS-16, MS-17, and MS-19) (TRH4, 1996).

It should be pointed out that each of the above treatments has a different effect on the pavement condition index (PCI) and present serviceability index (PSI) (Fetch, 2011). As shown in Table 2.4, all treatments improve the PCI, but only a few treatments improve the ride quality or PSI. Use of a life-cycle cost analysis makes it possible to determine which treatments are most cost-effective for a given situation (The Asphalt Institute, 1997).

**Table 2.4: Typical effect of various road treatments PCI and PSI**

| Maintenance Treatment | Effect of treatment on: | |
|---|---|---|
| | PCI (Pavement condition Index) | PSI (Pavement Serviceability Index) |
| Chip Seal | Increases | Little or no effect |
| Slurry Seal | Increases | Little or no effect |
| Micro-surfacing | Increases | Slight increase |
| Thin HMA Overlay | Increases | Significant |

*Source: (TRH4, 1996)*

#### 2.5.2.4 Rehabilitation

Treatments for AC include the following:

a) **Overlays:** Conventional dense- or open-graded mixes are normally used on highways to rehabilitate asphalt concrete pavements. The recommended overlay thick-ness should be determined by a consultant to ensure it will accommodate the anticipated traffic. Normally, this will require some type of non-destructive deflection testing to determine the structural capacity of the existing pavement. (Werkmeister *et al*., 2004)

b) **Mill and fill:** This is one of the most popular rehabilitation method, used to repairing deformed and failing asphalt pavements. The process consists of milling and removal of existing distressed pavement to depths of 50 mm and filling the cavity with a dense-graded asphalt mix (Cepas, 2012). Sometimes open-graded mixes are also used for repairs. However, drainage channels must be constructed to remove the water, which may accumulate in the trenched areas. A mill and fill process alone does not efficiently strengthen the road pavement. The pavement strength is achieved by applying a suitable overlay on top of a mill and fill (Woods & Adcox, 2004).

c) **Recycling:** Natural resources have recently become more scarcer and costly to procure, and as a result their recycling and re-use has lately become an important popular practice in rehabilitations. Asphalt cement and aggregates used in road construction have become very crucial investment to authorities. (The Asphalt Institute, 1997). These two resources are mostly invaluable and play a major role in the road construction. The ability to recycle such material has a good positive impact and implications for both construction and environment, enhancing both energy saving and minimising construction costs. Recycling asphalt concrete pavements can be accomplished through: removal and transport to another location for crushing and reprocessing with transport to the new site for lay-down and rolling; or through cold milling the surface; and/or conventional removal, with crushing, reprocessing, lay-down and rolling accomplished on the site (Kumpala *et al*., 2018).

## 2.6 SUSTAINABILITY

Sustainability in construction and civil engineering is the optimisation of built structures in a way that they no longer have harmful impacts on resources, environment and living ecosystems. It is a way of minimising harmful environmental effects of construction initiatives (The Constructor, 2013).

Significant types of sustainability in construction include:

a) Economic costs;
b) Appropriate technology;
c) Local availability;
d) Social acceptance;

e) Environmental acceptance.

Sustainability in construction is important because construction has a direct impact on the environment because of the following reasons (Hezri, 2004):

a) Generation of waste materials;
b) Emissions from vehicles and machinery;
c) Noise pollution from heavy vehicles and construction machinery;
d) Release of waste and pollutants into the water, ground and atmosphere.

It is imperative to evaluate the sustainability of projects to ensure that they no longer cause harmful consequences for the living ecosystem, while optimising the value of construction. This is to ensure the availability of resources for future generations (Enshassi & Kochendoerfer, 2016).

### 2.6.1 Reducing the Effect of Road Construction and Repair Waste on Sustainability

The following steps should be taken to reduce the impact of construction waste on sustainability (Enshassi & Kochendoerfer, 2016):

- Eliminate – avoid producing construction waste in the first place.
- Reduce – minimise the amount of waste that is produced.
- Re-use – re-use the construction waste in other works.
- Recover (recycling, composting, energy) – recycle whatever waste possible after it has been re-used.
- Dispose – dispose of whatever waste is still left in a responsible way.

Using durable construction materials and carrying out quality control on structure durability on site is a step towards minimising the generation of construction waste (Lubbers & Bonner, 2002).

### 2.6.2 Use of Sustainable Building Materials

Construction materials such as sand and gravel have been used for hundreds of years in construction. The demand for these is growing daily, as demand for infrastructure improvement is increasing (Yang *et al.,* 2015). However, use of building materials such as river sand and gravels has a negative influence on the environment. Excessive mining of gravel and sand causes degradation of rivers. Mining in rivers lowers the river bottom, which might lead to river-bank erosion (Hezri, 2004). This contributes to the destruction of aquatic and riparian habitat through enormous changes in the channel morphology. Impacts include bed degradation, bed coarsening, lowered water tables close to the stream-bed, and channel instability (CSIR, 2016).

Further study is required to determine all the harmful impacts of the mining of river sand and gravels. The use of alternate construction materials can reduce the effect on the environment. The following steps should be taken to minimise the effect of road construction and repair activities on environmental, economic and social sustainability (Eisele & Frawley, 2000)::

- Reduce the supply chains to reduce transport costs.
- Exercise waste minimisation and recycle construction material.
- Choose durable and high-quality building components that will last for the appropriate refurbishment or demolition cycle.
- Use construction materials which are available locally.
- Re-use of existing buildings or structures can reduce the construction waste. Strengthening and rehabilitating roads can also save construction cost.
- Plan the management of site waste not only during construction, but also during use or operation. Minimise the use of energy in construction (Eldin, 2002).

## 2.7 POTHOLES

A pothole is a structural failure in the surface of road, and can occur in hard-surfaced (asphalt/concrete) and gravel roads. Water and traffic are the main factors that cause potholes (Oregon Department of Transport, 2009). The condition of the road-surface is regarded as a service by the road user and as a load-bearing structure that needs frequent maintenance by the engineer. Visible distress on a road structure, categorised by the type, degree and extent, reduces the capacity of a road to provide the service expected by the road user and the function required by the engineer (TMH9, 1992).

The City of Cape Town reportedly spends over R110 million per year to repair 250 potholes per week (Wheels24, 2016). In Johannesburg, an average of 1000 potholes is reported to the road authorities every week, although the city claims to repair up to 4500 potholes per month (Wheels24, 2016).

### 2.7.1 Causes of Potholes

Potholes form mostly during the rainy season; however, potholes can form also during the dry season as a result of traffic load and temporary wet conditions from local irrigation, ponding and water seepage (Paige-Green, 2012). Potholes form on both types of road surfaces, i.e. asphalt and concrete. The main focus of this study was on asphalt surfacing since this was used to construct most of the roads in Bloemfontein City (Fetch, 2011).

The weights of vehicles have effects on the roads, particularly in areas with weak soils. Erosion also has serious effects on the formation of road potholes. Bitumen is eroded normally in areas where there are cracks and depressions. These cracks are widened by erosive action. Surface and volume integrals are used to fill the potholes and repair the surface area (Khaing & TinHtwe, 2014).

a) **Poor asphalt, and other bituminous, seals on road surfaces**

In South Africa, the standard thickness of an asphalt surface is generally between 25mm and 50mm (COLTO, 1998). An asphalt surface is normally laid over a stabilised base that is at least 100mm thick. The formation of potholes in an asphalt surface can be caused in two ways:

i. by cracks forming in the asphalt surface because of age or fatigue which, in turn, allows water to seep into the support base, or
ii. by water penetrating into a porous asphalt layer which then results in the asphalt being stripped off the road (Paige-Green, 2012).

b) **Cracks in an asphalt surface**

Cracks in an asphalt surface usually result from a poor support base or sub-base (Figure 2.8), which eventually leads to surface fatigue and cracking (Komba, 2010). The surface can also crack when subjected to extreme natural effects like sun, oxidation, heat or cold, which might cause the asphalt surface to expand and shrink. Also, when the underlying cement layers set, this might cause simultaneous cracking on the surface. The weakness in the underlying support layers results in high surface displacement under traffic loads (COTO, 2012)

*Source: (Paige-Green, 2012)*

**Figure 2.8: Cracking because of support failure**

c) **Water penetrating into the road structures**

Water penetration might result in the separation of asphalt overlays from the underlying supports and, ultimately, cause the development of shallow potholes (Paige-Green, 2012).

d) **Design of roads and traffic load**

Heavy traffic loading, usually above the limits of the road-surface design, results in load deflections through the road structure. When these deflections are repeated over a period of time, they result in surface cracking and water seepage (Fetch, 2011).

*Source: (Paige-Green, 2012)*

**Figure 2.9: Poor Pothole Maintenance**

**e) Poor repairs**

The correct materials are not always used to repair potholes, even for temporary measures (Figure 2.9). Poor and incorrect material might escalate the pothole damage, especially when the material gets wet (Kandhal, 2008).

**f) Poor adhesion between base and seals**

Priming is essential when surfacing with asphalt or other bituminous material to ensure adequate adhesion between the support layer (base) and the surfacing (Komba, 2010). Poor adhesion will lead to the separation of the two layers during lateral traffic movement and, ultimately, deterioration of the surface layer, resulting in pothole formation (Hong *et al*., 2014).

**g) Weakness in the standard design of roads**

Other causes to be considered include (Naveen *et al*., 2018):

- **i)** Failure of existing patches;
- **ii)** Re-instated service trenches (poor compaction and surface replacement);
- **iii)** Unusual forms of pothole development, caused by soluble salts for

example.

### 2.7.2 Pothole Repairs

Potholes must be repaired by using the material, procedure and techniques that are appropriate for specific regions and, in particular, appropriate for each and every pothole in terms of the material and applying COLTO principles (COLTO, 1998).

#### 2.7.2.1 Pothole repair materials

The materials used to repair potholes are highly significant together with the appropriate method. The following should be considered:

a) **Cold blend black-top (CMA):** CMA is associated usually with small- to medium-sized potholes. Although there are no standard specifications for the properties of CMA, Agreement SA has developed a standard procedure which must be followed to understand the use of CMA on potholes (Manoj Yadav & Anusha, 2018).

b) **Hot blend black-top (HMA):** HMA is the most appropriate material to use for fixing potholes and has been used for a long time. The temperature of the material must be taken into account when using HMA. HMA is associated generally with medium-sized to substantial and more profound potholes. The use of HMA black-top must be finished in compliance with the fundamental specifications of s4203 of COLTO (COLTO, 1998).

#### 2.7.2.2 Pothole repair strategies

It is essential to understand the different, appropriate strategies that are available to use when repairing potholes. The following should be considered (TRH4, 1996):

- Shallow black-top for black-top surfaces to repair only black-top surface layers of between 75mm -100mm thickness;
- Medium-profundity black-top repair;
- Deep repair (black-top surfacing);
- Shallow-surface repair (thin bituminous seal);
- Medium profundity repair (thin bituminous seals);
- Deep repair (thin bituminous seals).

### 2.7.3 Essential Aspects of Potholing Failure

Aspects of potholing failure include evaluation, confirmation of the nature of potholes, appraisal technique and institutionalisation. Distress in the form of potholes (loss of material from the base layer) refers to support distress and avoiding surface distress. The two devices used to estimate street distress are as follows (TMH9, 1992):

a) Degree: The level of a specific kind of distress is a measure of its seriousness (TMH, 1992). The degree is represented numerically where:
    - Degree 1 represents the primary confirmation of a specific kind of distress (slight);
    - Degree 3 represents noticeable distress that requires consideration;
    - Degree 5 represents the most serious degree of distress.

b) Extent: The extent of a specific kind of distress is a measure of how far the distress spreads over the length of a section of road (TMH9, 1992). The extent is represented numerically where:
    - Extent 1 represents isolated occurrence of distress (sometimes);
    - Extent 3 shows intermittent occurrence of distress over the vast majority of the road segment;
    - Extent 5 represents broad occurrence of a specific type of distress.

Potholes, generally, are regarded as a basic distress, which is one of the possible types of distress that is created by breaking or complete loss of aggregate. (Manoj Yadav & Anusha, 2018) Potholes are caused by movement and formed usually from basic splitting in wheel ways. The entry of dampness into the asphalt layers can result in the aggregate loss of the basic limit of asphalt layers, which are uprooted by the forces caused by activity (Automobile Association, 2016).

The level of potholing can be described by the distance across, and profundity of, the potholes. The description of the degrees of distress, or potholing and is given in Table 2.5.

**Table 2.5: Description of degrees of failure or potholing**

| Degree | Description | |
|---|---|---|
| | Failures | Potholing |
| 1 | Not defined for failures | Not defined for potholes |
| 3 | Failure developing. Minor depression (< 30mm). Start of surface distress and shoving. | Potholes ≈ 200mm diameter and of significant depth ( > 25 mm). |
| 5 | Severe failure with loss of surfacing | Potholes > 300mm diameter and of |

| | | |
|---|---|---|
| | and base material. Severe depression ( > 50mm) and shoving. | serious depth ( > 50 mm ) and/or severe secondary defects. |

*Source: (TMH9, 1992)*

The extent of failures/potholing should be determined according to the definitions given Sub-section 2.7.3 b) above. It is noted that types of distress categorised under failure (e.g. cracks and pumping) should not be rated separately. Edge breaking should not be rated the same as a pothole unless it extends into a wheel track (TMH9, 1992).

## 2.8 BASICS AND CONCEPTS OF THE MODERN, ROAD-PAVING MAINTENANCE MANAGEMENT SYSTEM (PMMS)

The administrative framework for the maintenance of asphalt is a hardware system that enables constructors to decide on ideal methodologies to assess the condition of existing asphalt and to support the asphalt to have an adequate life-span for a desired timeframe (Anderson & Steger, 2003). For a little city or rustic roadway layout, a basic framework for visual assessment might be adequate (Lubbers & Bonner, 2002). However, for a greater city or urban roadway network, a computerised framework for monitoring is generally more suitable (Agreement SA, 2010).

PMMS has the capacity to provide critical information to enhance the productivity of decision-makers. The arrangement of PMMS require enormous huge information to store in the database, at that point, through preparing, the framework will change over them into data. The data in the wake of preparing is utilized in supporting the choice and arranging. This is the reason for repairing a potholed street (Chalke, 2018).

### 2.8.1 PMMS Methodology

1) The initial phase in using the PMMS method is the order in which the roadways are organised (urban or provincial). This followed by zonings. In the case of an urban region, the roadways are organised into district zones while, in the case of a country region, areas of roads and road segments are considered (*Dong et al*., 2014).
2) In the next phase, the roadway numbering and recognisable proof are operationalised. In a regional zone, the roadways are separated into segments of 50m to 300m in length. An identification number (ID) is required for each segment or fragment, covering one road only (3m to 3.5m wide), and the load-bearing is also specified (Chalke, 2018).

3) The GIS and the GPS co-ordinates can be operationalised at this stage to organise the process of documenting the information (The third step is to assess the condition of the asphalt surface either by outward observation or by mechanised procedures. The surface imperfections are accounted for in a diagram or photograph. The report is evaluated in the workplace to establish the degree and extent of each occurrence of distress (low, medium or high) (E Maaty *et al*., 2016).
4) The fourth step involves capturing data about the territory or less densely populated area of a zone and determining the loss and cause of each occurrence of distress and its seriousness in terms of the numerical models introduced above. The aggregate loss value is computed and amended taking into account the various kinds of road-surface failure (Singh & Sarkar, 2018).
5) In the fifth step, the programme administrator rates each area based on an understanding of the established occurrence of distress (Cepas, 2012). The final appraisal is obtained then the required support option is chosen using a process of prioritisation. The cost of every maintenance option is assessed and selected by the administrator to provide a budget for the segment (Negaraju, 2015).
6) In the sixth step, the roadway system is checked intermittently or every six months, according to the long-term asphalt checking framework (LTPPS). The information about the condition of the asphalt is added to the database to create a display of the decay (CSIR, 2016). A display of the investigated cost of the life-span cycle is created in the process.

### 2.8.2 PMMS Guidelines

Asphalt eventually falls apart and the relative cost of recovery at different stages in its life-span is high. The effect of deferring support for the state of asphalt, being a rapid drop in serving its purpose, has been noted. From a hypothetical perspective, black-top, solid asphalt performs well for most of its planned life, after which it loses its adaptability because of oxidation and maturing, and starts to fall apart quickly (Singh & Sarkar, 2018). Various studies have demonstrated that maintaining an asphalt surface in adequate condition versus restoring an asphalt surface in poor condition intermittently is four to five times more affordable. The number of years for which an asphalt surface remains in excellent condition before falling apart rapidly depends on various elements, including quality and composition during development, asphalt usage, atmosphere, and maintenance (The Asphalt Institute, 1997).

Maintenance plans are easier to design if a framework such as PMMS is used to check asphalt surfaces after they have been put into service. The state of the crumbling and the focus of the ideal maintenance differ significantly and a range of manuals are available that help with recognising the type of asphalt distress and recommending possible support treatment from a specialised perspective (Negaraju, 2015).

### 2.8.3 Typical Repair Procedure

The area being repaired must be marked, stamped, cut, unearthed and cleaned. The surface area must be sealed with a bitumen emulsion tack coat. The black-top (HMA or CMA) should then be put into the cavity and raked level, in single layers. In the event that the cavity is deeper than 75 mm, it ought to be filled in with layers of not more 75mm, and each one compacted independently (CSIR, 2016). The black-top should then be compacted using hand or plate compactors, or pedestrian rollers can be used for bigger patches (Kandhal, 2008).

The area of repair must be free from any loose material. However, it is valuable to cover the repaired surface, immediately after compaction, with fine sand or gravel to form a layer between the surface bond and vehicle tyres (Fetch, 2011). The repaired section can then be opened to traffic. Once complete, the level of the final layer of the repair should be checked. It is suggested that the final surface layer should be approximately 5mm - 10mm above the surrounding road, depending the thickness of the fill. This will allow for further compaction by movement once the street is opened to use (Obaidi *et al*., 2017)

## 2.9 ENFORCEMENT OF ROAD USE STANDARDS AND REQUIREMENTS

### 2.9.1 Intersection and Access Control

The use of effective crossing points and access control measures can enhance the stream of activity and road safety (CSIR, 2016). Need control can be effective when activity volumes are low and the number of contentious issues is limited. However, at higher levels of movement, need control is insufficient and different types of control become justified. While traffic signals are effective in restricting the use of a side or access road, they must be considered when justified and where dispersing convergence is a pre-requisite (Dasgupta & Tam, 2005).

The roundabout is an optional form of control that can be extremely successful and effective, particularly in retro-fit circumstances. Roundabouts effectively facilitate right-turn and U-turn activities. This is particularly useful on streets where access to peripheral destinations is necessary and allowing U-turns at downstream crossing points is in the best interest (Eisele & Frawley, 2000).

Enhancing the geometric plan of road convergences might add to reducing the erosion on a street. Upgrades could incorporate left- and right-turn helper paths and slip streets. Right-turn paths are especially effective in enhancing road safety (COTO, 2012).

### 2.9.2 Traffic Data

Traffic data shape the purpose of planning in SANRAL. Since it is vital for SANRAL to have accurate information about the movement of traffic for the whole national road network, this is obtained from carefully placed activity counters (Oke, 2012). These are situated permanently to focus on particular aspects of the system and are supplemented by temporary counters as and when required (Bennett, Coleman & Co. Ltd, 2019). As the road network develops, subject to the consolidation of streets, the areas in which additional counters are required will be determined. During the 2014/2015 financial year, extra permanent and temporary counters will be introduced (TMH14, 2013).

SANRAL has resolved to grow the system of counters to guarantee that there is information for every single national road (Toba *et al*., 2015). Recently, SANRAL received new specifications for checking traffic activity and also new information designs. The particulars differ from the conventional specifications and the main pre-requisite for new contracts is quality information. New research organisations were appointed in 2014 and urgent review of the new details was undertaken during the subsequent five years (South African Tourism, 2018). New programming also was created in-house to oversee and approve the information. Encouraging improvement of the product also influenced the accomplishment of movement checking during the subsequent five years. Framework providers and research organisations must also be certified through Agreement South Africa in order to participate in future tenders (Agreement SA, 2010).

### 2.9.3 Overload Control

SANRAL has continued to contribute to techniques to control the over-burdening of national roads during the five years since 2014 as follows (COTO, 2012):

- Upgrading and restoring existing traffic control centres (TCC) at Heidelberg, Kroonstad, Senekal, Stop Rynie, Mooi Stream, Mantsole and the N4 (East) during 2015/16. The scope of TCCs was extended to limit the redirection routes for heavy vehicles. The development of another TCC on the N4, just east of Zeerust, was initiated. SANRAL also investigated the best site for another TCC in Limpopo Province, between Dendron and Vivo on the R521 (Department of Transport SA, 2008).
- Constructing another TCC at Eteza on the KwaZulu Natal North Drift and in Kokstad;

  Intensifying agreements with road users in general and the private sector to guarantee a productive and practical limitation to over-burdening the roads (The Guardian, 2001).

## 2.10 ECONOMIC IMPACT OF POTHOLE MAINTENANCE ON THE EXTENDED PUBLIC WORKS PROGRAMME

The Extended Public Works Programme (EPWP) is a nationwide programme which makes deliberate use of labour-intensive techniques and open tendering to create a conducive business environment in the marginalised networks, bearing in mind the goal of easing destitution among the general public (EPWP Report, 2013). Stage 1 of the programme, embraced in 2004/5 – 2009/10, accomplished the objective of creating one million work opportunities per year for the current calendar year. The strengthening of the work force in road works significantly affects the general execution and results of the EPWP. The use of labour-intensive work is endorsed by the government because it promotes the motivation of expanded business (EPWP Report, 2013).

The EPWP endeavour generated a sum of 48 million man-days' work during the 2010/11 programme stage. This equated to employing 209 000 people full-time (full-time proportionate) for an entire year. The total programme used approximately R35 billion during a similar period, of which 8.1% was spent on remuneration.

EPWP encompasses four areas, i.e. Framework, Social, Non-state, and Condition and Culture. Framework refers to the largest part of the programme accounting for 66% of the total expenditure from the EPWP Budget. Being the largest segment, the Framework creates the most jobs, generating more than 82 000 work years, giving piece work to 277 100 people (EPWP Report, 2013).

The Framework segment incorporates building works, power supply, street works, sanitation, storm water seepage, waste water administration and water supply. Building works is the biggest section, constituting approximately 61% of total expenditure in the 2010/11 financial year, but records the most reduced work power at 2.6% (EPWP Report, 2013).

The second biggest section in the Framework segment is the street works programme, with 28% of total use, producing 57% of the work in this segment and 22% of all business in the EPWP. Within the street division, 73% of all business involves street support works. The work power rate for support is 27%, compared with 4.7% for street development works (EPWP Report, 2013).

The work force rate is 13% for road works in the local divisions and 9% for works done by the districts. The main reason is the way in which the local offices oversee the majority of the maintenance work programmes. Expansive development ventures have low work power of just 3%. The most noteworthy potential for expanding work in the EPWP exists in pothole maintenance as the cost of creating jobs in normal road support is significantly lower than that for development works. Additionally, it is a sound approach from a framework resource administration perspective (EPWP Report, 2013).

## 2.11 CONCLUSION

The literature review contained a discussion of the details of what road design entails, and the dynamics of the maintenance processes undertaken during the service life of roads. Of particular interest were the maintenance aspects of the review which deal in depth with the material and techniques used to maintain roads and, particularly, to repair potholes.

The elements covered in the potholing repair processes were considered in detail, from designing the road, to the stages of deterioration, identifying and rating the damage to the road structure in terms of the degree and extent of damage, to the stages of maintenance and their deliverables. According to the findings of the review, potholes are identified in a certain way and, thereafter, a particular technique for repairing them is followed using the material currently available on the market, mainly in the form of Hot Mix Asphalt, Cold Mix Asphalt and Slurry.

Both the techniques and materials currently used for pothole repair have been reviewed in this study to consider alternative materials, new maintenance repair methods and means of maintenance management. Initially, the use of new and different techniques and different materials might be influenced by practical situations, e.g. where a pothole must be repaired from a base-course level, instead of considering only Hot Mix Asphalt which applies mainly to the surface, different material such as BTB (Bitumen Treated Base) should be used as an alternative.

# CHAPTER THREE: CASE STUDY AREA

## BLOEMFONTEIN CITY: GEOGRAPHIC LOCATION

Bloemfontein is a city in the Free State Province in South Africa. Figure 3.1 show the location of the Study Area on all three levels namely national, provincial and local position.

Bloemfontein's location is:

- 29.12 latitude,
- 26.21 longitude,
- at an elevation of 1396 meters above sea level.


Figure 3.1 (a) South Africa


Figure 3.1 (b) Free State Province


Figure 3.1 (c) Bloemfontein

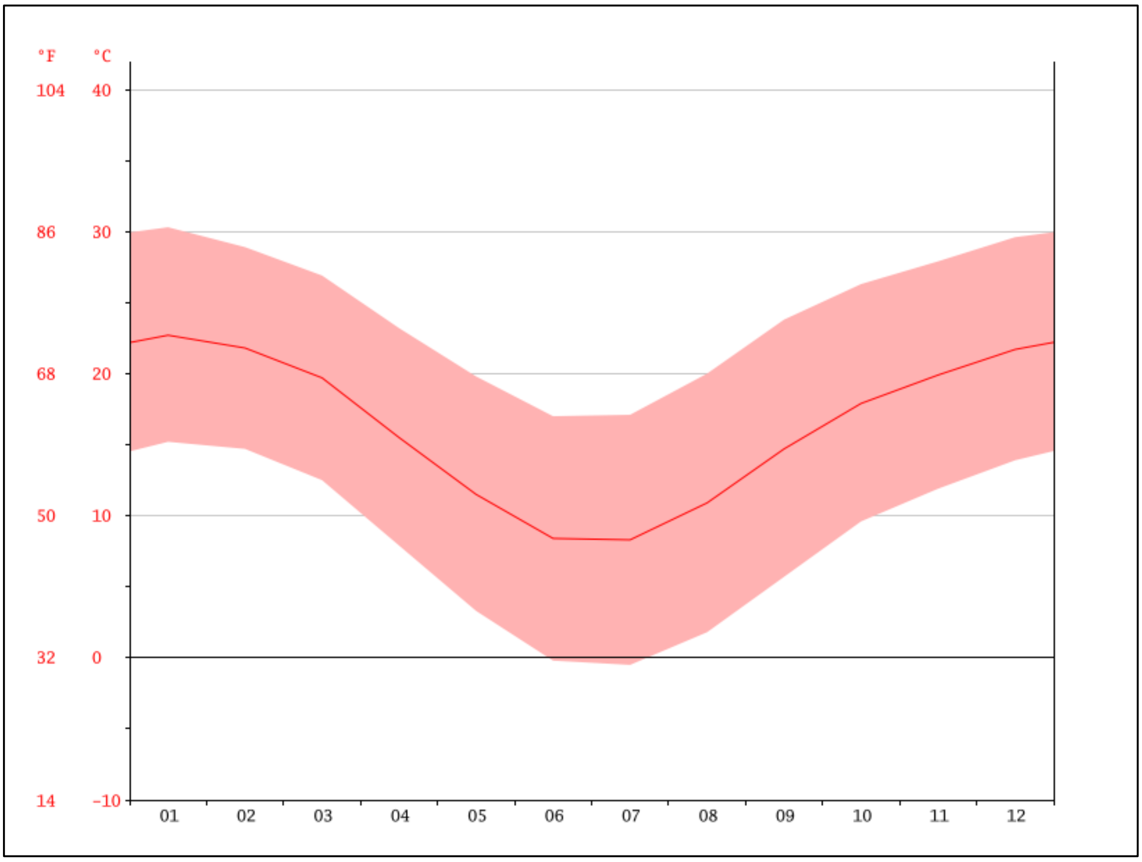
*Source:(Mangaung Metropolitan Municipality, 2017- 2019)*

**Figure 3.1: Maps showing the location of Bloemfontein City in South Africa**

## 3.1 CLIMATE AND WEATHER

Bloemfontein is influenced by the local steppe climate, classified as BSk by the Köppen-Geiger System. The city does not have much rainfall throughout the year, receiving an average of 548mm.

The average annual temperature in Bloemfontein is 16.1°C. The warmest month of the year is January, with an average temperature of 22.7°C. July is the coldest month of the year with an average temperature of 8.3°C (see Figure 3.2). (Local Services in Bloemfontein, 2011)




*Source: (Mangaung, 2010)*

**Figure 3.2: Bloemfontein average monthly temperature**

The difference in precipitation between the driest month and the wettest month is 77mm. The variation in annual temperature is approximately 14.4°C. (Local Services in Bloemfontein, 2011). The average monthly temperatures and rainfall for Bloemfontein are shown in Table 3.1.

**Table 3.1: Bloemfontein weather per month**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Avg. Temperature (°C) | 22.7 | 21.8 | 19.7 | 15.5 | 11.5 | 8.4 | 8.3 | 10.9 | 14.7 | 17.9 | 19.9 | 21.7 |
| Min. Temperature (°C) | 15.2 | 14.7 | 12.5 | 7.9 | 3.3 | -0.2 | -0.5 | 1.8 | 5.7 | 9.6 | 11.9 | 13.9 |
| Max. Temperature (°C) | 30.3 | 28.9 | 26.9 | 23.2 | 19.8 | 17 | 17.1 | 20 | 23.8 | 26.3 | 27.9 | 29.6 |
| Avg. Temperature (°F) | 72.9 | 71.2 | 67.5 | 59.9 | 52.7 | 47.1 | 46.9 | 51.6 | 58.5 | 64.2 | 67.8 | 71.1 |
| Min. Temperature (°F) | 59.4 | 58.5 | 54.5 | 46.2 | 37.9 | 31.6 | 31.1 | 35.2 | 42.3 | 49.3 | 53.4 | 57.0 |
| Max. Temperature (°F) | 86.5 | 84.0 | 80.4 | 73.8 | 67.6 | 62.6 | 62.8 | 68.0 | 74.8 | 79.3 | 82.2 | 85.3 |
| Precipitation / Rainfall (mm) | 83 | 86 | 76 | 50 | 21 | 9 | 10 | 14 | 20 | 48 | 65 | 66 |

*Source: (Mangaung, 2010)*

## 3.2 DEMOGRAPHY

Area = 236.17km²

Population = 256,185 (1,084.76 per km²)

Households = 81, 286 (344.19 per km²)

Density = 1,100/km²

Area Code = 051

Postal Code = 9300

The South African Census study of 2011 has detailed the demographics of Bloemfontein City as detailed in Table 3.2. Demographics are important in planning of any significant infrastructure, especial with projections of population to determine the patterns of land use and subsequent transport usage.

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**Table 3.2: Bloemfontein Demographics**

| Gender | | |
|---|---|---|
| | **Number** | **Percentage** |
| **Male** | 129 372 | 50,50% |
| **Female** | 126 813 | 49,50% |
| **Population group** | | |
| | **Number** | **Percentage** |
| **Black African** | 143 736 | 56,11% |
| **White** | 76 325 | 29,79% |
| **Coloured** | 32 827 | 12,81% |
| **Indian or Asian** | 2 100 | 0,82% |
| **Other** | 1 196 | 0,47% |
| **First language** | | |
| | **Number** | **Percentage** |
| **Afrikaans** | 101 647 | 42.53% |
| **Sesotho** | 79 737 | 33.36% |
| **English** | 17 852 | 7.47% |
| **IsiXhosa** | 16 972 | 7.10% |
| **Other** | 24 440 | 9.54% |

*Source: (Census, 2011)*

## 3.3 BLOEMFONTEIN LAND USE AND FUNCTION

The total area of Bloemfontein is 236km². Urban areas/towns include: Bloemfontein, Botshabelo, Dewetsdorp, Mangaung, Soutpan, ThabaNchu, Van Stadensrus, and Wepener. The principal economic sectors are: community administration (35.3%), black (26.8%), trade (16%), transport (11.8%) and production (3.5%) (Census, 2011).

The economy is strongly influenced by the administration sector, which has experienced the quickest development over the past five years because of expanded government programmes in job creation interventions. The funding division is the second fastest developing because of highly dynamic grant and development activities. (Local Services in Bloemfontein, 2011)

Independent companies have an important part to play in the South African economy, especially in Mangaung, in terms of business creation, salary, wage and yield development. It is estimated that more than 12 million individuals in South Africa are actively involved in the SMME division, which represents approximately 60% of all work in the economy and 40% of the yield (Mangaung, 2010).

In a region, such as Mangaung, with its relatively high levels of joblessness and destitution, it can be expected that the SMME sector plays a significantly more important role in work creation and poverty mitigation. The informal economy makes a vital contribution to the financial and social well-being of Mangaung. Owing to the decrease in formal work and ensuing increase in joblessness, numerous individuals look for alternative methods to obtain an income.

The following are the main features and key considerations with regard to the land use and spatial structure of the Mangaung Metropolitan Municipality (Mangaung, 2010):

- The municipality consists of three urban nodes of which Botshabelo and Thaba Nchu are located approximately 55km and 67km to the east of Bloemfontein respectively.
- Bloemfontein is the primary business node in Mangaung (and Free State Province) and includes a range of retail, office, commercial and industrial activities clustered in a central core area around the CBD.
- The dominant movement pattern in Bloemfontein is radial with all the major routes converging in the central core area, which comprises the CBD, several industrial and commercial areas, as well as some of the highest order community facilities/institutions e.g. the university and regional sports and recreational facilities.
- However, the CBD is in decline with many economic activities locating and relocating towards the west. Although limited at present, there is also a trend for new economic activities to cluster around the four access interchanges along the N1 freeway, where it runs through the western parts of the city.
- Similarly, middle- and high-income, residential development expands gradually towards the west and more specifically the northwest, while low-income residential development continues towards the southeast.
- This growth pattern, in opposite directions, perpetuates the spatial structure of Bloemfontein initiated during the apartheid era and the relocation of economic activity towards the north-west and west marginalises the disadvantaged communities to the south-east (Local Services in Bloemfontein, 2011).

## BLOEMFONTEIN TRANSPORT SYSTEM

### 3.3.1 Road

National and regional roads in the vicinity of Bloemfontein include the following. The N1, which is a major national road running roughly south-east to north-west from Cape Town to Johannesburg and further towards Musina and Zimbabwe, bypasses Bloemfontein to the west. The N8 runs from east to west, connecting Bloemfontein, Lesotho and Kimberly. Bloemfontein is also linked to the north by the N6 road, heading mainly southwards to the Port of East London. At a T-junction just before the city, the N6 becomes the M30 and, therefore, the intersecting road is designated as the N6. This road ends in an interchange with the N1 (Department of Transport SA, 2008).

There are two-digit, R routes: The R64, popularly known as the old Kimberly road, runs via Dealesville and Boshof and ends at the N1. The R30 ends at the N1 north of Bloemfontein and is the road to Welkom (Mangaung, 2010).

There are three-digit, R routes that have their origin in city. The R706 starts from the N8, within the city centre, and heads south-east towards Jagersfontein and Fauresmith (Department of Transport SA, 2008). The R702 also starts from the N8 in the city centre and heads south-west towards small towns such as Dewetsdorp and Wepener. A third road, the R700, starts in the southern part of the city centre from the M30 and heads north, crossing the N8 and N1 towards Bultfontein.

Bloemfontein also has a range of metropolitan or M roads. These roads are numbered independently of the M roads in other South African cities (Mangaung, 2010).

### 3.3.2 Rail

Bloemfontein has an extensive railway network. The city is located on the important rail junction between Johannesburg and Cape Town, with daily rail services to Johannesburg, Port Elizabeth and East London. The rail service is configured as follows:

- The East London/Port Elizabeth – Bloemfontein - Johannesburg railway line crosses the Bloemfontein urban junction in a south - north direction (Department of Transport SA, 2006).
- There have been no commuter services recently within the Mangaung area and

the lines are used by Transnet Freight Rail (TFR) for freight transport and by Shosholoza Meyl for long distance passenger transport along the Port Elizabeth – Bloemfontein - Johannesburg service, the East London – Bloemfontein - Johannesburg service, and the Cape Town – Kimberley – Bloemfontein – Pietermaritzburg – Durban service.

### 3.3.3 Air

Bloemfontein city has two airports, Bram Fischer International Airport and the New Tempe Aerodrome. New Tempe Aerodrome is only used as a training facility for aviators and flying schools. Bram Fischer International Airport has scheduled flights to all South Africa's major cities (Department of Transport SA, 2008).

### 3.3.4 Public Transport

The Mangaung Metropolitan Municipality was busy with the Integrated Public Transport system project. The project consisted of two phases: the first phase was the main construction of bus-ways through the metropolitan city; the second phase was the construction of depots and stations (Department of Transport SA, 2008)

## 3.4 MANGAUNG TRANSPORT SYSTEM

More than 17% of all work-related trips in Mangaung are made by walking all the way from origin to destination (National Household Travel Survey (NHTS), 2013). Furthermore, in the NHTS 2013, using Traffic Analysis Zone (TAZ), it was estimated that approximately 190 000 work-related trips were made during this period. The highest number of trips were recorded by the Mangaung TAZ (91 000), followed by the Botshabelo/Thaba Nchu (42 235) cluster and Bloemfontein (45 454) (Mangaung, 2010) The mode used mostly by travellers from Bloemfontein was the private vehicle, whereas most trips from Mangaung and Botshabelo/Thaba Nchu were made by walking and public transport (Mangaung Metropolitan Municipality, 2017- 2019). The travel mode split per origin, according to TAZ for the Mangaung Metropolitan area was taxi: 32.56%; bus: 10.55%; lift-clubs or as a passenger: 8.44%; and private vehicles 29.3% (Mangaung, 2010)

More than 40% of passenger trips are made by public transport and at least 17% of passengers, travelling during the morning peak period, walk all the way to work. The Municipality was in the process of finalising the Integrated Public Transport Network (IPTN) Plan 2014, which was expected to be completed by April 2017. The aim of the IPTN was to bring an affordable public transportation alternative to the citizens in Mangaung and it would address trends in demand for transport services by mode, income group and average trip lengths (Mangaung Metropolitan Municipality, 2017- 2019).

## 3.5 ROAD NETWORK IN BLOEMFONTEIN CITY

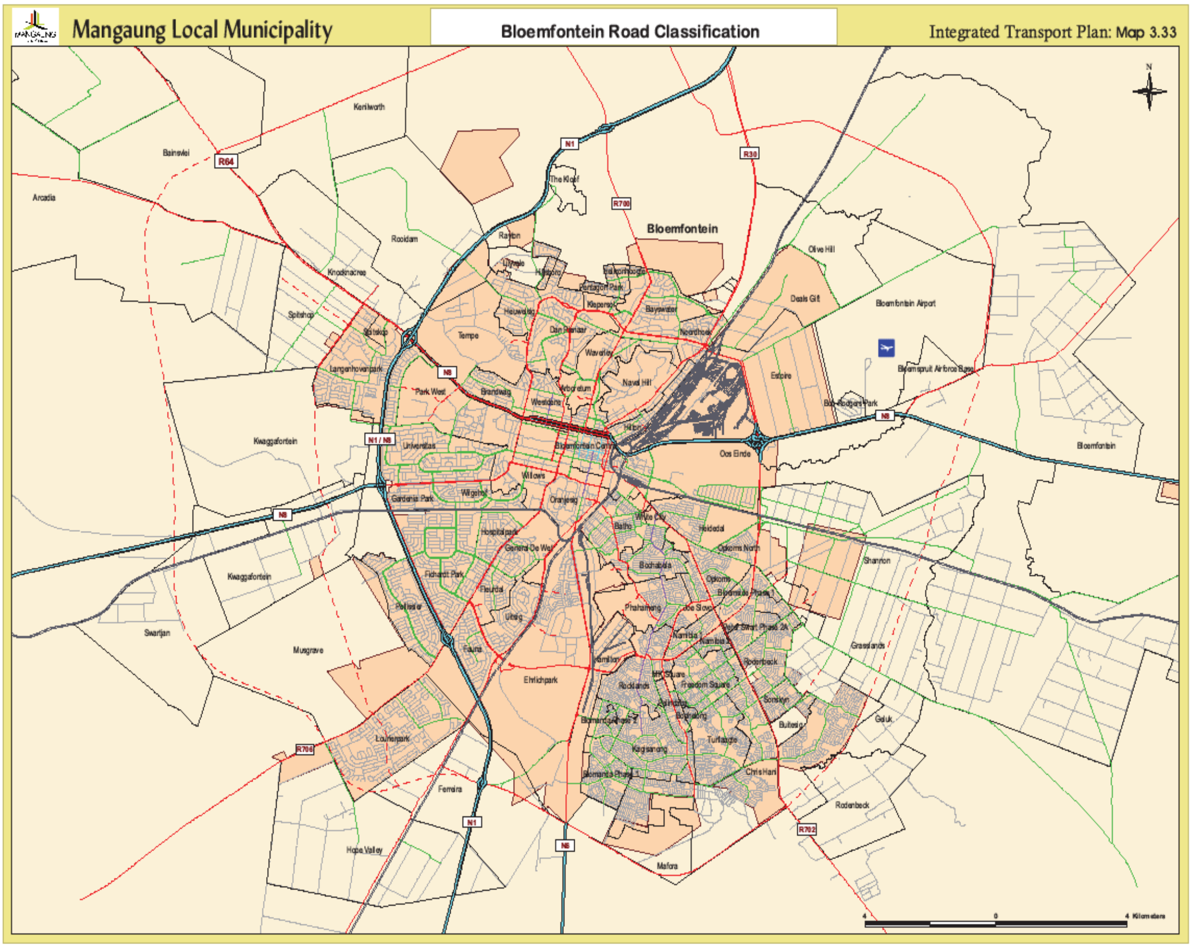
### 3.5.1 Classification of the Roads and Street System

The customary, five-level hierarchy of road classification has been relinquished, considering that it over-accentuated the vehicular development capacity of the road framework (Department of Transport SA, 2008). In addition, the use of a hierarchical system conveyed the idea that one component in the system was more essential than another. The system involves an arrangement of interlinking boulevards, serving distinctive capacities, and frequently serving these diverse capacities in an unexpected way (TMH14, 2013).

Over-accentuation of the significance of one road connection at the cost of another does not only constitute poor design, but also can put the entire system at risk (The Constructor, 2003). All parts of the system should be taken into account. To help designers to comprehend the new classification framework is discussed in this section, offering a correlation between the previous, five-level framework, the Urban Transport Guideline (UTG) arrangement, and that presently utilised (Toba, *et al*., 2015). Regardless, it should be comprehended clearly that there is no recognised correlation between the current and alternative road classifications. The five-level and the UTG classification frameworks are restricted to addressing development regarding a range of availability *versus* portability, while the present arrangement addresses all elements of streets and roads (Toba, *et al*., 2015).

### 3.5.2 Classification of Roads: Mangaung Municipality

As shown in Figure 3.3 the existing road network in the Bloemfontein urban node is characterised by a radial form. The road network consists of various road classes, of which Class 1 (National Roads/Freeways) and Class 2 (Arterials) form structural elements within the urban nodes.




*Source: (Mangaung Metropolitan Municipality, 2017- 2019)*

**Figure 3.3: Mangaung road network**

The Bloemfontein urban node is characterised by the following, key, road-network elements, (Toba, *et al*., 2015):

i. **Class 1: National roads / freeways**
   - National Route N1 (connecting Gauteng to Cape Town)
   - National Route N8 (connecting Botshabelo / Thaba Nchu, Bloemfontein and Kimberly)
   - National Route N6 (connecting East London and Bloemfontein)

ii. **Class 2: Arterials**
   - Raymond Mhlaba Street (R30)
   - Kenneth Kaunda Road (R700)
   - General Dan Pienaar Road

- Nelson Mandela Drive (R64)
- Walter Sisulu (N8 western extension)
- Jagersfontein / Curie / Kolbe Avenue (R706)
- Ferreira Road
- Church Street (M30 / N6 southern extension)
- Dewetsdorp Road (R702)
- Meadows Street
- Thaba Nchu Road

**iii. Class 3: Internal / local streets**

- Greyling Avenue
- M10
- Other access roads

The radial road network is characterised also by an outer- and an inner-ring-road system. The outer-ring road is formed by the N1, approaching from the north, following the western boundary of Bloemfontein, and exiting to the south. The N6 extension along the southern boundary, between the N1 and the R701, completes a portion of the outer-ring-road loop (Mangaung, 2010). The eastern portion of the ring-road loop had not been constructed, but plans were available to complete this portion of the ring road, thereby linking the N6 extension (from R706) with the N1 (towards the north). This extension of the ring-road's eastern section would provide very important regional access to the eastern parts of the Bloemfontein urban node, and particularly to the planned airport node development (Department of Transport SA, 2008).

The inner ring-road is formed by the M10 alignment which runs along the southern and eastern boundaries of the Bloemfontein urban node, and becomes Rudolf Greyling Avenue as the M10 crosses the National Route N8, thereafter becoming Wilkocks Road and Deale Road, forming the northern edge of the inner ring-road, thereafter turning south again, along General Dan Pienaar and Parfitt Avenue, which forms the western boundary of the inner ring-road (Toba, *et al*., 2015).

Bloemfontein has a complex road network under the administration of Mangaung Municipality. Bloemfontein City connects to three National roads, N1 (from Cape Town to Johannesburg), N6 (Bloemfontein to East London) and N8 (from Kimberly to Maseru) (Toba, *et al*., 2015). The city has five major Metropolitan roads running across the City i.e. R64 (old road to Kimberly, which joins N1), R30 (from Bloemfontein to Welkom, which joins N1), R700 (from Bloemfontein South to Bultfontein, which joins N1 and N8), R702 (from the City Centre to Dewetsdorp and Wepener), R706 (from the city centre to Fauresmith, which joins N8). Apart from these major roads there are many other streets that provide access and special integration between the City's towns, townships and commercial areas (Mangaung Metropolitan Municipality, 2017- 2019).

## 3.6 QUALITY OF ROADS

### 3.6.1 Unpaved roads

Bloemfontein City had less than 5% of unpaved roads, which were situated mainly in the township areas and the outskirts of the city. The design of all unpaved roads was specified in Technical Recommendations for Highways (TRH4, 1996), in terms of the thickness cover and type of gravel material needed. The structural design of paved roads has, developed into a highly sophisticated branch of engineering in the last two to three decades. The design of unpaved roads, on the other hand, has received minimal attention. Unpaved roads might form an initial stage towards paved roads and designs should take this into consideration (The Constructor, 2003).

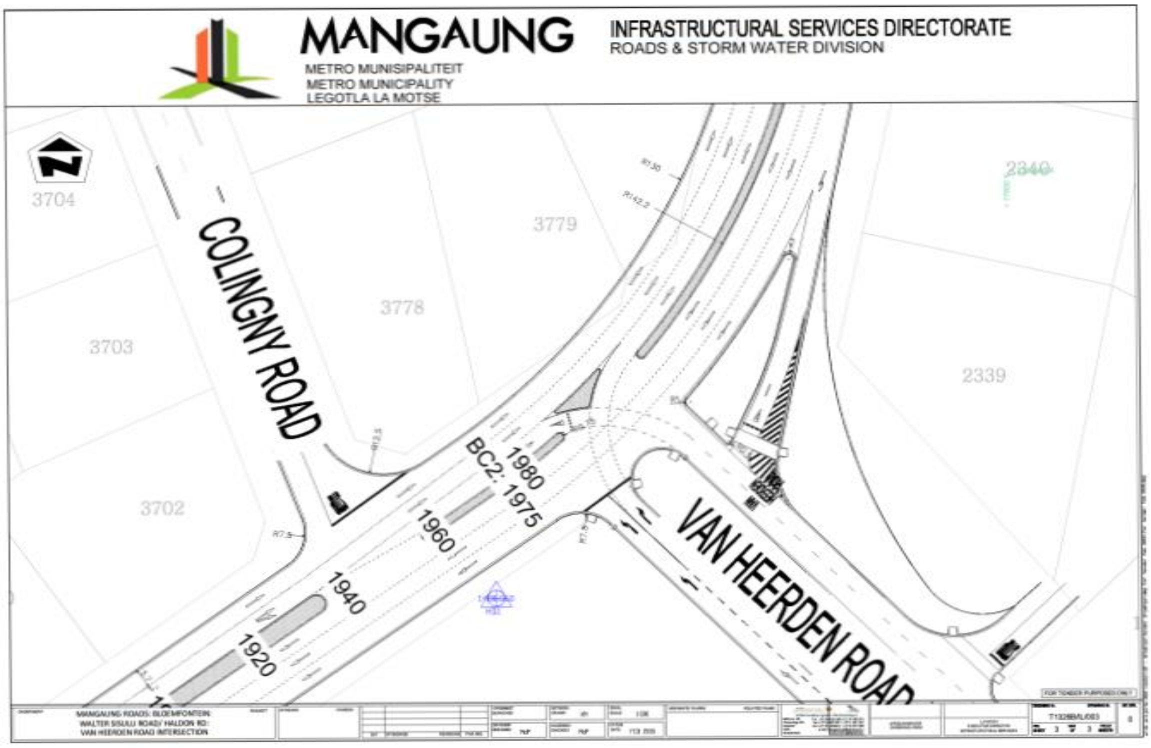
No scientific, structural, design procedure for unpaved roads was being used regularly in Southern Africa. The Maintenance and Design System (MDS) incorporated work carried out at the Waterways Experiment Station where models were developed to predict the rut depth from material properties, traffic and surfacing thickness. Unfortunately, no design thickness models were included, but the variables in the models were transposed to predict the design thickness (Shingloo, 2016).

### 3.6.2 Paved roads (Flexible Pavement)

The transposed model produced a more realistic cover thickness than the models developed earlier and indicated that, for sub-grade CBR values greater than 5 (at Proctor compaction) with at least 150 mm of surfacing material thickness (Proctor CBR greater than 30), 10 000 repetitive truck loads would be required to produce rutting of approximately 75 mm thick (Karoliny & Gasper, 2015). The failure criteria of 75 mm-deep ruts was considered to be excessive for typical rural roads in Southern Africa, especially in the wetter eastern areas where the ruts might trap water for longer periods. This increased rut depth was a deficiency affecting the feasibility of applying most overseas work in local road conditions (Department of Transport SA, 2008).

Although the ruts would normally have been removed by routine grader maintenance, a significant proportion of them would be in the form of sub-grade deformation resulting in a loss of wearing course material (The Guardian, 2001). The actual gravel loss which occurred over time and under traffic, resulted in a dynamic situation and, therefore, the optimum thickness of wearing course was valid effectively for only a short period of time. These considerations, local observations and measurements made it possible to develop a structural design procedure for use under Southern African conditions (Visser, 2017).

Flexible road paving design was popular and used widely in the Mangaung region. Road paving layers in Bloemfontein City were designed with a standard of 5 to 6 layers, unless specified differently for heavier and higher volumes of traffic. Figure 3.4 shows a section of Walter Sisulu Road, that was under re-construction in Mangaung Municipality, and its paving design layers are shown in Table 3.3. (Mangaung Metropolitan Municipality, 2017-2019)




*Source: (Mangaung Metropolitan Municipality, 2017 – 2109)*

**Figure 3.4: Walter Sisulu Road design**

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**Table 3.3: Walter Sisulu Road, paving design specification**

| Layer | Description |
|---|---|
| **Layer 1** | 40mm Surfacing: Continuously graded asphalt |
| **Layer 2** | 150mm Base: Imported crushed stone G1, compacted at 88% of apparent relative density |
| **Layer 3** | 250mm Sub-base: Imported stabilised natural gravel C3, compacted to 97% MOD AASHTO density |
| **Layer 4** | 150 Upper Selected G7: Imported natural gravel, compacted to 95% MOD AASHTO density |
| **Layer 5** | 150 Lower Selected G7, imported natural gravel, compacted to 95% MOD AASHTO |
| **Layer 6** | Cut and Fill |

*Source: (Mangaung Metropolitan Municipality, 2017- 2019)*

## 3.7 CHALLENGES OF POTHOLES

The formation of potholes, as in many other cities throughout South Africa, was a problem in Bloemfontein. Table 3.4 shows the extent of road damages that occur in some of the roads in Bloemfontein (TMH9, 1992). As can be seen in the photograph, the road had deteriorated to the core, mostly because of poor drainage and fatigue. Most of the roads that have developed potholes were those which have exceeded their design life-span. For example, the roads below were located in Hamilton, South of Bloemfontein at a corner junction on R706 near the Coca Cola Distribution Centre. The R706 was over 25 years old and had a poor maintenance record. Potholes emerge on various roads throughout the city and, although they were repaired, it was observed that they re-occurred within a year of maintenance (Mangaung, 2010). Local roads mostly were affected by potholes. On average, a local road section had over 13 major potholes (Degree 5) within any given kilometre section of road (Extent 2) and over 22 minor/emerging potholes (Degree 1 and 3 combined) over a kilometre section (Extent 3 and 4). This was the situation mainly on roads with a lifespan of over 20 years without rehabilitation (TMH9, 1992).

**Table 3.4: Emerging and recurring potholes in Bloemfontein South: R706, Mangaung, 2019**

| Type of potholes based on degree and extent | | | |
|---|---|---|---|
| **Road** | **Average degree** | **Average extent** | **Picture** |
| **Nelson Mandela Drive** | 1 | 1 |  |
| **Zastron Street** | 1 | 1 |  |
| **Gladstone Road** | 3 | 3 |  |

| | | | |
|---|---|---|---|
| **Bergstraat Street** | 3 | 3 |  |
| **Meadows Road** | 1 | 0 |  |
| **Dewetsdorp Road** | 3 | 5 |  |
| **M10 Road** | 3 | 5 |  |

| | | | |
|---|---|---|---|
| **Church Street** | 3 | 3 |  |
| **Moshoeshoe Street** | 1 | 3 |  |
| **Robert Burns Street** | 5 | 3 |  |
| **Cnr Church St and Hartley St** | 5 | 5 |  |

## 3.8 CONCLUSION

Mangaung does not receive much rainfall, but has a very hot climate, which plays a role in the development of potholes in the city. The city experiences large traffic volumes with heavily loaded trucks and buses. The road design system of up to 6 layers within the city was not adequate for such high traffic volumes and heavy loads. This could be a problem if no adjustments are made soon to address existing and future demands on the use of the road network.

Mangaung Metropolitan Municipality had an extensive land-use stratum, yet the transport system was lagging. People working in Bloemfontein city used mainly road networks as a means of transport, which resulted in higher traffic volumes. The city also had a wide range of economic and industrial activities, resulting in heavy traffic loads. Road classification informed by traffic loads on unplanned road structures was another challenge in the city. This resulted in road deterioration because of poor structural road capacity to address the present traffic volumes and loads.

# CHAPTER FOUR: METHODOLOGY

## 4.1 INTRODUCTION

The research methodology was designed to solve and answer systematically the research problem regarding the sustainable repair of potholes. For this study, it was appropriate to carry out the research process in a scientific manner. The methodology was used to guide the researcher through various steps using various tools in a logical manner. (Cooper & Schindler, 2013) stated that the selection of the research method is crucial to what conclusions can be drawn about the outcomes of the topic researched, and this was adhered to closely in the study. The methodology critically affected what has been presented about the cause of potholes and the factors that influence repairing them (Lub, 2015).

## 4.2 METHODOLOGY

In this study an ontological, positivist approach was followed (Cresswell, 2015). Based on this approach, both quantitative and qualitative methods were used. A thorough literature review was essential in selecting the design features of the research and served as a guide in selecting the methodology (Cooper & Schindler, 2013). The design of the methodology is shown in detail in Figure 4.1.

An empirical study about potholes was undertaken in Bloemfontein. A case study was conducted on selected roads which had potholes. The case-study approach was chosen because it was necessary to investigate the sustainability of road repairs in South Africa. The case-study area served the road transport needs of the greater Free State Province. The roads which were selected for this study included national, provincial and local road networks linked to Bloemfontein City. This justified an empirical, case-study research approach as being the most appropriate research design. The use of a case-study approach was the most appropriate in researching answers to the type of questions such as: "Why do potholes occur? " and "How can potholes be repaired sustainably? " (Zikmund *et al*., 2009).

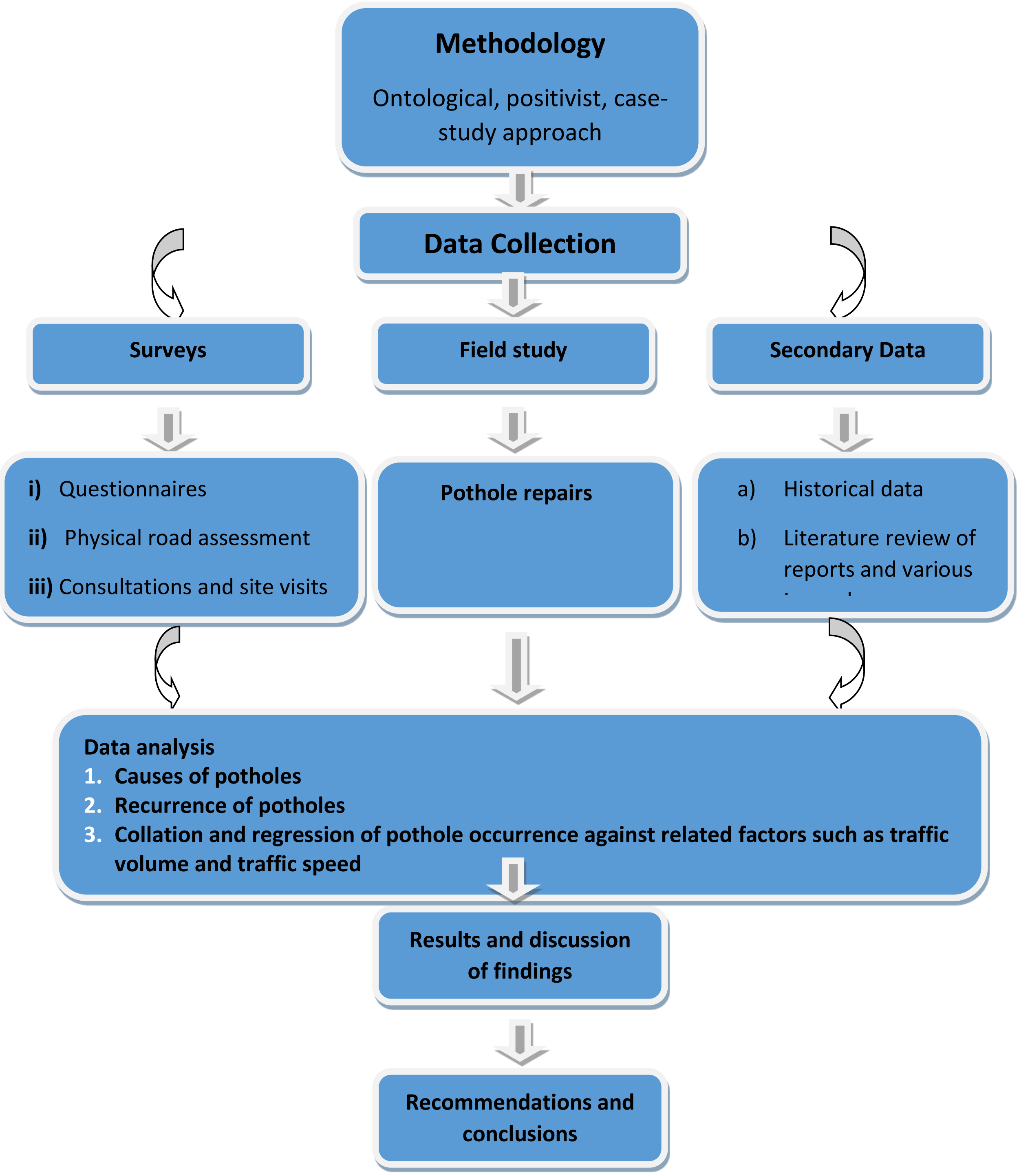



**Figure 4.1: Methodology flow chart**

## 4.3 DATA COLLECTION

The data collected (See Table 4.1) included information on the study area of Bloemfontein City, such as:

- Profile of the respondents to questionnaire.
- Technical and general public inputs through a set of questionnaires.
- Pavement designs from the municipality to examine the type of designs implemented on the road structures within the city, particularly road-paving design.
- Climatic conditions and how they affect the road infrastructure.
- Bloemfontein transport system.
- Road-network study and road classifications.
- Road conditions from a few selected roads (in no particular order) in Bloemfontein City.
- Traffic volumes in the city from the sample of roads selected.
- Potholes - classification and frequency.
- Current repair strategies.

The data collected provided parameters on the types of roads found, maintenance systems followed and the pothole challenges experienced in Bloemfontein City. Extensive data were obtained also about public opinion, their personal experience of potholes, causes of these potholes and their recommendations for better maintenance of the roads in the city.

**Table 4.1: Data collection parameters and methods used for this study**

| Parameter | Method of collection | Source | Form | Method of analysis | Validation |
|---|---|---|---|---|---|
| Profile of the respondents to questionnaire. | Requested in writing for access to data base. Literature review and questionnaire. | Data bases in Mangaung Municipality. | Text tables. | Tables, graphs and infinite series. | Observed data, expert view, system checks. |
| Road-paving designs from the Municipality to examine the type of designs implemented on the road structures within the city, particularly | Requested in writing for access to data base. Literature review and consultation | Literature Review. Data bases in Mangaung Municipality. | Design drawings, maps and text. | Tables and Graphs. | Observed data, expert view, system checks. |

| | | | | | |
|---|---|---|---|---|---|
| paving design. | | | | | |
| Climatic conditions and how they affect the road infrastructure of the Bloemfontein Transport system. | Requested in writing for access to data base. Literature review. | Literature review. | Graphs, tables and text. | Graphs and infinite series. | Observed data, expert view, system checks. |
| Road-network study and road classifications. | Literature review and consultation. | Data bases in Mangaung Municipality Literature review. | Design drawings, maps and text. | Tables and maps. | Observed data, expert view, system checks. |
| Road conditions from selected roads (in no particular order) in Bloemfontein City. | Questionnaires, literature review and consultation. | Physical surveys. Databases in Mangaung. Municipality | Design drawings, tables, pictures and text | Tables, pictures and graphs | Observed data, expert view, system checks. |
| Traffic volumes in the city on selected roads. | Traffic count and consultation. | Traffic count. | Drawings, tables and text. | Drawings, tables and graphs. | Observed data, expert view, system checks. |
| Potholes - classification, frequency and current repair strategies. | Literature review and consultation. | Literature review. Databases in Mangaung Municipality | Drawings, maps and text. | Tables and graphs. | Observed data, expert view, system checks. |
| General questions and answer comments. | Questionnaire. | | Text. | Graphs and infinite series. | Observed data, expert view, system checks. |

### 4.3.1 Primary Data Collection

Surveys were used to collect data from different sources such as Mangaung Municipality, public questionnaires, physical road assessments, site visits, and traffic surveys. A physical survey of a sample of critical roads was conducted to assess the condition of the roads, followed by a questionnaire survey, amongst stakeholders, about the quality of roads and their current conditions in Bloemfontein City. an outline of the critical methods used in the data collection is given below:

**i. Questionnaires**

Questionnaire surveys were conducted and analysed in detail under Appendix A, B and C. The guiding research questions were refined through pre-tests to ensure the responses would make an appropriate level of analysis possible. Interviews were used to acquire key quantitative and quantitative data and databases that were relevant to the research study. The interviews included questions that addressed issues such as:

a) Main causes of potholes and deterioration of roads in the city;
b) The current road conditions in the city;
c) Type of maintenance currently in use;
d) Type of material currently in use;
e) The impact caused by current road conditions and poor road conditions in general;
f) Suggestions for effective and efficient future road maintenance.

A total of 100 people answered the general questionnaires, while 20 people answered the technical questionnaires. Interviews relating to all technical questions were conducted with people who had experience in the road construction and maintenance industry, which included road authorities from the Department of Police, Roads and Transport, Mangaung Municipality and people with qualifications who had considerable experience in the field such as contractors and operations managers.

**ii. Physical road assessments and site visits**

Site visits were made on various sites around Bloemfontein for observations of road construction and pothole maintenance. The criteria followed in selecting the site visits was based on the nature of operation on these sites, road rehabilitation maintenance and pothole repairs were a priority. Sites visited were on the following selected roads:

a) R702, Dewetsdorp Road: Pothole Maintenance Project, 2018;
b) A26, Shannon Road: Road Maintenance Project, 2017;
c) Walter Sisulu Road: Road Maintenance Project, 2017;

d) M10 Road: Pothole Repair, 2017.

Physical examinations of road quality and current conditions, average number of pothole occurrence per km section, pothole degree and extent were conducted by walkabouts.

**iii. Traffic survey**

Traffic counts were consulted to determine the traffic volume on the selected road sections. Traffic volume surveys were conducted by manual counting of traffic on the selected road networks for this particular study. All types of vehicles were physically counted, categorised and converted later into Car Passenger Units (CPUs) to determine the traffic volume on each road for every 15 minutes, from 06h00am to 20h00pm.

**iv. Consultations and direct conference:**

Districts of the examined regions were drawn from the data identified based on the proximity to the study area. This data incorporated identification of potholes while making record to the last phase of repairing the potholes. The data made reference to how frequently a pothole has been fixed in the same spot within 5 years. Consultations have been made with roads authorities such as Mangaung Municipality, department of Police Roads and Transport, Civil Engineering Consultants, Contractors, People with qualifications and expertise in the industry as well as general public and stakeholders.

### 4.3.2 Field Study: Pothole Repair

A field study was conducted to examine one of the main, existing methods used to repair potholes on Bloemfontein Roads. The field study was conducted in Hamilton, Bloemfontein to demonstrate the methodology used to repair potholes. The significance of the field study was the knowledge gained from examining the quality and extent of pothole repair using the existing methods and standards. Materials were tested in appropriate laboratories to determine their properties and behaviour under different conditions to ensure compliance to quality standards. The field study procedure and outcome is detailed on section 5.2 in Chapter 5.

### 4.3.3 Secondary Data Collection

**i. Historical and Statistical data**

Statistics were gathered and studied from various study areas including Bloemfontein City. The statistics gave a clear indication of what actually happened periodically from when potholes were identified until their final repair. The statistics included:

- The number of potholes that occurred in a particular area in a particular period, preferably on a monthly basis.
- The classification of such potholes according to their respective degrees.
- The type and nature of potholes that occurred in an area in different seasons.
- The type of topography and climate where potholes were likely to form and the technique and method used to repair them according to their respective degrees and under various climates.
- The normal outcome obtained after the potholes were determined.
- Comparison of the different approaches and methods applied in repairing the potholes from all, different, prospective study areas.

The data and information were obtained from the Mangaung Municipality, various databases, semi-structured interviews, case studies and a literature review. Several databases in major national monitoring systems/programmes were accessed. These included:

- SANRAL;
- National Traffic Information System;
- South Africa Road Agency;
- Road Traffic Management Corporation;
- Ground study walkabouts (physical examinations).

#### 4.3.4 Sampling

Bloemfontein City has a total population of just over 400 000 people. The sample for this study includes: 10 roads, a total of 120 people were selected for the questionnaires, which is about 1% of the overall population of the people using these roads on a daily basis. Out of 120 people, 100 people were selected for the general questionnaire interview. The remaining 20 people were selected for technical interviews, from key organisations, such as the Department of Police, Roads and Transport, because of their specific expertise and perspective on pothole repairs. At least 10% of the technical insight would assist with the answers to the pressing technical questions. The research had to reach this threshold even though it’s a very tiny minority from the overall public that possess such technical knowledge. The outcome from all the questionnaire findings is analysed and presented in detail under Appendix A, B and C.

Interview questionnaires were prepared to understand in detailthe factors associated with road deterioration such as drainage, traffic loads, traffic volume etc. The questions were arranged in simple terms for non-technical people and comprehensively to technical people.

## 4.4 RELIABILITY AND VALIDITY

### 4.4.1 Reliability

The reliability of this study was enhanced by applying the same method of data collection or use of an instrument under the very same conditions, and at the same pace or rate. For example, exactly the same method and technique in the same scenarios, under the same conditions, were applied to compare the outcome results of repairing potholes of the same degree class.

### 4.4.2 Validity

Data were collected from relevant platforms and stakeholders. The questionnaires were distributed to residents of Bloemfontein who used the roads on a daily basis and had an understanding of the questions and the subject. The questionnaires were designed in the simplest terms possible to ensure clear understanding by the respondents.

Responses and data collected from various stakeholders were not generalised. The research supervisor was requested frequently to review and weigh the credibility of the data obtained.

## 4.5 ETHICAL CONSIDERATIONS

Ethical protocols were followed during data collection.

## 4.6 DATA ANALYSIS

Relevant analyses of the various results obtained were carried out. For instance:

i. Causes of potholes were analysed using statistic methods, tabulation and descriptive statistics.
ii. Recurrence of potholes was analysed using histogram descriptive statistics and tabulation (see Appendix B & C).
iii. Coefficient and regression analysis were conducted to establish the relationship between pothole occurrence, traffic volume, traffic speed, layer thickness and wheel load (see Appendix D).
iv. Field study was conducted on site during actual pothole repairs in Mangaung. Findings as well performance results were examined on the field. Material testing was conducted at a laboratory and analysed thereafter. The repairs were carried out by the Department of Police, Roads and Transport.

## 4.7 CONCLUSION

Data for this study were collected from a literature review and semi-structured interviews with appropriate stakeholders of the Mangaung Local Municipality to obtain insight into the alignment of the pothole repair and road performance management system of the Mangaung Local Municipality. Various performance management theories, such as the balanced scorecard, the South African Excellence Model, total quality management and logic model were used to understand how performance management processes must be implemented, from planning to evaluation.

The literature review included the Municipal Systems Act (Act 32 of 2000) and the Municipal Structures Act (Act 117 of 1998) which were the legislation that underpinned the development of the pothole repair and performance management system. The pothole repair and performance management system frameworks, the service delivery and budget implementation plan (SDBIP) and Municipal performance reports were reviewed. The documents that were reviewed helped to gain greater understanding of the roads performance management system of the Mangaung Local Municipality.

Data were analysed using various, relevant tools, such as statistical methods, tabulation, descriptive statistics, charts and graphs.

# CHAPTER FIVE: RESULTS AND FINDINGS

## 5.1 INTRODUCTION

The main objective of this research was to find solutions to the problem of potholes recurring in Bloemfontein City road networks by developing methods for sustainable repairs. The findings and results obtained from the research study in Bloemfontein City have been presented in detail in this chapter. A few roads were selected in the study area to examine their condition, life-cycle, maintenance routine and their sustainability. The chapter contains findings and results about the following:

- The road designs, conditions and their respective maintenance;
- Traffic volume, speed, wheel loads and their effects on the road infrastructure and its sustainability;
- Potholes in the city, their respective degrees and extent on a sample of selected road sections;
- Repair strategies, their challenges and engineering methods applied.

## 5.2 RESULTS AND FINDINGS OF POTHOLE REPAIR EXPERIMENT

The experiment was conducted to examine one of the main methods that was being used to repair potholes in Mangaung Metropolitan Municipality (see figure 5.1). The experiment took place as follows:

Location: Motheo District, Bloemfontein

Date: 16 November 2018

Time: 09h30am

Weather: Dry and hot, 23°C

**Figure 5.1: Pothole repairs in Motheo District**

### 5.2.1 Significance of the Experiment

The significance of this experiment was the results and findings from examining the quality and extent of pothole repair using the existing methods and standards. Materials were tested in appropriate laboratories to determine their properties and behaviour under different conditions. Densities, Shear strength, and viscosity of material used were determined and evaluated i.e. hot-mix asphalt behaves differently under different temperature conditions (Viljoen, 2001). It is imperative to have this knowledge to apply the material correctly in different climatic regions. Standard methods were observed as far as possible for material sampling, mixing and compaction.

### 5.2.2 Experiment Apparatus

a) Patching material:

- Emulsion, SS60;
- BTB;
- Hot-mix asphalt;
- Cold-mix asphalt.

b) Patching equipment

- Concrete cutter;
- Concrete breaker;
- Shovels;
- Rakes;
- Brooms;
- Brushes;

- 750kg compaction roller.

c) Labourers

- Technical supervisors x2
- Labourers x10

**Problem**: Potholes emerged on the road structure and, subsequently, had been there for over 6 months. For the purpose of this experiment, the potholes, distress and deformation were classified according to (TMH, 1998) as presented in Table 5.1 and Table 5.2 for both the pothole degree and extent respectively.

**Degree:** The degree of a particular type of distress is a measure of its severity and is indicated by a number where:

Degree 1: indicates the first evidence of a particular type of distress (slight).
Degree 3: indicates a warning (requires attention).
Degree 5: indicates the worst-case (severe).

**Table 5.1: Classification of potholes by degree**

| Degree | Severity | Description |
|---|---|---|
| 0 | | No distress visible. |
| 1 | Slight | Distress difficult to discern. Only the first signs of distress are visible. |
| 2 | Between slight and warning | |
| 3 | Warning | Distress is distinct. Start of secondary defects. Distress notable with respect to possible consequences. Maintenance may be required in near future e.g. sealing of cracks. |
| 4 | Between warning and severe | |
| 5 | Severe | Distress is extreme. Secondary defects are well developed (high degree of secondary defects) and/or extreme severity of primary defect (Urgent attention required). |

*Source: (TMH9, 1992)*

**Extent:** The extent of distress is a measure of how widespread the distress is over the length of a road segment. The extent is also indicated by a number where:

Extent 1: indicates an isolated occurrence (seldom).
Extent 3: indicates intermittent occurrence over most of the length of the road (scattered).
Extent 5: indicates the extensive occurrence of a particular type of distress. Distress on paved-road shoulders should be included in the assessment of the extent.

The general description of the extent classifications is given in Table A3 below

**Table 5.2: Pothole extent: Classification**

| Extent | Description |
|---|---|
| 1 | Isolated occurrence; not representative of the segment length being evaluated (seldom). |
| 2 | Intermittent (scattered) occurrence, over parts of the segment length (more than isolated). |
| 3 | Intermittent (scattered) occurrence, over most of the segment length (general), or extensive occurrence over a limited portion of the segment length. |
| 4 | More frequent occurrence over a major portion of the segment length. |
| 5 | Extensive occurrence. |

*Source: (TMH9, 1992)*

It is important to know and asses the potholes in terms of extent to determine the amount of material needed for repair, and the effect this will have on motorists throughout the road structure. The assessment of the potholes in the experimental area is shown in Table 5.3

**Table 5.3: Classification of assessment of experimental potholes**

| Assessment of experimental potholes | | | |
|---|---|---|---|
| **Degree** | 5 | Severe | Extreme Distress |
| **Extent** | 3 | Scattered | Intermitted occurrence |

*Source: (TMH9, 1992)*

### 5.2.3 Maintenance Procedure (refer to Figure 5.2):

- Set up procedures to accommodate traffic.
- Cut the asphalt surface layer using a concrete cutter/asphalt cutter
- Break the material within the area cut by the concrete cutter.
- Carry out minor excavation and remove all loose material within the area.
- Ensure the area is excavated neatly and evenly to a depth of at least 40mm.
- Remove any form of loose material within the excavated area using shovels and brooms.
- Apply tack coat using SS60 emulsion at a ratio of approximately 1litre/$m^2$.
- Leave the area for at least 30 minutes for the emulsion to be absorbed properly by the layer being repaired.
- Lay fresh hot-mix asphalt material in the excavated area, at a minimum temperature of 120°C during, and until the end of, the application.
- Level the repaired surface at a level higher than the existing asphalt surface (compaction factor allowance), but not exceeding 20mm.
- Compact the layer using a smooth roller weighing 750kg.
- Clean the surface and the surrounding area.
- Take core sample within 48 hours to carry out density tests in a laboratory.

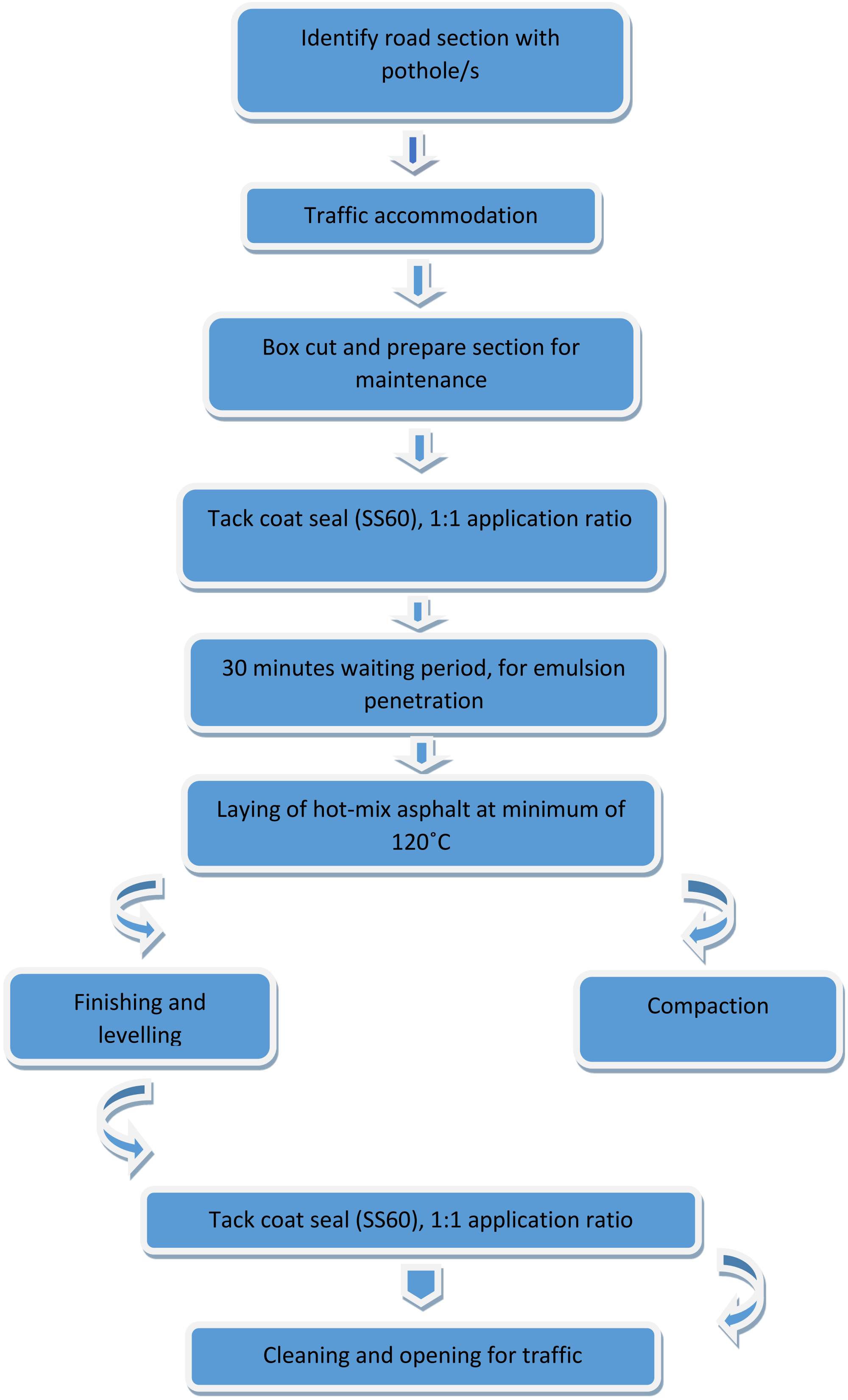
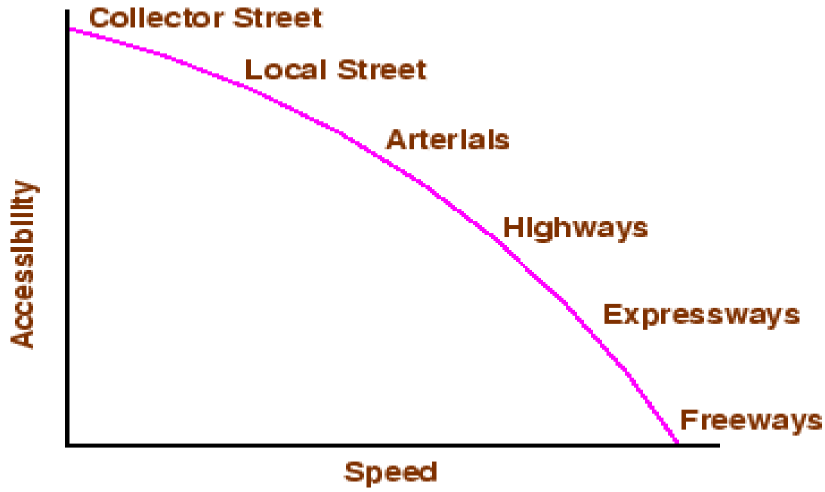



**Figure 5.2: Experiment flow chart**

## 5.3 ROAD SCENARIO

Road networks were classified according to their functions and capacity. The Road Infrastructure Strategic Framework for South Africa (RISFSA) was the basic manual followed for the planning and development of road infrastructure in South Africa. In the manual, the roads were classified based on TRH26: South African Road Classification and Access Management Manual (COTO, 2012). The manual provided guidance to national, provincial and municipal spheres of government on the functional classification of roads and the methodology to be followed in undertaking the classification of roads. Figure 5.3 showcase the classification of roads according to their levels and functionality.




*Source: (TRH4, 1996)*

**Figure 5.3: Road classification using TRH4**

The existing road network in the Bloemfontein urban node was characterised by a radial form. The road network included several road classes, of which Class 1 (national roads/freeways) and Class 2 (arterials) formed structural elements within the urban nodes. The Bloemfontein urban node was characterised by the key road network elements shown in Table 5.4.

**Table 5.4: Classification of road types in Bloemfontein City**

| Road | Classification | Connection | Function |
|---|---|---|---|
| **1. Nelson Mandela Drive** | Regional Distributor | City Centre to N1 | Public road, between the city capital, municipality administration centres and N1. |
| **2. Zastron Street** | Regional Distributor | N1 to the City Centre | Public road, between the N1, city capital and municipality administration centres. |
| **3. Meadows Road** | District Collector | M10 to Dewetsdorp Road | Public road, between large township residential areas, the city centre and farm areas |
| **4. Dewetsdorp Road** | Regional Distributor | Dewetsdorp town to the City Centre | Public road, between Dewetsdorp town, city capital and municipality administration centres. |
| **5. Church Street** | Regional Distributor | N6 to the City Centre | Public road, between the N6, city capital and municipality administration centres. |
| **6. M10 Street** | Regional Distributor | N8 to the City Centre | Public road, between the N8, city capital and municipality administration centres. |
| **7. Moshoeshoe Street** | District Distributor | Local Street, Intersects M10 and Fort Street | Public road, between municipality centres and township residential areas. |
| **8. Walter Sisulu Road** | Regional Distributor | N1 to the City Centre | Public road, between the N1, city capital and municipality administration centres. |
| **9. N1 to Bloemfontein** | Primary Distributor | N1 to Bloemfontein | Public road, between, through and within the provincial capitals and key cities. |
| **10. N8 to Bloemfontein** | Primary Distributor | N8 to Bloemfontein | Public road, between, through and within the provincial capitals and key cities. |

Bloemfontein City is connected to three national roads, N1 (from Cape Town to Johannesburg), N6 (Bloemfontein to East London) and N8 (from Kimberly to Maseru). There are five major metropolitan roads running through the City i.e. R64 (old road to Kimberly, joins N1), R30 (from Bloemfontein to Welkom, joins N1), R700 (from

Bloemfontein South to Bultfontein, joins N1 and N8), R702 (from the city centre to Dewetsdorp and Wepener), R706 (from the city centre to Fauresmith, joins N8). Apart from these major roads there are many other streets that provide access and special integration between the city's towns, townships and commercial areas (Mangaung Metropolitan Municipality, 2017- 2019).

### 5.3.1 Life Cycle of Roads

Road life-cycle is the life-span of a road from construction to undergoing all the maintenance stages until a total reconstruction of the road. The normal life-span or design-life of a road in the Mangaung Metro Municipality was 20 -25 years, which was followed by the road assessment processes scheduled to occur every three years for prompt maintenance. Table 5.5 depicts the road life-cycle in Bloemfontein city.

**Table 5.5: Summary of road life-cycles in Bloemfontein**

| Roads | Design life-cycle | Actual (age) life-cycle | Remarks |
|---|---|---|---|
| **1. Nelson Mandela Drive** | 30 | 23 | The road was still within the design life-cycle. Must be closely monitored and maintained. |
| **2. Zastron Street** | 30 | 21 | The road was still within the design life-cycle. Required maintenance attention. |
| **3. Meadows Road** | 25 | 6 | The road was still within the design life-cycle. |
| **4. Dewetsdorp Road** | 30 | 17 | The road was still within the design life-cycle. |
| **5. Church Street** | 30 | 22 | The road was still within the design life-cycle. Must be maintained closely. |
| **6. M10 Street** | 25 | 28 | The road had exceeded its design life-span by three years. |
| **7. Moshoeshoe Street** | 25 | 18 | The road was still within the design life-cycle. |
| **8. Walter Sisulu Road** | 30 | 2 | The road had just undergone rehabilitation maintenance. It was fairly new. |
| **9. N1 to Bloemfontein** | 30 | 16 | The road was still within the design life-cycle. |
| **10. N8 to Bloemfontein** | 30 | 24 | The road was still within the design life-cycle. Required close monitoring. |

Nelson Mandela Drive and Zastron road were fast reaching their design-life of 30 years. It was necessary to monitor closely all roads that had exceeded 60% of their life-span, such as Nelson Mandela Drive and Zastron Road, for urgent maintenance requirements because potholes frequently emerge on such roads on a weekly basis. (Mangaung, 2010) Roads that have deteriorated critically would need to be rehabilitated before, or at the expiry of, their life-span.

### 5.3.2 Condition of Roads

Road condition is a status or standard of any road section at any given time. Roads are designed according to the best standard conditions but they deteriorate to poor conditions as they become older, with lack of, or poor, maintenance leading to quick deterioration. Road conditions can be measured in in terms of the number of potholes rutting and cracks that have developed in that road as listed in Table 5.6.

**Table 5.6: Description of road conditions**

| Degree | Condition | Description |
|---|---|---|
| **0** | **Good** | No potholes or defects noticeable. |
| **1** | **Fair** | Very few negligible defects. |
| **2** | **Poor** | Distress is distinct; start of secondary defects. Distress noticeable with respect to possible consequences. |
| **3** | **Very Poor** | Distress is highly noticeable and can be extreme. |

Road conditions have serious, direct effects on the occurrence of potholes. Areas with poor road conditions generally have a larger number and extent of potholes than an area with good road conditions. Poor road conditions usually occur in areas where the roads are very old or likely to have exceeded their design-life. The age of roads, coupled with lack of, or poor, maintenance, contributes significantly to road deterioration and development of potholes.

Visual assessments and consultation methods were used to assess the condition of the 10 roads in the city, selected for the purpose of this study, as recorded in Table 5.7. Walter Sisulu Road and the M10 showed extreme distresses of Degree 3. These roads required maintenance attention urgently, such that it might have been necessary to implement a rehabilitation strategy. The roads showing Degree 2 deterioration of various defects required maintenance. Those showing Degree 1 defects had to be monitored closely to avoid unnecessary, rapid deterioration. Roads classified as being in Degree 1 condition usually were the newly rehabilitated roads or those which were well maintained and still in good condition. Most of the roads in the case study showed structural defects and it was necessary for maintenance in the city to be prioritised and implemented effectively and efficiently (see Table 5.7).

**Table 5.7: Conditions of roads in Bloemfontein City**

| Road | Condition (degree) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | PH | EB | CC | SF | LC | SC | AL | RT | BD |
| 1. Nelson Mandela Drive | 1 | 1 | 2 | 1 | 2 | 2 | 0 | 1 | 2 |
| 2. Zastron Street | 1 | 1 | 2 | 1 | 2 | 2 | 0 | 1 | 2 |
| 3. Meadows Road | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 2 |
| 4. Dewetsdorp Road | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| 5. Church Street | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 |
| 6. M10 Road | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 2 | 1 |
| 7. Moshoeshoe Street | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8. Walter Sisulu Road | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 9. N1 to Bloemfontein | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 10. N8 to Bloemfontein | 2 | 1 | 1 | 0 | 1 | 2 | 2 | 0 | 1 |

**Key**: PH = Potholes
EB = Edge Breaks
CC = Crocodile Cracks
SF = Surface Failure
LC = Longitudinal Cracks
SF = Surface Cracks
AL = Aggregate Loss
RT = Rutting
BD = Bleeding

### 5.3.2.1 Road cross-section

The road cross-section is a crucial element of the geometric design phase. It shows the position of the road carriage-way with the designed paving layers, constructed or to be constructed, on a design layout. The cross-section also reflects the other lanes included in the road structure, such as a bicycle lane, sidewalks and cross slopes. Figure 5.4, below, shows a typical cross-section structure for road designs in Mangaung.

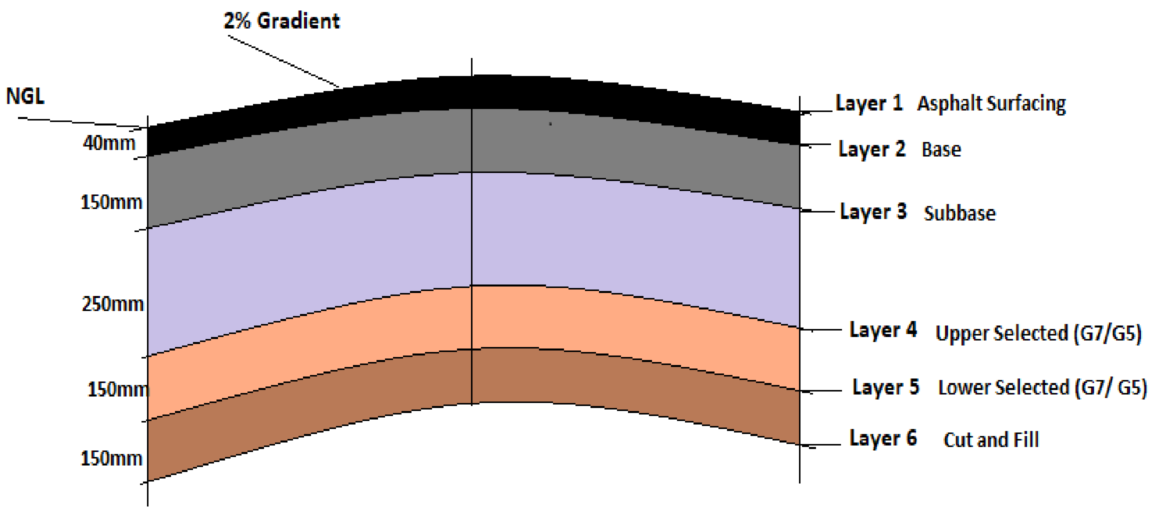



**Figure 5.4: Cross-section: Typical road-paving design of roads in Bloemfontein**

## 5.3.3 Material Used

It is critical to select the most suitable material for a road-paving structure because the paving results in a convenient riding surface that can withstand the expected traffic load. The construction material used in road-paving structures contributes to road durability and performance.

The common practice in road construction is to use mainly cement, concrete, aggregates, and selected material like G1, G2, G5 and bituminous asphalt. This was the case in the construction of road infrastructures in Bloemfontein as shown in Table 5.8.

**Table 5.8: Material used to construct roads in Bloemfontein**

| Road | Description | | |
|---|---|---|---|
| | Prescribed design material | Actual design material | Remarks |
| **1. Nelson Mandela Drive** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 300 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 300 selected G7 | Actual design material conforms to prescribed design |
| **2. Zastron Street** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1, C3<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1, C3<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | Actual design material conforms to prescribed design |
| **3. Meadows Road** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 200mm sub-base C2<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G2<br>Sub-base: 180mm sub-base C2<br>SSG : 150 selected G7 | Deviation on base material from the prescribed design |
| **4. Dewetsdorp Road** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C5<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1/G2<br>Sub-base: 200mm sub-base C5<br>SSG : 130 selected G7 | G2 was also used to build the base layer on other parts of the road section |
| **5. Church Street** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 200mm sub-base C2<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 200mm sub-base C2<br>SSG : 150 selected G7 | Actual design material conforms to prescribed design |
| **6. M10 Street** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 300 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 250 selected G7 | Actual design material conforms to prescribed design |
| **7. Moshoeshoe** | Surfacing: AC med | Surfacing: AC med | G2 was also |

| | | | |
|---|---|---|---|
| **Street** | asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | asphalt<br>Base: 150mm stabilised G1/G2<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | used to build the base layer on other parts of the road section |
| **8. Walter Sisulu Road** | Surfacing: AC med asphalt<br>Base: 150mm stabilised G2, C3<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G2, C3<br>Sub-base: 200mm sub-base C2<br>SSG : 150 selected G7 | Actual design material conforms to prescribed design |
| **9. N1 to Bloemfontein** | Surfacing: AC med asphalt<br>Base: 80mm BTB<br>Base: 150mm stabilised G1<br>Sub-base: 300mm Stabilised G5, C2<br>SSG : 200 selected G7 | Surfacing: AC med asphalt<br>Base: 80mm BTB<br>Base: 150mm stabilised G1<br>Sub-base: 270mm Stabilised G5, C2<br>SSG : 200 selected G7 | Actual design material conforms to prescribed design |
| **10. N8 to Bloemfontein** | Surfacing: AC med asphalt<br>Base: 200mm stabilised G1<br>Sub-base: 250mm Stabilised G5, C2<br>SSG : 150 selected G7 | Surfacing: AC med asphalt<br>Base: 150mm stabilised G1<br>Sub-base: 250mm sub-base C2<br>SSG : 150 selected G7 | Actual design material conforms to prescribed design |

As shown in Table 5.8, the material used to construct the base for the national roads, N1 and N8, was of higher quality than the material used for local roads such as Moshoeshoe Street. The N1 has a BTB layer before final surfacing, while the N8 has a much thicker base. Aggregate material used for roadway construction on the national roads has high resistance to abrasion.

Heavy traffic loads, combined with various climatic conditions, contribute significantly to cracking of the road structure. This was the main reason why greater attention should be focused on the material used in road construction in Mangaung. The selection and utilisation of high-quality material can assist in resolving structural failures such as bleeding and cracking defects, which are common on the roads around Bloemfontein and partly related to the city’s climatic conditions as discussed in Chapter Three.

### 5.3.4 Road Maintenance Strategies in Mangaung Metropolitan Municipality

Road maintenance is undertaken to ensure road safety and to sustain the service level and high performance of a facility. Road maintenance involves remedying defects such as potholes and cracks that frequently emerge on roadways, ultimately leading to structural failure.

Most municipalities and government departments have developed their own maintenance strategies for road maintenance to be implemented regularly. Implementation of these strategies is informed by the situation on the roads in terms of the nature and extent of damage. The Free State Department and Mangaung Municipality developed the strategies, contained on Table 5.9, to address the maintenance challenges in the city and throughout the province.

**Table 5.9: Road maintenance strategies in Bloemfontein**

| Roads | Prescribed Maintenance frequency | Type of Maintenance | Actual Maintenance | Type of Maintenance | Remarks |
|---|---|---|---|---|---|
| **1. Nelson Mandela Drive** | Every Year | Routine | Every year | Periodic | Different maintenance as and when potholes emerge |
| **2. Zastron Street** | Every Year | Routine | Every Year | Periodic | Only maintained when defects surface |
| **3. Meadows Road** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |
| **4. Dewetsdorp Road** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |
| **5. Church Street** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended when there are defects |
| **6. M10 Street** | Every Year | Routine, Rehab. after | After 2 years | Periodic | Only attended when there are defects |

| | | | | | |
|---|---|---|---|---|---|
| | | 20 Years | | | |
| **7. Moshoeshoe Street** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |
| **8. Walter Sisulu Road** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |
| **9. N1 to Bloemfontein** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |
| **10. N8 to Bloemfontein** | Every Year | Routine, Rehab. after 20 Years | After 2 years | Periodic | Only attended to when there are defects |

Road maintenance is one of the critical parameters in sustaining road infrastructure both locally and globally. It is the best means to keep the roads in a desirable condition. Some of the elements included in road maintenance are pothole patching, road upgrades, surface correction, re-sealing and crack filling. The structures of roads in Bloemfontein that are not maintained effectively and timeously deteriorate quickly and incur higher maintenance costs in the long run, as it is more expensive to maintain roads with structural defects of higher degree and extent.

## 5.4 TRAFFIC SCENARIO

Traffic volume refers to the number of vehicles that pass through a particular road section within a given time. For this study, road sections in Bloemfontein City were selected randomly in which to count traffic to determine traffic volume in a 12-hour period, which included both morning and afternoon peak hours.

Traffic volume is one of the main factors that contribute to failing road structures. Inaccurate estimates of traffic volumes lead to the design and construction of structures with poor capacity to withstand the actual traffic volume and loads on a given section of road. The volume and type of traffic are major factors that affect the sustainability of road conditions.

The results of the traffic counts for this case study have been recorded in Figure 5.5, 5.6

& 5.7, then tabled in Table 5.11.

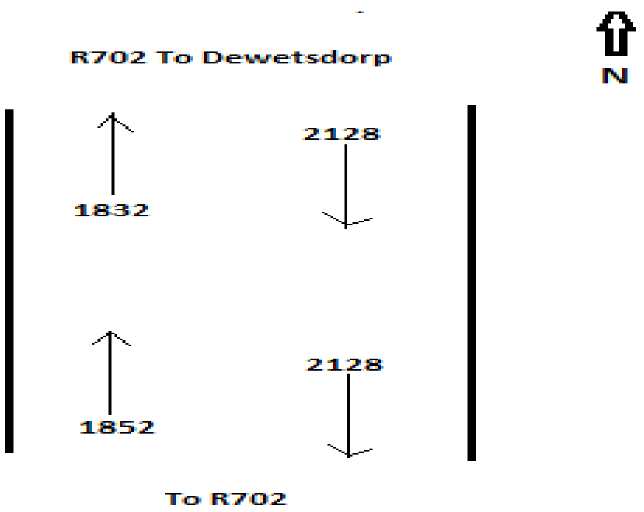



Figure 5.5: Traffic volume on R702 over a 12-hour period

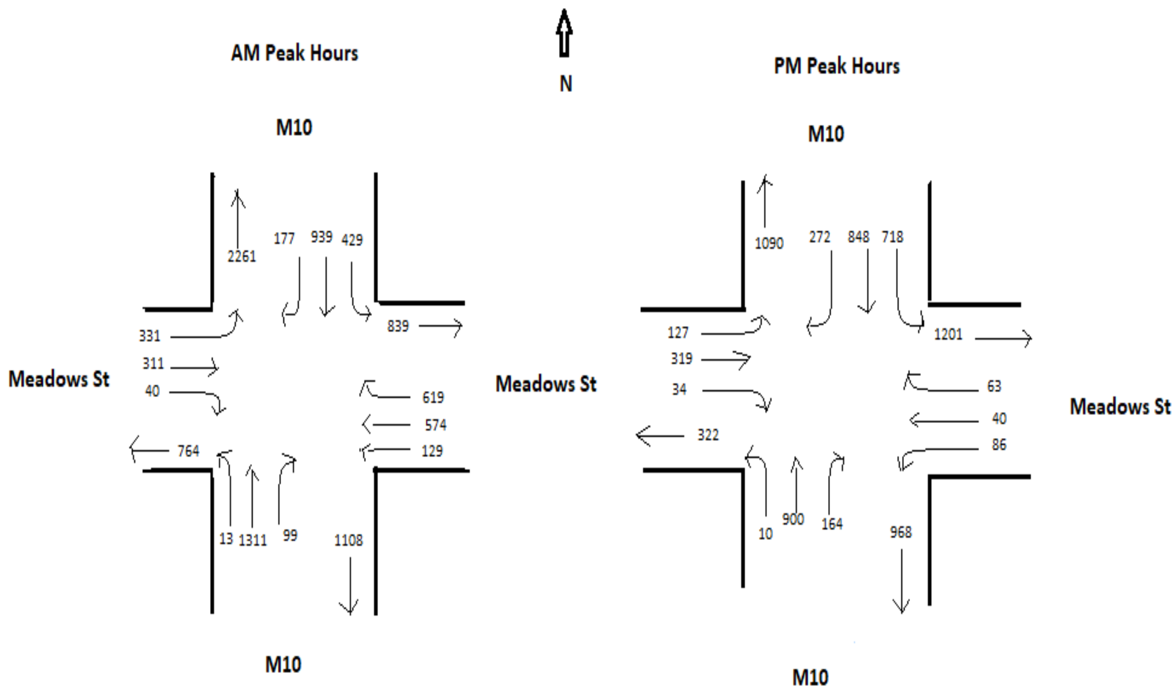



Figure 5.6: M10 traffic volume: Morning and afternoon peak hour

## Table 5.10: Traffic volume in Bloemfontein

| Total Traffic Count (PCU) | | | | | | | | | | | | | | | | | TOT (PCU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date: 13 March 2019 | | | | | | | | | | | | | | | | | |
| Road | | Time | | | | | | | | | | | | | | | |
| | | 06h00 | 07h00 | 08h00 | 09h00 | 10h00 | 11h00 | 12h00 | 13h00 | 14h00 | 15h00 | 16h00 | 17h00 | 18h00 | 19h00 | 20h00 | |
| 1. Nelson Mandela Drive | WEST BOUND | 301 | 612 | 765 | 662 | 545 | 501 | 441 | 408 | 470 | 509 | 593 | 734 | 416 | 420 | 334 | 7 711 |
| 2. Zastron Street | EAST BOUND | 484 | 807 | 1108 | 903 | 601 | 712 | 442 | 562 | 514 | 386 | 784 | 851 | 642 | 509 | 500 | 9 805 |
| 3. Meadows Road | NORTH BOUND | 21 | 29 | 62 | 22 | 30 | 44 | 32 | 48 | 36 | 32 | 28 | 51 | 42 | 41 | 29 | 547 |
| | SOUTH BOUND | 27 | 30 | 42 | 24 | 22 | 54 | 31 | 50 | 42 | 51 | 52 | 58 | 61 | 45 | 43 | 632 |
| 4. Dewetsdorp Road | NORTH BOUND | 142 | 170 | 222 | 140 | 163 | 149 | 179 | 193 | 212 | 249 | 243 | 328 | 242 | 180 | 164 | 8 652 |
| | SOUTH BOUND | 163 | 215 | 263 | 172 | 128 | 166 | 157 | 163 | 120 | 171 | 195 | 207 | 207 | 154 | 136 | 8 941 |
| 5. Church Street | NORTH BOUND | 98 | 104 | 116 | 950 | 545 | 455 | 382 | 374 | 470 | 450 | 572 | 602 | 594 | 550 | 488 | 6 750 |
| | SOUTH BOUND | 120 | 138 | 945 | 466 | 600 | 414 | 422 | 447 | 416 | 460 | 484 | 805 | 715 | 683 | 655 | 7 770 |
| 6. M10 Street | NORTH BOUND | 404 | 550 | 1001 | 672 | 523 | 530 | 545 | 480 | 460 | 633 | 671 | 842 | 520 | 532 | 400 | 8 763 |
| | SOUTH BOUND | 920 | 1400 | 2080 | 857 | 718 | 684 | 615 | 710 | 715 | 712 | 800 | 792 | 670 | 565 | 502 | 12 740 |
| 7. Moshoeshoe Street | NORTH BOUND | 342 | 521 | 566 | 448 | 441 | 323 | 502 | 516 | 388 | 287 | 582 | 648 | 681 | 602 | 725 | 7 572 |
| | SOUTH BOUND | 288 | 325 | 476 | 384 | 324 | 401 | 386 | 419 | 552 | 610 | 783 | 902 | 726 | 693 | 654 | 7 923 |
| 8. Walter Sisulu Road | EAST BOUND | 391 | 564 | 609 | 542 | 531 | 544 | 392 | 203 | 298 | 336 | 401 | 473 | 387 | 366 | 320 | 6 357 |
| | WEST BOUND | 191 | 223 | 262 | 201 | 195 | 184 | 203 | 189 | 269 | 314 | 469 | 574 | 418 | 312 | 367 | 4 371 |
| 9. N1 to Bloem. | SOUTH BOUND | 645 | 660 | 671 | 848 | 522 | 940 | 624 | 490 | 482 | 520 | 625 | 702 | 604 | 582 | 488 | 9 403 |
| | NORTH BOUND | 705 | 660 | 700 | 798 | 522 | 940 | 597 | 511 | 482 | 541 | 648 | 672 | 555 | 418 | 395 | 9 144 |
| 10. N8 to Bloem. | WEST BOUND | 547 | 638 | 960 | 882 | 715 | 658 | 546 | 594 | 602 | 701 | 910 | 1233 | 1256 | 1114 | 1002 | 12 358 |
| | EAST BOUND | 601 | 667 | 1020 | 600 | 645 | 688 | 750 | 821 | 748 | 645 | 846 | 871 | 920 | 874 | 822 | 11 518 |

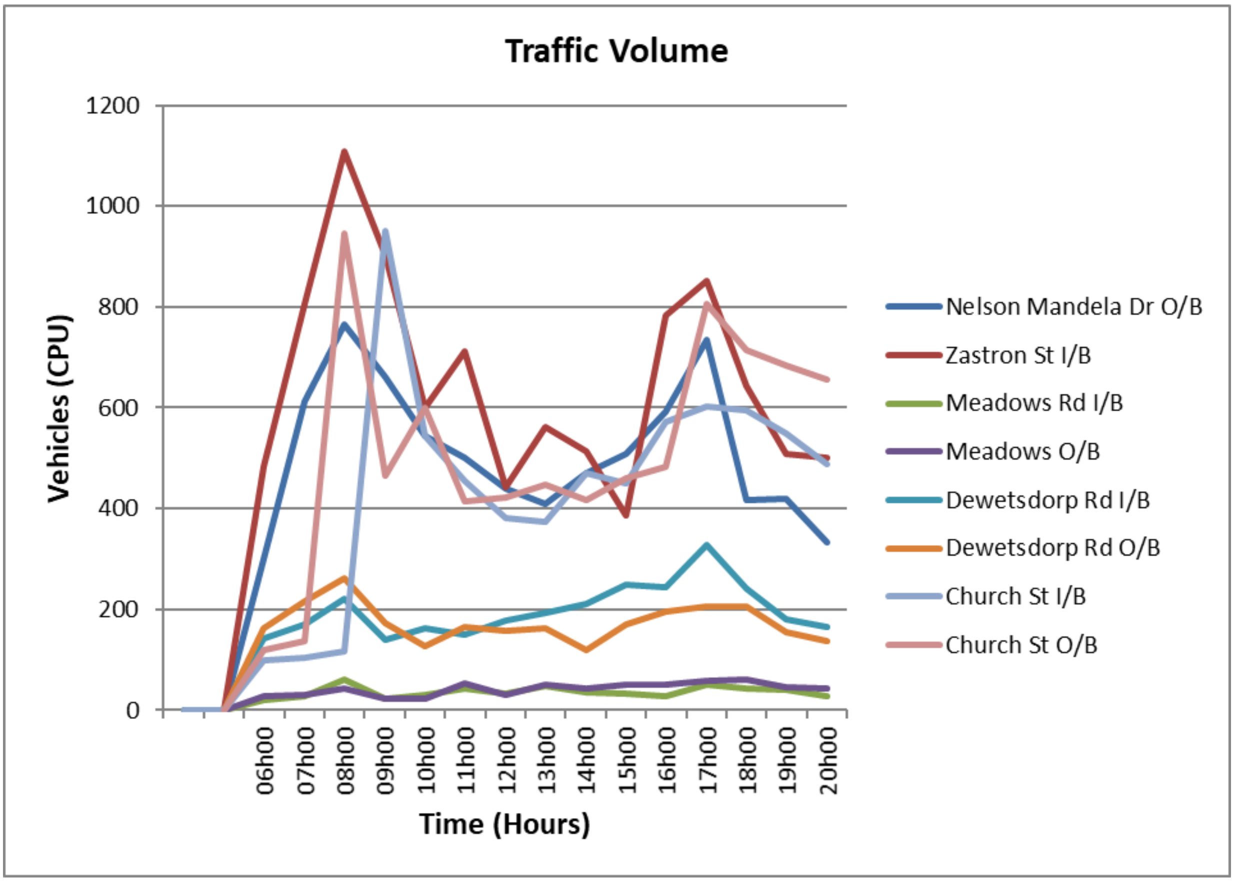



**Figure 5.7: Traffic volume in Bloemfontein**

Traffic volumes in Meadows and Dewetsdorp Roads were relatively low. This might have been because of their geographic location outside the city circle in the South. Whereas roads like Nelson Mandela Drive, Zastron and Church Street, which are directly linked to the Central part of the City, had high traffic volumes and congestion during peak hours. Underestimating traffic volumes and projections will lead to a lower design standard, which will result in rapid structural failure of the road later and development of potholes.

### 5.4.1 Traffic Speed

Traffic speed is one of the main factors that affects the rate of deterioration of a road structure. As recorded in Table 5.11, below, the speed limit was exceeded 85% of the time on Free Flow Speed on most of the roads. This had a negative impact on road safety and structural durability.

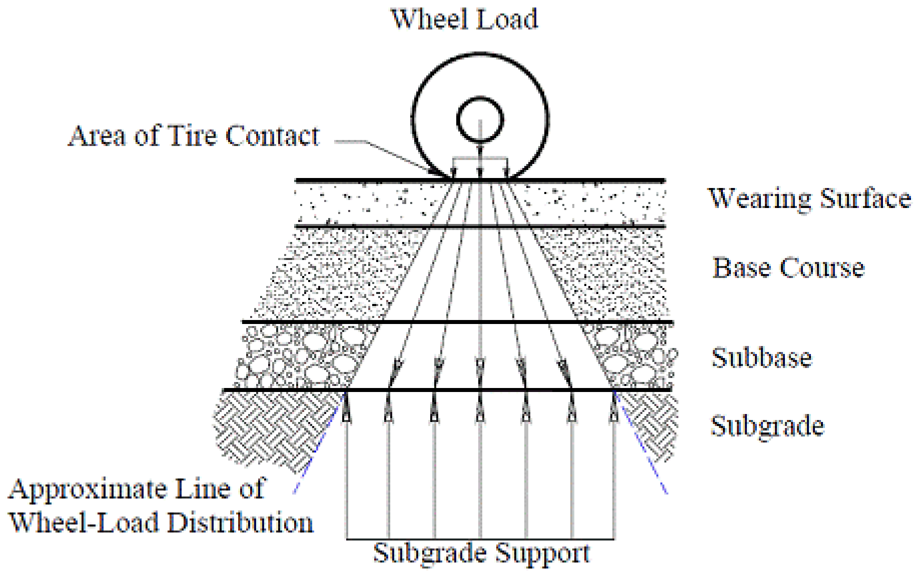
**Table 5.11: Traffic speed in Bloemfontein**

| Roads | (Actual) Average Driving Speed (ADS) (km/h) | Average Free Flow Speed (FFS) (km/h) | Maximum Speed Limit (km/h) | Remarks |
|---|---|---|---|---|
| 1. Nelson Mandela Drive | 80 | 100 | 60 | Speed limit exceeded under both ADS and FFS |
| 2. Zastron Street | 80 | 100 | 60 | Speed limit exceeded under both ADS and FFS |
| 3. Meadows Road | 60 | 80 | 60 | Speed limit exceeded under FFS |
| 4. Dewetsdorp Road | 60 | 80 | 60 | Speed limit exceeded under FFS |
| 5. Church Street | 80 | 100 | 60 | Speed limit exceeded under both ADS and FFS |
| 6. M10 Street | 100 | 120 | 80 | Speed limit exceeded under both ADS and FFS |
| 7. Moshoeshoe Street | 40 | 60 | 60 | ADS below speed limit |
| 8. Walter Sisulu Road | 60 | 80 | 60 | Speed limit exceeded under FFS |
| 9. N1 to Bloemfontein | 100 | 120 | 80 | Speed limit exceeded under both ADS and FFS |
| 10. N8 to Bloemfontein | 100 | 120 | 70 | Speed limit exceeded under both ADS and FFS |

From the data presented in the table above, provided all assumptions were accurate, the Southern and Northern links would yield almost the same level of travel benefits to motorists in terms of time saving; the distance differs by approximately 3kms.

### 5.4.2 Wheel Load

The focus of this section is on analysing the traffic load on the selected road-paving structures. Figure 5.8, illustrates how the traffic load is distributed from the road surface through to the sub-grade level on any given road structure.




*Source:(Vinod, 2018)*

**Figure 5.8: Distribution of wheel load**

#### 5.4.2.1 Repetitions of axle

The damage caused by an axle depends on the load, configuration and repetitions it exerts on a road structure. The damage caused by the repetitions of different axles can be evaluated by converting them into equivalent repetitions of a standard axle using equivalent axle-load factors.

#### 5.4.2.2 Road capacity

Wheel Road capacity is the ability of a road to carry traffic under given circumstances. It is determined by the maximum number of vehicles which can be expected reasonably to pass a given point per hour. Table 5.12 details the capacity of each selected road for the study.

### Table 5.12: Road capacity

| Road capacity (PCU) | | | | | | |
|---|---|---|---|---|---|---|
| **Road** | **Direction** | **Average daily PCU** | **AM peak hour** | **PM peak hour** | **Off-peak traffic** | **Capacity** |
| **1. Nelson Mandela Drive** | WEST BOUND | **7 711** | 1377 | 1327 | 5 007 | 9 015 |
| **2. Zastron Street** | EAST BOUND | **9 805** | 1915 | 1635 | 6 255 | 9 015 |
| **3. Meadows Road** | NORTH BOUND | **547** | 91 | 79 | 377 | 5 891 |
| | SOUTH BOUND | **632** | 72 | 110 | 450 | |
| **4. Dewetsdorp Road** | NORTH BOUND | **2 976** | 392 | 571 | 2 013 | 5 891 |
| | SOUTH BOUND | **2 617** | 478 | 402 | 1 737 | |
| **5. Church Street** | NORTH BOUND | **6 750** | 220 | 1174 | 5 356 | 5 891 |
| | SOUTH BOUND | **7 770** | 1083 | 1289 | 5 398 | |
| **6. M10 Street** | NORTH BOUND | **8 763** | 1551 | 1513 | 5 699 | 5 891 |
| | SOUTH BOUND | **12 740** | 3480 | 1592 | 7 668 | |
| **7. Moshoeshoe Street** | NORTH BOUND | **7 572** | 1087 | 1230 | 5 255 | 5 891 |
| | SOUTH BOUND | **7 923** | 801 | 1685 | 5 437 | |
| **8. Walter Sisulu Road** | EAST BOUND | **6 357** | 1173 | 874 | 4 310 | 5 891 |
| | WEST BOUND | **4 371** | 485 | 1043 | 2 843 | |
| **9. N1 to Bloemfontein** | SOUTH BOUND | **9 403** | 1331 | 1327 | 6 745 | 5 891 |
| | NORTH BOUND | **9 144** | 1360 | 1320 | 6 464 | |
| **10. N8 to Bloemfontein** | WEST BOUND | **12 358** | 1598 | 2143 | 8 617 | 5 891 |
| | EAST BOUND | **11 518** | 1687 | 1717 | 8 114 | |

Traffic capacity helps to indicate whether a particular road section is able to carry the amount of traffic and expected magnitude of traffic load. The tables above showed the expected capacity of the roads in comparison with the actual capacity of the roads as imposed by the current traffic volumes. Nelson Mandela Drive, Zastron Street, N1 and N8 reflected relatively higher levels of traffic capacity than the other internal streets. However, the traffic capacity of roads such as the M10, which were designed with higher expected traffic capacity, was limited in practice by the relatively slow traffic flow caused by the deterioration of the road, which affected the free flow speed and, ultimately, the road capacity.

#### 5.4.2.3 Traffic Wheel Load

As recorded in Table 5.13, wheel load in the case-study area was relatively lower on more than 70% of the roads. This meant that it would be necessary soon to increase the capacity of 70% of the roads to carry and meet the required demand of traffic in the city. This might be done by expanding the current traffic lanes by means of extensions.

**Table 5.13: Wheel load**

| Wheel Load | | | | | | |
|---|---|---|---|---|---|---|
| **Road** | **Direction** | **Vehicles (CPU)** | **Wheel load per vehicle (lb)** | **Capacity wheel load** | **Actual wheel load** | **Remarks** |
| **1. Nelson Mandela Drive** | WEST BOUND | **7 711** | 0.0337 | 305 | 274 | Wheel load lower than capacity by 15% |
| **2. Zastron Street** | EAST BOUND | **9 805** | 0.0880 | 305 | 330 | Wheel load higher than capacity by 8% |
| **3. Meadows Road** | NORTH BOUND | **547** | $8.5 \times 10^{-7}$ | 200 | 19 | Wheel load lower than capacity by 90% |
| | SOUTH BOUND | **632** | $1.52 \times 10^{-6}$ | 200 | 22 | |
| **4. Dewetsdorp Road** | NORTH BOUND | **2 976** | $7.472 \times 10^{-4}$ | 200 | 188 | Actual wheel load lower than capacity by 50% |
| | SOUTH BOUND | **2 617** | $4.468 \times 10^{-4}$ | 200 | 137 | |
| **5. Church Street** | NORTH BOUND | **6 750** | 0.01978 | 200 | 233 | Actual wheel load higher than capacity by 19% |
| | SOUTH BOUND | **7 770** | 0.0347 | 200 | 262 | |
| **6. M10 Street** | NORTH BOUND | **8 763** | 0.01562 | 200 | 295 | Actual wheel load higher |

| | | | | | | |
|---|---|---|---|---|---|---|
| | SOUTH BOUND | **12 740** | 0.251 | 200 | 430 | than capacity by 45% |
| **7. Moshoeshoe Street** | NORTH BOUND | **7 572** | 0.0313 | 200 | 255 | Actual wheel load higher than capacity by 24% |
| | SOUTH BOUND | **7 923** | 0.0375 | 200 | 268 | |
| **8. Walter Sisulu Road** | EAST BOUND | **6 357** | 0.01556 | 200 | 215 | Actual wheel load lower than capacity by 9.5% |
| | WEST BOUND | **4 371** | 0.00348 | 200 | 147 | |
| **9. N1 to Bloemfontei n** | SOUTH BOUND | **9 403** | 0.0745 | 305 | 318 | Actual wheel load higher than capacity by 2.5% |
| | NORTH BOUND | **9 144** | 0.0666 | 305 | 308 | |
| **10. N8 to Bloemfontei n** | WEST BOUND | **12 358** | 0.2222 | 305 | 417 | Actual wheel load higher than capacity by 24% |
| | EAST BOUND | **11 518** | 0.1677 | 305 | 388 | |

## 5.5 POTHOLE SCENARIO

### 5.5.1 Quantity of Potholes

Physical assessment was conducted on roads that were selected in no particular order, to calculate an average number of potholes on any given section of road. The results are recorded in Table 5.14:

**Table 5.14: Average number of potholes on selected roads in Bloemfontein**

| **Average Number of potholes (per km)** | | |
|---|---|---|
| **Road** | **Average degree** | **Average No. of potholes (per km)** |
| **Nelson Mandela Drive** | 1 | 6 |
| **Zastron Street** | 1 | 7 |
| **Gladstone Road** | 3 | 13 |
| **Bergstraat Street** | 3 | 42 |
| **Markgraff Street** | 0 | 2 |
| **Meadows Road** | 1 | 3 |
| **Dewetsdorp Road** | 3 | > 100 |
| **M10 Road** | 3 | > 100 |
| **Church Street** | 3 | > 100 |

| | | |
|---|---|---|
| **Moshoeshoe Street** | 1 | > 100 |
| **Robert Burns Street** | 5 | 11 |
| **N8** | 1 | 6 |
| **N1** | 0 | 1 |

### 5.5.2 Types of Potholes

The various types of potholes on selected roads in Bloemfontein City is detailed in section 3.7 under Challenges of Potholes in chapter 3, (see Table 3.4). Potholes are classified according to their degree and extent, as described in TMH (1998):

**Degree**: The degree of a particular type of distress is a measure of its severity (see table 5.15), indicated by a number where:
Degree 1: indicates the first evidence of a particular type of distress (slight);
Degree 3: indicates a warning (requires attention);
Degree 5: indicates the worst-case degree (severe).

**Table 5.15: Degree and severity of potholes**

| Degree | Severity | Description |
|---|---|---|
| 0 | | No distress visible. |
| 1 | Slight | Distress difficult to discern, Only the first signs of distress are visible. |
| 2 | Between slight and warning | |
| 3 | Warning | Distress is distinct. Start of secondary defects. Distress noticeable with possible consequences. Maintenance might be required in near future e.g. sealing of cracks |
| 4 | Between warning and severe | |
| 5 | Severe | Distress is extreme. Secondary defects are well developed (high degree of secondary defects) and/or extreme severity of primary defect (Urgent attention required). |

### 5.5.3 Historic Pothole Scenario (Frequency of Occurrence)

The figures presented on Table 5.16 were calculated and affected by various external factors such as weather, traffic volume and type. However, the figures in Table 5.16, showing the frequency of pothole occurrence, were projected over a period of four weeks (a month) with the assumption that all factors would remain the same in terms of rainfall and the volume and type of traffic. This would be the situation on the roads selected for examination based on data from the municipality's historic records.

**Table 5.16: Average frequency of potholes in Bloemfontein City**

| Average frequency of potholes (per km) | | | | | | |
|---|---|---|---|---|---|---|
| **Road** | **Average degree** | **Average no. of potholes (per km) in a week, after maintenance** | | | | |
| | | **Week 1** | **Week 2** | **Week 3** | **Week 4** |
| **Nelson Mandela Drive** | 1 | 0 | 1 | 1 | 2 |
| **Zastron Street** | 1 | 0 | 0 | 1 | 1 |
| **Gladstone Road** | 3 | 0 | 1 | 2 | 2 |
| **Bergstraat Street** | 3 | 2 | 3 | 4 | 4 |
| **Markgraff Street** | 0 | 0 | 0 | 0 | 1 |
| **Meadows Road** | 1 | 0 | 0 | 0 | 1 |
| **Dewetsdorp Road** | 3 | 2 | 3 | 5 | 7 |
| **M10 Road** | 3 | 3 | 4 | 6 | 10 |
| **Church Street** | 3 | 1 | 1 | 3 | 3 |
| **Moshoeshoe Street** | 1 | 0 | 0 | 2 | 2 |
| **Robert Burns Street** | 5 | 0 | 1 | 1 | 3 |
| **N8** | 1 | 0 | 0 | 2 | 3 |
| **N1** | 0 | 0 | 0 | 1 | 1 |

The projected outcomes shown in the table above correlated with the structural quality and condition of the roads. It was evident from the projections that the roads which had serious structural failures would continue to develop more potholes, faster over the period of a month.

### 5.5.4 Pothole Repair Strategies Used in Mangaung, Free State

The Roads and Storm Water Division of Mangaung Municipality had a pavement management system (PMS) which was used mainly to assess the structures of different roads and road sections in and around Mangaung. From the assessments the division was able to identify what types of problems were associated with particular roads and which of the problems were associated with the formation of potholes. This helped in prescribing the appropriate methods of maintenance (Mangaung Metro Archives, 2016)

The Mangaung Municipality, Roads and Storm Water Division then assign its Roads Maintenance Office to patch and repair the damage after they had finalised their pothole assessment and classification. A consulting company would then be appointed and the maintenance of the roads would be carried out by contractors or sub-contractors (Mangaung Metro Archives, 2016). Table 5.17 details the Mangaung statistics on pothole development and turn around period for maintenance.

**Table 5.17: Pothole maintenance in Mangaung**

| **Mangaung statistics** | |
|---|---|
| Complaints per week | 18 |
| Average porthole area reported per week | $200m^2$ |
| Response turn-around time | 2 days |
| Complaints attended to per week | 70% – 80% |
| Major causes of potholes | Storm water |

*Source: (Mangaung Metropolitan Municipality, 2017- 2019)*

The following standard equipment was used for maintenance in Mangaung Municipality (Mangaung Metropolitan Municipality, 2017- 2019):

- Asphalt cutting machine x1;
- Pedestrian roller x1;
- Shovels, picks and rakes;
- Jack hammer.

The following material was used (Mangaung Metropolitan Municipality, 2017- 2019):

- Emulsion (SS60);
- Medium grade, hot-mix asphalt;
- Cold-mix asphalt;

The following preparation method and procedure were followed:

- Inspection by road superintendent to determine the extent of damage and mark the area to prepare for maintenance;

- Pothole cutting;
- Base preparation (repairs to affected pavement layers using gravel material);
- Compaction of base layer and application of emulsion;
- Asphalt levelling and compaction.

## 5.6 RECURRING POTHOLES

Recurring potholes are those that develop after maintenance has been carried out on the road sections with potholes. In this study it was found that potholes recurred mostly within 3 months, depending on the type of road and traffic conditions. The factors causing recurring potholes included: the use of unsuitable material, the technique applied during maintenance, and heavy traffic volume and load immediately after the repairs. Table 5.18 shows the recurrence of potholes compared with how often roads were repaired.

**Table 5.18: Potholes recurring after maintenance in Bloemfontein**

| Roads | PMF | TM | AM | TM | RP (km) | Remarks |
|---|---|---|---|---|---|---|
| **1. Nelson Mandela Drive** | Every year | Routine | Every year | Periodic | 6 | Different maintenance as and when potholes emerge. |
| **2. Zastron Street** | Every year | Routine | Every year | Periodic | 7 | Only maintained when defects surface. |
| **3. Meadows Road** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 13 | Only attended to when there are defects. |
| **4. Dewetsdorp Road** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 20 | Only attended to when there are defects. |
| **5. Church Street** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | >100 | Only attended to when there are defects. |
| **6. M10 Street** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | >100 | Only attended to when there are defects. |
| **7. Moshoeshoe Street** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 8 | Only attended to when there are defects. |

| | | | | | | |
|---|---|---|---|---|---|---|
| **8. Walter Sisulu Road** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 0 | Only attended to when there are defects. |
| **9. N1 to Bloemfontei n** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 4 | Only attended to when there are defects. |
| **10. N8 to Bloemfontei n** | Every year | Routine. Rehab. after 20 years | After 2 years | Periodic | 8 | Only attended to when there are defects. |

**Key**: PMF = Prescribed Maintenance Frequency
TM = Type of Maintenance
AM = Actual Maintenance
RP = Number of Recurring Potholes

## 5.7 RELATIONSHIP BETWEEN POTHOLE FORMATION AND CAUSAL FACTORS

The formation of potholes in the roads selected for this case study in Bloemfontein was caused mainly by: traffic volume, wheel load, traffic speed, road-paving layer design (thickness), calculation tables are presented in Appendix D. Correlation coefficients were determined to evaluate the level and intensity of association of these factors with the actual development of potholes as follows.

### 5.7.1 Correlation between Potholes and Road Traffic-Related Variables

Correlation is the degree of association between two variables. A correlation coefficient between potholes and wheel load would assist in understanding the rate of pothole formation in relation to traffic volume, layer thickness, traffic speed and wheel load. Assuming the quality of material to be the same the relationship between these variables was determined and projected using the correlation coefficient (see Table 5.19).

**Table 5.19: Correlation coefficient of traffic-related variables and formation of potholes in Bloemfontein**

| Corelation coefficient for all factors | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CALCULATED CORRELATION COEFFICIENT OF THE VARIABLE FACTORS | | | | | | | | | | | | |
| ROAD | Traffic Volume | | | Layer Thickness | | | Traffic Speed | | | Wheel Load | | |
| | Traffic Volume (x) | Average Potholes per km (y) | Coefficient | Layer Thickness (x) | Average Potholes per km (y) | Coefficient | Traffic Speed (x) | Average Potholes per km (y) | Coefficient | Wheel Load (x) | Average Potholes per km (y) | Coefficient |
| 1. Dewetsdorp Rd | 17 593 | 127 | | 510 | 127 | | 60 | 127 | | 88 | 127 | |
| 2. M10 Road | 21 501 | 138 | | 685 | 138 | | 100 | 138 | | 725 | 138 | |
| 3. Church Street | 14 520 | 104 | 0,95 | 540 | 104 | 0,59 | 80 | 104 | 0,170 | 492 | 104 | 0,80 |
| 4. Moshoeshoe St | 15 495 | 128 | | 480 | 128 | | 40 | 128 | | 523 | 128 | |
| 5. Nelson Mandela Drive | 7 117 | 42 | | 740 | 42 | | 80 | 42 | | 260 | 42 | |

### 5.7.2 Multi-collinearity and Variance Inflation Factor.

#### a) Multi-collinearity

Multi-collinearity exists when there is a linear relationship or correlation between one or more of the independent variables or inputs. Multi-collinearity creates a problem in multiple regression if the inputs all influence each other, because they are not actually independent, which makes it difficult to test the extent to which the combination of variables affects the dependent variable or outcome within the model.

#### b) Variance Inflation Factor, VIF

$$VIF = \frac{1}{1-R^2} \quad \text{.......................................................................Equation 6}$$

**Where:** VIF = Variation Inflation Factor

R = Regression Value

VIF is the measure of the extent of multi-collinearity in a set of multiple regression variables. It is used to test the effects of multiple variables on a particular outcome. The dependent variable is the outcome that is affected by the independent variables, which are the inputs into the model. Table 5.20 depicts the variation inflation factor (VIF) between the four main causal factors and formation of potholes.

**Table 5.20: Variation Inflation Factor**

| VARIANCE INFLATION FACTOR, VIF = $\frac{1}{1-R^2}$ | | | | OUTCOME |
|---|---|---|---|---|
| **Variables** | **Potholes** | | | **Correlation Effect** |
| | **Correlation Coefficient, r** | $R^2$ | **VIF** | |
| | | | | |
| **Traffic Volume** | 0,95 | 0,898 | 0,102 | Very High |
| **Layer Thickness** | 0,59 | 0,344 | 0,656 | High |
| **Traffic Speed** | 0,17 | 0,028 | 0,972 | Low |
| **Wheel Load** | 0,80 | 0,647 | 0,353 | Very High |

### 5.7.3 Correlation Between Important Variables and Pothole Formation

#### a) Potholes and traffic volume

It was found that traffic volume had a direct relation with the formation of potholes. The correlation coefficient showed a significant value of 0,82. This meant that, for every increase in traffic volume, there was **a strong, positive** degree of association of 0,95 or 95% as shown in Table 5.22.

The linear regression graph (see figure 5.9) also showed that, for any given amount of traffic volume, the number of potholes was multiplied by 0.007, also indicating a strong, positive relationship. The relationship was linear and represented by Equation 7:

$$y = 0{,}007x - 1{,}424$$ **Equation 7**

Where:

Y = number of potholes

X = the given traffic volume

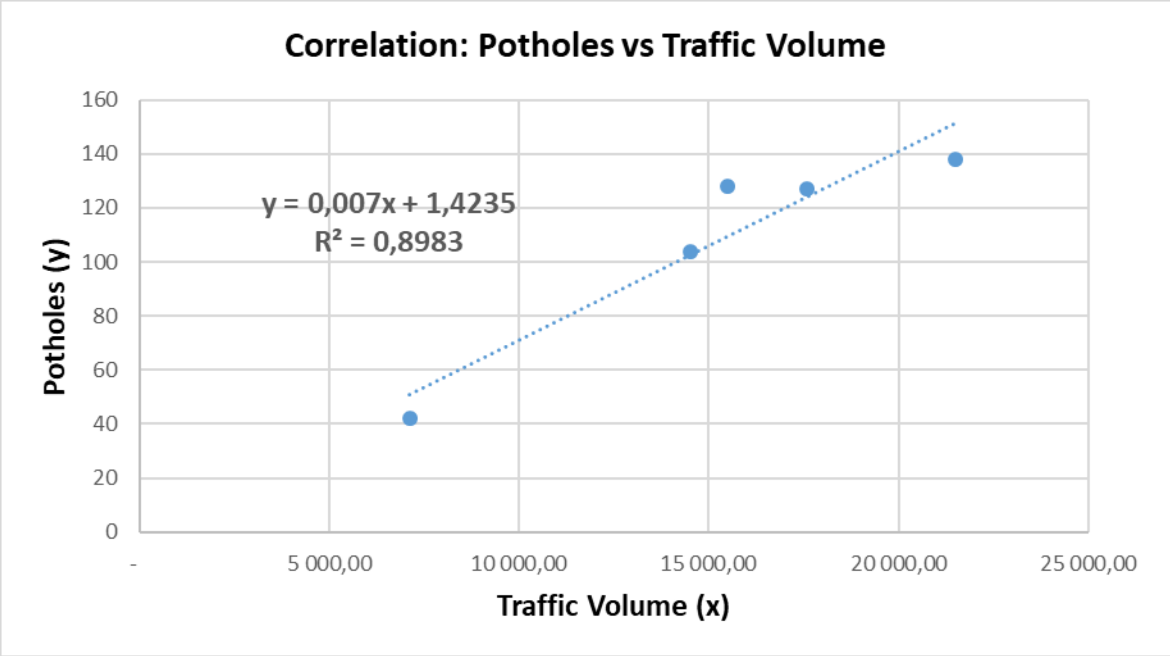



**Figure 5.9: Linear regression: Potholes vs Traffic Volume**

The study showed that there was a strong positive association between traffic volumes and the formation of potholes. The correlation coefficient was 0,95, which meant there was 95% chance of pothole formation with every increase in traffic volume on the same road section.

**b) Potholes and layer thickness**

It was found that layer thickness had a direct relation with the formation of potholes. Although the correlation coefficient was small, it was a significant coefficient. This meant that, for every increase in layer thickness, there was a 0,59 rate of reduction in the formation of potholes, as recorded in Table 5.22.

The linear regression graph (see figure 5.10) also showed that, for any given amount of layer thickness, the number of potholes was reduced by 0.223, indicating a negative relationship. The relationship was linear and represented by Equation 8:

$$y = -0{,}223x + 241{,}95 \qquad \textbf{Equation 8}$$

Where:

Y = number of potholes

X = the given layer thickness

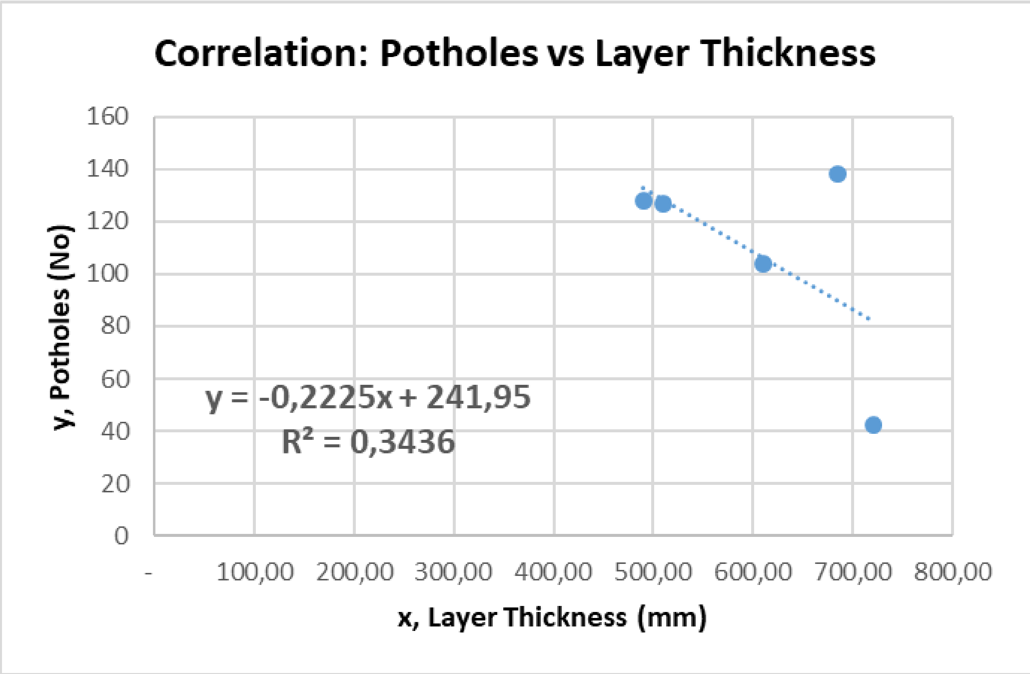



**Figure 5.10: Linear regression: Potholes vs Layer Thickness**

Layer thickness has a negative correlation coefficient of 0,59 in relation to the formation of potholes. This means that for each increase in the thickness of the road-paving layers, the formation of potholes was likely to be reduced by 59%

### c) Potholes and traffic speed

It was found that traffic speed had a direct relation with the formation of potholes. Although the correlation coefficient was small, it was significant. This meant that, for every increase in traffic speed, the formation of potholes was likely to increase by a rate of 0,170, as shown on Table 5.22.

The linear regression graph (see figure 5.11) also showed that, for any given amount of traffic speed, the number of potholes was multiplied by 0,283, indicating a positive relationship. The relationship was linear and represented by Equation 9:

$$y = -0{,}283x + 128{,}15 \quad \textbf{Equation 9}$$

Where:

Y = number of potholes

X = the given traffic speed

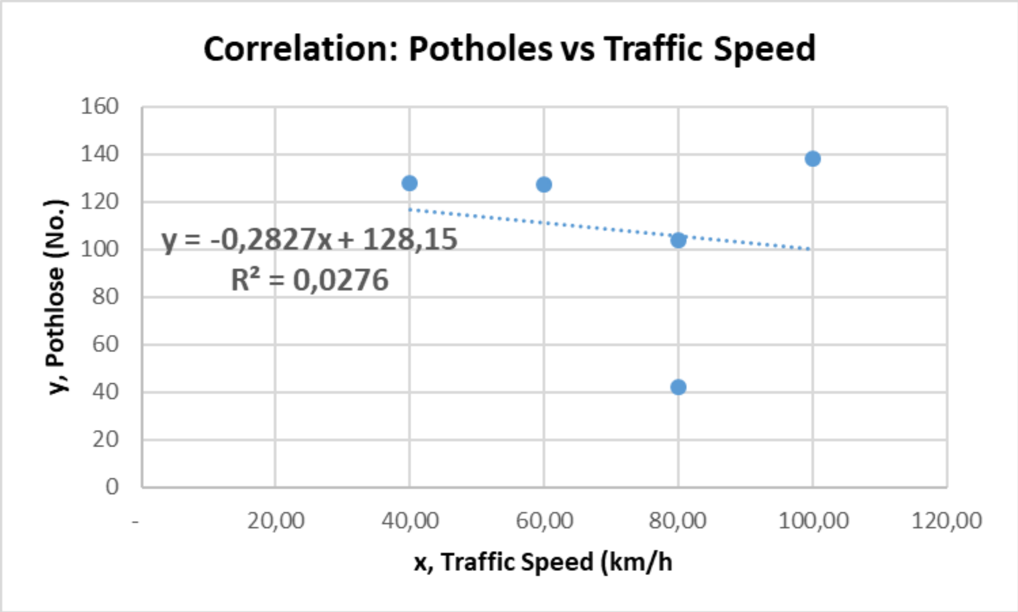



**Figure 5.11: Linear regression: Potholes vs Traffic Speed**

Traffic speed showed a positive correlation of 17%, which meant there was a small chance of pothole formation related to traffic speed.

### d) Potholes and wheel load

It was found that wheel load had a direct relation with the formation of potholes. The correlation coefficient showed a significant value of 0,80. This meant that, for every increase in wheel load, there was **a strong, positive** degree of association of 0.80 or 80%, in Table 5.22.

The linear regression graph (see figure 5.12) also showed that, for any given amount of wheel load, the number of potholes was multiplied by 0.142, indicating a strong, positive relationship. The relationship was linear and represented by Equation 10:

$$y = 0{,}142x + 44{,}738$$ **Equation 10.**

Where

Y = number of potholes

X = the given wheel load

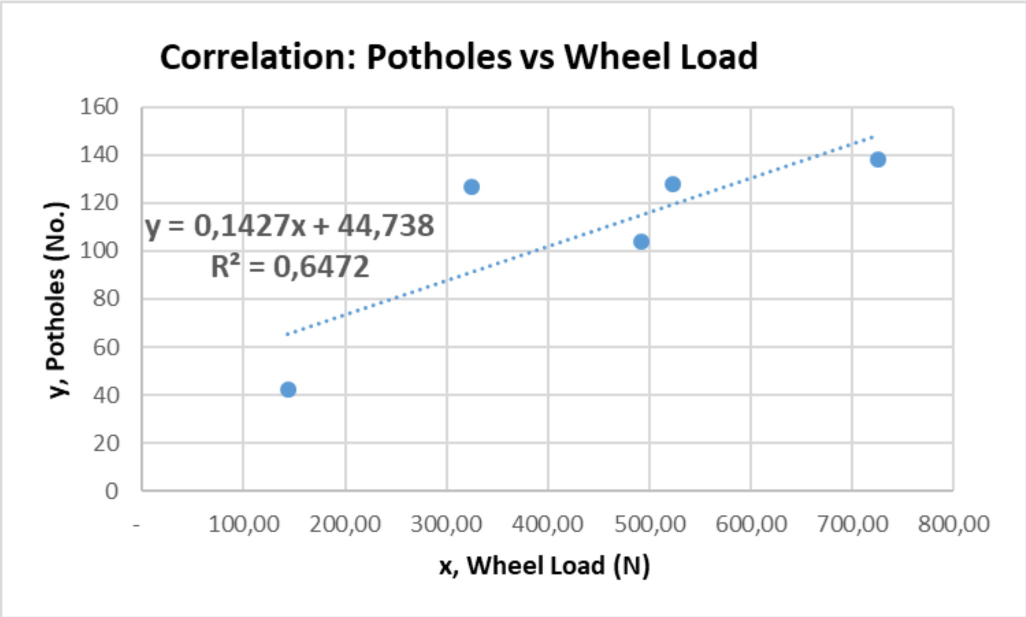



**Figure 5.12: Linear regression: Potholes vs wheel load**

The study showed that there was a strong, positive relation between potholes and wheel loads, associated mainly with heavy vehicles. The correlation coefficient of 0.80 meant there was an 80% chance of pothole formation with every increase in wheel loads on the same section of road.

### 5.7.4 Other Factors Influencing Pothole Formation

**a) Soil conditions**

Geo-technical soil assessments should be undertaken to examine the effect of soil conditions on the infrastructure of the city's road networks.

**b) Weather conditions**

The weather conditions in Bloemfontein are highly variable. The temperatures become very high during the summer season and very low during the winter season. This variation can cause serious instability in the strength and durability of the road structures in the city.

**c) Drainage**

The drainage system in Bloemfontein should be assessed and evaluated, defects identified and maintenance monitored closely to prevent blockages and failures that might occur otherwise.

**d) Moisture**

Moisture content embedded in the road-paving layers also might have detrimental effects on the road structure itself. It might be necessary to assess the moisture contained in the road structural layers to determine the amount of moisture and how long it has been present.

Higher moisture content might be undesirable, particularly when it is present for longer than appropriate. Low moisture content also can lead to structural deterioration, as layers which stay too dry for too long might lead to substantial structural failures.

**e) Workmanship**

High-quality workmanship is critical in construction, even without supervision. The quality of construction depends greatly on the type of skill applied and how it is applied during the construction. Qualifications, experience, knowledge and skills must sought after and applied correctly to ensure high standards to enhance quality and durability.

**f) Material used**

High-quality material must be used in the construction of roads with hands-on supervision and testing that ensures the required quality standards are achieved. It is important to determine and adhere to appropriate mix designs.

## 5.8 DISCUSSION

The findings of the field research showed: the quantity of potholes in the selected roads; the existing road conditions; and their impact on further formation of potholes. Also from the research, the factors the contributed to potholes were identified in relation to the road conditions and maintenance strategy applied by the Mangaung Municipality (Mangaung Metropolitan Municipality, 2017- 2019). During the study, the designs undertaken to construct the roads were examined, particularly the road-paving designs which were shown to have a direct impact on the durability of the road structure and its ultimate deterioration (Mangaung, 2010). In addition, the maintenance strategy was considered in relation to the historic maintenance background, existing methods, material used, frequency of maintenance and its efficiency.

Furthermore, questionnaires were used in the study to obtain public opinion about: how road users were affected by potholes, what they thought might cause the formation of potholes and what they thought should be done (Mangaung Metropolitan Municipality, 2017- 2019). The questionnaires were extended also to people with technical knowledge and experience to obtain technical engineering insight into what the causes were, whether the existing maintenance strategy was working and what suggestions they might have to improve the efficiency and effectiveness of maintenance and pothole repair in the city (Toba, *et al*., 2015).

### 5.8.1 Road Conditions

Assessments of the condition of the 10 sampled roads within the city were conducted. Some roads showed advanced deterioration and poor conditions while some were still in fair condition. Various methods were used to assess the road conditions ranging from the number of potholes found on a particular road to identification of cracks, rutting, and bleeding (TMH, 1998). Some of these factors were inter-related, for example, more cracks in a road section might eventually result in the formation of potholes.

Analysis of road conditions assisted in understanding the regular maintenance of the roads and its efficiency. This also showed the relationship between the time taken to attend to potholes and the expansion or emergence of new potholes (Mangaung Metropolitan Municipality, 2017- 2019). Findings reveal that roads in poor condition that were not maintained frequently had a relatively higher rate of pothole development than those that were maintained frequently. Major roads such as Nelson Mandela Drive, or national roads appeared to receive more attention than minor access roads such as Moshoeshoe Street.

### 5.8.2 Causes of Potholes

The study findings have shown a great correlation between the formation of potholes and poor drainage, poor maintenance, traffic load, poor pavement design in the form of low layer thickness. This was mainly revealed by the correlation coefficient calculations in agreement with questionnaire outcomes. The findings of this study contain similar findings as those of (Paige-Green, 2012) and (Fetch, 2011) which revealed that amongst other factors, potholes are caused by ingress of water, on cracked road surfaces, into the underlying layers of the road structure such as the base or sub-base. Factors that influence such processes include the thickness and poor strength of the layers of the road structure, high traffic volumes, poor drainage systems, heavy traffic, forces exerted by traffic during acceleration especially on turning sections, such as road intersections and bus bays, where high deterioration rates and formation of potholes can be observed readily.

Bloemfontein City proved to have been subjected to similar several factors which contributed considerably to the formation of potholes Data collected from the questionnaires and public interviews, particularly from the technical questionnaires have also revealed a strong correlation between the formation and recur of potholes with the same above factors. At least 70% the experienced technical people interviewed have all indicated that sections which were poorly designed deteriorated faster, especially under heavier traffic loads and high volumes. They have also mentioned that poor drainage systems have showed to be a major factor of deterioration as some road surfaces quickly absorb the ponding running water and ultimately resulting structural failure and pothole formation.

### 5.8.3 Maintenance Strategy

The maintenance strategy in the Mangaung Municipality, as examined in Section 5.5.4, was based on the Pavement Management System used to assess the structural conditions of roads and apply appropriate mechanisms to address the problems identified (COLTO, 1998). There were three main methods used to repair potholes in Bloemfontein City: hot-mix asphalt, cold-mix asphalt and bitumen treated base (BTB) material. Hot-mix asphalt and cold-mix asphalt methods were used to address the same problems, which were limited to surface repairs, while BTB was used to address base issues of the road structure because of its relatively larger aggregates (see Table 5.21), binder content and voids percentage (Mangaung Metropolitan Municipality, 2017- 2019)

**Table 5.21: Comparison of HMA/CMA and BTB functionality**

| USING HMA/CMA | USING BTB |
|---|---|
| Composed of fine aggregates | Composed of larger aggregates |
| Has higher binder content | Relatively low binder content |
| Small voids percentage | High voids percentage |
| To repair the surface of the road structure | To repair the base and surface of the road structure |
| More flexible but subject to rutting | Relatively more rigid than HMA with longer durability |

Using BTB to repair potholes appeared to have become a more popular option to HMA and CMA in the city, particularly on sections where the structure has failed from the base level, which was often the case (Department of Transport SA, 2006). Road sections repaired with BTB tend to have more durability than those corrected with HMA, but methods are not ideally sustainable.

## 5.9 CONCLUSION

For this study, data collection was carried out by using questionnaires personally administered to the relevant staff in the four towns that make up Mangaung Local Municipality (Bloemfontein). This was support by a literature review of various journals, reports and records in various data-bases.

The correlation coefficient that was calculated showed a significant degree of association between the formation of potholes and traffic volume, layer thickness, traffic speed and wheel load, with coefficients of 0.95, 0.59, 0.17 and 0.80 respectively. This meant that there was a significant degree of association between traffic volume, wheel load and the formation of potholes, compared with the other parameters considered in assessing the factors that cause potholes.

# CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

## 6.1 CONCLUSION

The purpose of this study was to address the research problem of the formation of potholes on the roads in Bloemfontein City, and their recurrence after maintenance. It was the aim of this research to examine the causes of the re-occurrence of potholes in the city and to propose engineering solutions to resolve the problem.

The objectives of the study were to: examine the causes of potholes in the city; examine the existing maintenance strategies in use; determine the correlation between existing road and traffic variables, such as wheel loads, traffic speed, layer thickness, traffic volume and other external factors, such as drainage systems and other related, environmental factors, on the city's roads and their effects on the formation of potholes.

An ontological, positivist approach was adopted to conduct the research. The methodology included data collection using questionnaires, physical road assessments and site visits, a traffic survey, consultations and direct conferences. A field study was conducted also to assess the effectiveness of one of the maintenance strategies used by the Department of Police and Transport in the city.

The findings of the research showed the main causes of potholes based on the literature review study, public responses to questionnaires, as well as experiments conducted on site. Overall, the outcomes had in common three main causes of recurring potholes in Bloemfontein City: 1) Traffic volume and heavy loads which, according to the public's observations contributed, approximately 25% to road infrastructure deterioration in the city; 2) Storm water resulting from poor drainage; and 3) Poor maintenance of roads in general which contributed 15%. The poor maintenance of roads would include, amongst other factors, poor management, poor material, and application of inappropriate or less effective technology, based on the responses to the questionnaire study, supported by the findings of the literature review.

The first approach to finding a solution would be to address the issues raised that were not addressed by the existing techniques and means utilised in the industry. Answering the questions to the causes of potholes, as diagnosed in the study, would lead to better and more efficient means of addressing the problem.

## 6.2 STUDY LIMITATIONS

This research project was a challenging undertaking. The researcher was confronted with various obstructions during the research in the study area chosen, both on the ground and during electronic data collection. The limitations of the research included the following:

- Confidential information relevant to the study was withheld by road authorities.
- Responses to the questionnaires were mostly from people who had time and/ or interest.
- Technical people and experienced labourers were required to conduct the experiment on site.
- Field studies were carried out by appointment, as planned by project managers, using materials and techniques of their choice.
- Laboratory fees for extensive road-paving investigations were expensive.

## 6.3 RECOMMENDATIONS

### 6.3.1 Traffic Volumes

Particularly during peak hours, 60% of the roads in Bloemfontein, connected to the city centre, have very high traffic volumes. It was necessary to rehabilitate roads with large traffic volumes in the city, which in some instances exceeded the roadway capacity, for the purpose of expansion to increase road capacity. This should be done using a systematic engineering process, for which traffic volumes must be known and projected to ensure road capacity efficiency and durability for a duration of at least 25 years.

### 6.3.2 Layer Thickness

Some roads in Bloemfontein City, such as Church Street, were found to have insufficient layer thickness. Minimum layer thickness must be prescribed by the road custodians according to traffic needs, before road-paving design and be adhered to. The layer thickness of roads should be thoroughly investigated, well designed and constructed according to specification, without compromising the material aspects of the design and construction methods on roads which show insufficient road thickness and stability. Laboratory tests must be conducted to verify the road thickness as well as the material used during construction.

### 6.3.3 Wheel Load

The findings of the study showed that some roads in the city carried heavy traffic loads that were not planned for in the initial road-paving design. Road authorities should review the road-paving designs, well informed by the traffic conditions at the time with relevant projections. Details of road structure design must be followed, guided completely by the actual weight and traffic volumes to which the city's roads will be exposed. Projections of future traffic volumes and traffic wheel loads must be examined and factored into the road design effectively.

### 6.3.4 Soil Conditions

Geo-technical aspects must always be included in designs, to ensure the use of the most suitable material during the design and construction of road structures in and around the city. Some of the potholes on the city roads were the result of using unsuitable, *in situ* material affected by the soil conditions on which they were situated. Geo-technical investigations must be conducted thoroughly to inform appropriate remedial actions to enhance the soil stability in order to support durable road-paving design.

### 6.3.5 Material

Hot- and cold-mix asphalt was used to repair 80% of potholes the roads in Bloemfontein, while only 15% of the roads have been repaired using BTB, mostly by the Department of Police, Roads and Transport. BTB appears to be more effective where base deterioration is the main cause of the pothole formation, since BTB is used to address the base of the road structure. It might be necessary to use BTB more often in addressing such situations rather than hot-mix asphalt which is used only to repair the surface of the road structure. Road authorities must experiment the use of new materials from other countries as they are developed.

### 6.3.6 Technology used

Technology used for road repairs in Bloemfontein should be examined and improved where possible to prevent constant failures in the road structures. Tests for new, developing technologies from other countries must be encouraged.

### 6.3.7 Recommendations Based on Study Objectives

Table 6.1 summarises the recommendations informed by the study findings based on the initiated objectives.

**Table 6.1: Recommendations informed by research objectives**

| Objective | Recommendation |
|---|---|
| a) Assess potholes in terms of degree and extent of their occurrence on roads of Bloemfontein. | • The degree and extent damage on the road must be accurately determined according to TMH9.<br>• The damage extent on the roads must be assessed and classified accordingly to gain an insight on the type and nature of deterioration, in order to prescribe the most suitable maintenance strategy. |
| b) Investigate engineering factors for recurring potholes in the study area | • Investigations must be carried out by professionals with relevant expertise, applying the latest technology and methods.<br>• Drainage capacity of the roads must be assessed and maintained frequently and also be enhanced for efficiency whenever necessary. |
| c) Evaluate the impact of pavement design technology and construction applicable on the city road structure. | • Road pavement design must be investigated and evaluated fully, using pit holes, accurate identification of layer materials and their thickness.<br>• Layer thickness and material used in previous design might need to be revised and improved if they are outdated. |
| d) Examine suitability of engineering methods and maintenance strategies adopted for the repair of potholes and maintenance of roads. | • Resources for laboratory tests and experiments must be estimated accurately and allocated according to the extent of investigation that must be carried out.<br>• More experiments should be developed by engineering units from respective stakeholders, such as municipalities, to assist in obtaining appropriate and realistic results.<br>• Both internal and external factors that contribute to the formation of potholes i.e. base failure, drainage and heavy loads must be investigated separately to prescribe a suitable remedy. |
| e) Determine the correlation strength between the formation of potholes and the examined cause factors. | • Where a strong correlation exists between pothole formation and any given factor, as is the case with traffic volume, the road authorities must develop a long-term plan to manage the traffic volume and protect the roads from continuous deterioration.<br>• Where a strong correlation exists as is the case between layer thickness, wheel load and pothole formation, it might be necessary for the road authorities to revise the existing road-paving design and construction technology. |

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# APPENDICES

## APPENDIX A: Public Questionnaires

### Table: A.1: Completed Public Questionnaire Template

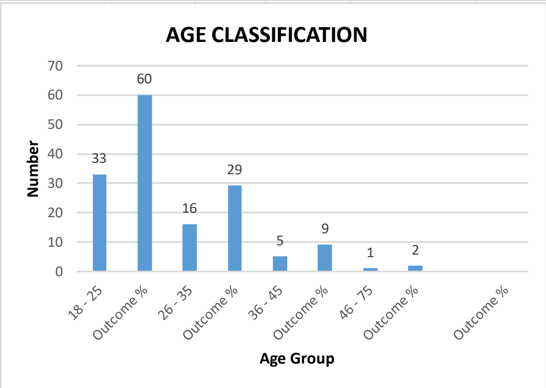
| Questionnaire number | Profession | Institution | Years of experience | Government authority | Main cause of pothole due to initial construction techniques | Bloemfontein roads have sufficient drainage systems | Construction methods applied on road construction produce the best quality | Technology applied in repairing potholes is advanced enough | Quality of material used for pothole maintenance is adequate | Major causes of recurring potholes in Bloemfontein | Solution to sustainable repair of recurring potholes in Bloemfontein | Tests methods to be conducted during pothole repairs | Challenges faced as government official in pothole repairs | Recommended improvement | General technical Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Engineer | DoR | 10 | Yes | YES | YES | YES | NO | NO | Construction technique | Repair technology | Traffic loads | Alternative maintenance technology | Rehabilitation of roads | Improve drainage |
| 2 | Regional engineer | PRT | 10 | YES | NO | YES | NO | YES | YES | Construction technique | Repair technology | Traffic loads | Allocate budget for maintenance | Rehabilitation of roads | Improve drainage |
| 3 | Chief road supredant | PRT | 25 | YES | NO | NO | NO | NO | NO | Construction technique | Poor drainage | Compaction techniques | Alternative maintenance technology | Materials & compaction tests | Allocate budget for maintenance |
| 4 | Engineer | PRT | 9 | YES | NO | NO | NO | NO | NO | Construction technique | Poor patching | Repair technology | Materials & compaction tests | Allocate budget for maintenance | Rehabilitation of roads |
| 5 | Public relations | UNISA | 3 | 0 | YES | NO | NO | YES | YES | Compaction techniques | Repair technology | Traffic loads | Materials & compaction tests | Allocate budget for maintenance | Rehabilitation of roads |
| 6 | Engineer Technician | PRT | 2 | YES | YES | NO | YES | NO | NO | 0 | 0 | 0 | Materials & compaction tests | Allocate budget for maintenance | Improve drainage |

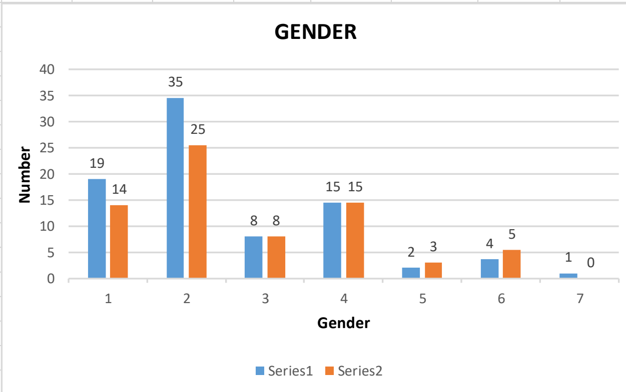
| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Engineer Technician | PRT | 3 | YES | NO | NO | YES | YES | YES | Poor drainage | Compaction techniques | Traffic loads | Alternative maintenance technology | Materials & compaction tests | Improve drainage |
| 8 | Engineer Technician | CUT | 5 | NO | NO | NO | YES | NO | YES | 0 | 0 | Poor patching | Alternative maintenance technology | Materials & compaction tests | Rehabilitation of roads |
| 9 | Engineer Technician | PRT | 10 | YES | YES | NO | NO | NO | YES | Poor drainage | Compaction techniques | Poor patching | 0 | 0 | 0 |
| 10 | Chief Engineer | PRT | 15 | YES | NO | YES | YES | YES | YES | Poor drainage | 0 | 0 | Materials & compaction tests | Rehabilitation of roads | Improve drainage |
| 11 | Engineer | PRT | 15 | YES | NO | NO | NO | NO | NO | Poor drainage | Repair technology | Traffic loads | Materials & compaction tests | Allocate budget for maintenance | Improve drainage |
| 12 | Engineer | PRT | 12 | YES | NO | NO | YES | NO | NO | Poor drainage | Traffic loads | 0 | Materials & compaction tests | Rehabilitation of roads | Improve drainage |
| 13 | Engineer | PRT | 15 | YES | NO | YES | YES | NO | YES | Traffic loads | 0 | 0 | Materials & compaction tests | Rehabilitation of roads | Improve drainage |

# APPENDIX B: Questionnaire Personnel Demographics

## Table B1: Questionnaire Demographics

| APPENDIX B: QUESTIONNAIRE DEMOGRAPHICS | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGE RANGE | | GENDER | | OCCUPATION | | TRANSPORT MODE | | RECURRING POTHOLES IN BFN | | POTHOLES REPAIRED ADEQUATELY | | POTHOLES REPAIR IN TIME | |
| Range | Amount | Male | Female | Category | Amount | CAR | PUBLIC | YES | NO | YES | NO | YES | NO |
| 18 - 25 | 33 | 19 | 14 | Students | 38 | 2 | 31 | 28 | 5 | 2 | 31 | 3 | 30 |
| **Outcome %** | **60** | **35** | **25** | | **69** | **4** | **56** | **51** | **9** | **4** | **56** | **5** | **55** |
| 26 - 35 | 16 | 8 | 8 | Employed F/T | 11 | 4 | 12 | 14 | 2 | 3 | 13 | 1 | 15 |
| **Outcome %** | **29** | **15** | **15** | | **20** | **7** | **22** | **25** | **4** | **5** | **24** | **2** | **27** |
| 36 - 45 | 5 | 2 | 3 | Employed P/T | 2 | 3 | 2 | 4 | 1 | 1 | 4 | 0 | 5 |
| **Outcome %** | **9** | **4** | **5** | | **4** | **5** | **4** | **7** | **2** | **2** | **7** | **0** | **9** |
| 46 - 75 | 1 | 1 | 0 | Self Employed | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| **Outcome %** | **2** | **2** | **0** | | **5** | **2** | **0** | **2** | **0** | **0** | **2** | **0** | **2** |
| | | | | Unemployed | 1 | | | | | | | | |
| Outcome % | | | | | **2** | | | | | | | | |
| **TOTAL (%)** | **100** | **55** | **45** | **0** | **100** | **18** | **82** | **85** | **15** | **11** | **89** | **7** | **93** |




Series 1 = Male
Series 2 = Female

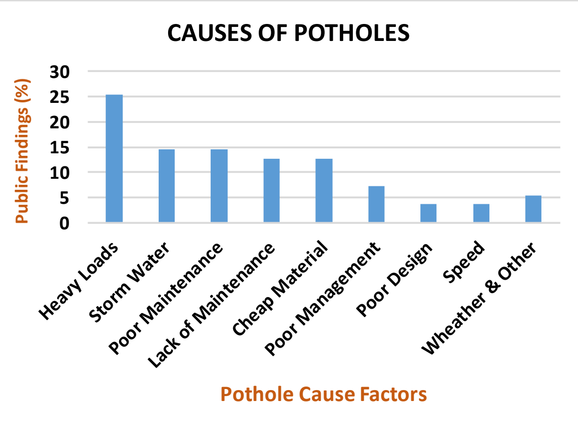
## Figure B.1: Questionnaire Demographics

## APPENDIX C: Questionnaire Outcome

| APPENDIX C1: QUESTIONNAIRE OUTCOME PART 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CAUSES OF POTHOLES** | | | **POTHOLE EFFECT** | | | | | |
| **Type** | **Amount** | **%** | **Type** | **Effet** | | | | |
| | | | | **Low** | **Average** | **High** | **Very High** | **Total** |
| Heavy Loads | 14 | **25** | **Travel Discomfort** | **12** | **5** | **26** | **12** | **55** |
| | | | Percentage Outcome % | 22 | 9 | 47 | 22 | 100 |
| Storm Water | 8 | **15** | **Travel Time loss** | **11** | **7** | **26** | **11** | **55** |
| | | | Percentage Outcome % | 20 | 13 | 47 | 20 | 100 |
| Poor Maintenance | 8 | **15** | **Accident Cases** | **13** | **9** | **28** | **5** | **55** |
| | | | Percentage Outcome % | 24 | 16 | 51 | 9 | 100 |
| Lack of Maintenance | 7 | **13** | **Vehicle Damage** | **6** | **6** | **30** | **13** | **55** |
| | | | Percentage Outcome % | 11 | 11 | 55 | 24 | 100 |
| Cheap Material | 7 | **13** | **Cost of Vehicle Maintenance** | **7** | **6** | **27** | **15** | **55** |
| | | | Percentage Outcome % | 13 | 11 | 49 | 27 | 100 |
| Poor Management | 4 | **7** | **Injuries** | **20** | **17** | **13** | **5** | **55** |
| | | | Percentage Outcome % | 36 | 31 | 24 | 9 | 100 |
| Poor Design | 2 | **4** | **Death Tools** | **33** | **7** | **12** | **3** | **55** |
| | | | Percentage Outcome % | 60 | 13 | 22 | 5 | 100 |
| Speed | 2 | **4** | | | | | | |
| Wheather & Other | 3 | **5** | | | | | | |
| **TOTAL** | **55** | **100** | | | | | | |

| CAUSES OF POTHOLES ( %) | |
|---|---|
| Heavy Loads | 25 |
| Storm Water | 15 |
| Poor Maintenance | 15 |
| Lack of Maintenance | 13 |
| Cheap Material | 13 |
| Poor Management | 7 |
| Poor Design | 4 |
| Speed | 4 |
| Wheather & Other | 5 |
| **Total** | **100** |

| POTHOLE EFFECT<br>Travel Comfort (%) | |
|---|---|
| Low | 12 |
| Average | 5 |
| High | 26 |
| Very High | 12 |
| **Total** | **55** |



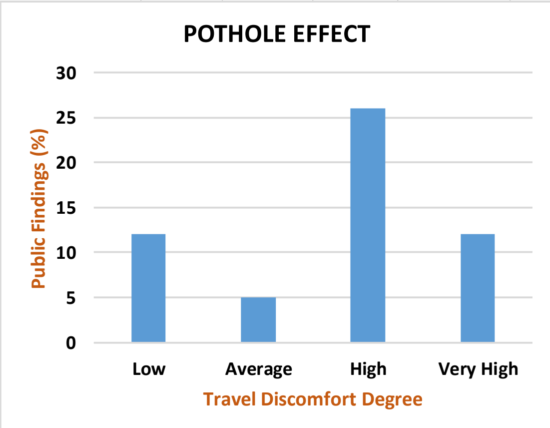



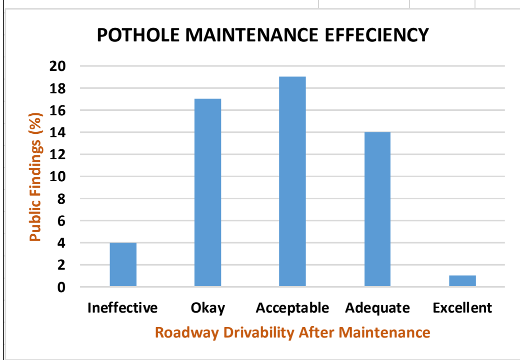

**Figure C.1: Questionnaire Outcome Part 1**

**APPENDIX C 2: QUESTIONNAIRE OUTCOME PART 2**

| MAINTENACE EFFECIENCY | | | | | | | PUBLIC MAINTENANCE SOLUTIONS | | |
|---|---|---|---|---|---|---|---|---|---|
| Type | Efficiency | | | | | | Type | Amount | % |
| | Ineffective | Okay | Acceptable | Adequate | Excellent | Total | | | |
| **Maintence Technique** | **18** | **21** | **12** | **4** | **0** | **55** | Improve material quality | 5 | **12** |
| Percentage Outcome % | 33 | 38 | 22 | 7 | 0 | 100 | | | |
| **Maintenance Technology** | **8** | **32** | **9** | **5** | **1** | **55** | Change Maintenance Technique | 11 | **26** |
| Percentage Outcome % | 15 | 58 | 16 | 9 | 2 | 100 | | | |
| **Material used** | **12** | **21** | **16** | **4** | **2** | **55** | Improve Road Design | 1 | **2** |
| Percentage Outcome % | 22 | 38 | 29 | 7 | 4 | 100 | | | |
| **Material Durability** | **17** | **25** | **10** | **3** | **0** | **55** | Improve Road Drainage | 3 | **7** |
| Percentage Outcome % | 31 | 45 | 18 | 5 | 0 | 100 | | | |
| **Surface Improvement after Maintenance** | **6** | **24** | **14** | **8** | **3** | **55** | Improve Management | 7 | **17** |
| Percentage Outcome % | 11 | 44 | 25 | 15 | 5 | 100 | | | |
| **Road Drivabilty after Maintenance** | **4** | **17** | **19** | **14** | **1** | **55** | Regular Maintenance | 4 | **10** |
| Percentage Outcome % | 7 | 31 | 35 | 25 | 2 | 100 | | | |
| | | | | | | | Attend to potholes urgently | 11 | **26** |
| | | | | | | | | **42** | **100** |

| POTHOLE MAINTENANCE EFFICIENCY<br>Roadway Drivability after Maintenance (%) | |
|---|---|
| Ineffective | 4 |
| Okay | 17 |
| Acceptable | 19 |
| Adequate | 14 |
| Excellent | 1 |
| **Total** | **55** |

| PUBLIC MAINTENANCE SOLUTIONS (%) | |
|---|---|
| Improve Material Quality | 12 |
| Change Maintenance Technique | 26 |
| Improve Road Design | 2 |
| Improve Road Drainage | 7 |
| Improve Management | 17 |
| Regulatr Maintenance | 10 |
| Attend to Potholes in Time | 26 |
| **Total** | **100** |



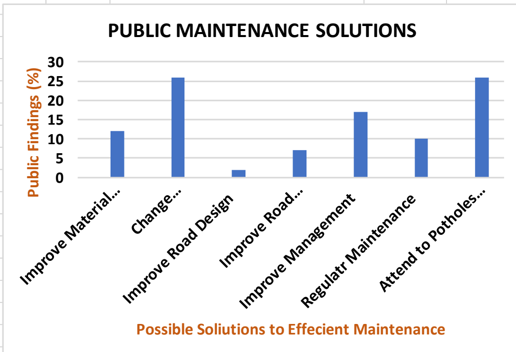




**Figure C.2: Questionnaire Outcome Part 2**

## APPENDIX D: Relationship Between Causal Factors and Formation of Potholes

### Table D.1: Correlation between Traffic Volume and Potholes

| APPENDIX D1 - Correlation between Traffic Volume and Potholes | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Road** | **x: Traffic Volume** | **y: No. of Potholes ( All Degrees )** | **FORMULA COMPONENTS** | | | | |
| | **x** | **y** | **x - ẋ** | **y - ȳ** | **(x - ẋ)(y -ȳ)** | **(x - ẋ)2** | **(y - ȳ)2** |
| 1. Dewetsdorp Rd | 17 593,00 | 127 | 4 826,00 | 33 | 159 258,00 | 23 290 276,00 | 1089 |
| 2. M10 Road | 21 501,00 | 138 | 8 734,00 | 44 | 384 296,00 | 76 282 756,00 | 1936 |
| 3. Church Street | 14 520,00 | 104 | 1 753,00 | 10 | 17 530,00 | 3 073 009,00 | 100 |
| 4. Moshoeshoe St | 15 495,00 | 128 | 2 728,00 | 34 | 92 752,00 | 7 441 984,00 | 1156 |
| 5. Bergstraat Street | 7 117,00 | 42 | - 5 650,00 | -52 | 293 800,00 | 31 922 500,00 | 2704 |
| **Σ** | **76 226,00** | **539** | **12 391,00** | **69** | **947 636,00** | **142 010 525,00** | **6985** |
| | | | | | | | |
| ẋ = | 12 767,00 | | | | | | |
| | | | | | | | |
| ȳ = | 94 | | | | | | |

## Table D.2: Correlation between Layer Thickness and Potholes

| APPENDIX D2: Correlation between Layer Thickness and Potholes | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Road** | **x: Layer Thickness** | **y: No. of Potholes ( All Degrees)** | **FORMULA COMPONENTS** | | | | |
| | **x** | **y** | **x - ẋ** | **y – ȳ** | **(x - ẋ)(y -ȳ)** | **(x - ẋ)2** | **(y - ȳ)2** |
| 1. Dewetsdorp Rd | 510,00 | 127 | - 81,00 | 33 | - 2 673,00 | 6 561,00 | 1089 |
| 2. M10 Road | 685,00 | 138 | 94,00 | 44 | 4 136,00 | 8 836,00 | 1936 |
| 3. Church Street | 610,00 | 104 | 19,00 | 10 | 190,00 | 361,00 | 100 |
| 4. Moshoeshoe St | 490,00 | 128 | - 101,00 | 34 | - 3 434,00 | 10 201,00 | 1156 |
| 5. Bergstraat Street | 720,00 | 42 | 129,00 | -52 | - 6 708,00 | 16 641,00 | 2704 |
| **Σ** | **3 015,00** | **539** | **60,00** | **69** | **- 8 489,00** | **42 600,00** | **6985** |
| | | | | | | | |
| ẋ = | 591,00 | | | | | | |
| | | | | | | | |
| ȳ = | 94 | | | | | | |

## Table D.3: Correlation between Traffic Speed and Potholes

| APPENDIX D3: Correlation between Traffic Speed and Potholes | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Road** | **x: Traffic Speed** | **y: No. of Potholes ( All Degrees)** | **FORMULA COMPONENTS** | | | | |
| | **x** | **y** | **x - ẋ** | **y - ȳ** | **(x - ẋ)(y -ȳ)** | **(x - ẋ)2** | **(y - ȳ)2** |
| 1. Dewetsdorp Rd | 60,00 | 127 | - 12,00 | 33 | - 396,00 | 144,00 | 1089 |
| 2. M10 Road | 100,00 | 138 | 28,00 | 44 | 1 232,00 | 784,00 | 1936 |
| 3. Church Street | 80,00 | 104 | 8,00 | 10 | 80,00 | 64,00 | 100 |
| 4. Moshoeshoe St | 40,00 | 128 | - 32,00 | 34 | - 1 088,00 | 1 024,00 | 1156 |
| 5. Bergstraat Street | 80,00 | 42 | 8,00 | -52 | - 416,00 | 64,00 | 2704 |
| **Σ** | **360,00** | **539** | **-** | **69** | **- 588,00** | **2 080,00** | **6985** |
| | | | | | | | |
| ẋ = | 72,00 | | | | | | |
| | | | | | | | |
| ȳ = | 94 | | | | | | |

## Table D.4: Correlation between Wheel Load and Potholes

| APPENDIX D4: Correlation between Wheel Load and Potholes | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Road** | **x: Wheel Load** | **y: No. of Potholes ( All Degrees)** | | | | | |
| | **x** | **y** | **x - ẋ** | **y - ȳ** | **(x - ẋ)(y -ȳ)** | **(x - ẋ)2** | **(y - ȳ)2** |
| 1. Dewetsdorp Rd | 325,00 | 127 | - 93,00 | 33 | - 3 069,00 | 8 649,00 | 1089 |
| 2. M10 Road | 725,00 | 138 | 307,00 | 44 | 13 508,00 | 94 249,00 | 1936 |
| 3. Church Street | 492,00 | 104 | 74,00 | 10 | 740,00 | 5 476,00 | 100 |
| 4. Moshoeshoe St | 523,00 | 128 | 105,00 | 34 | 3 570,00 | 11 025,00 | 1156 |
| 5. Bergstraat Street | 144,00 | 42 | - 274,00 | - 52 | 14 248,00 | 75 076,00 | 2704 |
| **Σ** | **2 209,00** | **539** | **119,00** | **69** | **28 997,00** | **194 475,00** | **6985** |
| | | | | | | | |
| ẋ = | 418,00 | | | | | | |
| | | | | | | | |
| ȳ = | 94 | | | | | | |