RE-ENGINEERING OF TRAFFIC SYSTEMS IN THE CENTRAL BUSINESS DISTRICT (CBD) OF A SOUTH AFRICAN CITY: THE CASE OF KIMBERLEY CITY

By

MS MMUSHO KEETSE

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Supervisor: Dr. D.K. Das

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ABSTRACT

Most cities of the world face the challenges of dealing with traffic congestion and its undesirable consequences. In South Africa many large and medium sized cities– and specifically the central business district (CBD) thereof – are experiencing traffic congestion and are severely affected by it. One such city which warranted this investigation, is Kimberley in the Northern Cape Province. Because of its unique physical and spatial attributes; its road network; economic characteristics and the requirement of the mobility of heavy vehicles in addition to the normal city traffic, Kimberley experiences typical traffic congestion challenges in its CBD area, particularly during peak hours. Thus, using the city Kimberley as a case study, an investigation was conducted to comprehend the traffic congestion scenario on the roads in and around Kimberley's CBD area with the aim to evolve plausible re-engineering interventions that could alleviate the traffic congestion challenges experienced by the city.

The conduction of the study involved the critical review of relevant literature, understanding of the control variables influencing traffic congestion and applying relevant empirical models to assess traffic congestion and evolve policy/strategic measures to alleviate the challenge. A survey research methodology was used for the collection of data, followed by statistical analyses of the data and the application of empirical models to assess the level of traffic congestion on the roads of the study area. Simulated scenarios based on different re-engineering interventions were then evolved, which assisted in engendering policies and strategic interventions that could reduce traffic congestion and improve smooth traffic flow in and around the Kimberley CBD area.

In this regards, the following major factors usually causing traffic congestion in and around CBD areas were investigated. They are traffic volume; type and composition of vehicles; specifically plying of heavy vehicles (large trucks); on-road parking facilities; type of junctions; traffic speed; inadequate number of lanes; inadequate turning radii; insufficient lane width/ road width (capacity); inadequate availability of space near junctions; availability of commercial function; availability of traffic nodes such as bus and taxi stops; and availability of civic/administrative functions close to the roads.

The study indicated an appreciable level of traffic congestion on some of the roads in the Kimberley CBD area –specifically during peak hours– which needs strategic intervention. The results of the application of empirical models such as Segment delay (Ds), Travel time index (TTI), Q index, Level of Service (LOS) and Queue length suggest that two of the major roads, namely Long Street and Transvaal Road (impacted by Pniel Road), are experiencing high levels of congestion during both normal and peak hours. Similarly, some of the other roads such as Bishop Road, Carter Road and Barkley Road (impacting Transvaal Road) and Schmidtsdrift Road are a cause of concern during peak hours. Future scenario analyses indicated that these roads – i.e. Long Street, Transvaal Road (Phakamile Mabija Road), Bishop`s Road, Carter Road and Barkley Road – will become severely congested. Besides, junctions connecting Long Street and Bultfontein Road (J1); Bishop-/Lyndhurst Street and Bultfontein Road/Delham Street (J2); Transvaal Road and Cecil Sussman Street (J3); and Transvaal Road and Old Main Street (J5); experience high queuing lengths during peak hours and are seemingly under pressure with regard to congestion.

However, the following re-engineering interventions this study envisages for the year projected year 2025 should reduce congestion on the roads in and around the CBD area of the city: appropriate traffic diversion from the congested roads to relatively less congested roads during both normal and peak traffic hours; segregation of heavy vehicles and the diversion of the appropriate proportion of normal cars during peak hours; optimal use of less congested roads for carrying diverted traffic; prevention of use of on street parking facilities during peak hours; and modification of signalling cycle time at major junctions during the peak hours. It has been determined that by adopting a policy of diverting a minimum percentage traffic from Long Street (20.77%), Transvaal Road (28.80%), Bishop Road (15.11%), Barkley Street (12.73%), Barkley section 2 (9.0%), Carter Road (14.10%) and Cecil Sussman Road (20.77%) and assigning all this traffic in the following proportions to Memorial Road (12.23%), Du Toitspan Road (20.77%), Lyndhurst Street (20.77%) and Main Street (25.80%), would appreciably reduce the traffic congestion in the congested roads without increasing the level of traffic congestion on the relatively free roads. Similarly, by adopting a policy, of diverting a minimum percentage of traffic from Long Street (33.71%), Transvaal Road (40.05%), and Bishop Street (17.79%) during peak periods in projected years and assigning this traffic in the following proportions to Memorial Road (25.0%), Barkley Road impacted by Pniel Street (25.0%), Du Toitspan Street (28.43%), Lyndhurst Street (28.43%) and Main Street (28.43%), will not significantly increase the level of traffic congestion on these roads whilst enabling the reduction of traffic congestion on the roads under pressure of traffic. Furthermore, simulated scenarios of traffic diversion based on travel time ratio and change in speed, show that with a reasonable level of diversion of traffic from congested roads to less congested roads, speed can be increased and travel time can be reduced on the roads in the CBD area of the city, thus allowing roads to be optimally utilised. These results also established the following two hypotheses on which this investigation has been based:

1) Segregation of traffic (modal split) will appreciably reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads in the CBD; and
2) Optimal traffic assignment (diversion to alternative roads) will significantly reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of CBD.

It can thus be concluded that re-engineering solutions such as traffic diversion from the congested roads to the under-utilised or least congested roads with appropriate traffic assignment and modal split (segregation of vehicles) could assist in easing the traffic congestion, increasing speed and reducing travel time, resulting in optimal utilisation of all the roads in the CBD area of the city.

Key words: Traffic Congestion; Level of Service; Central Business District; Peak Hours; Diversion of Traffic; Modal Split; Traffic Assignment.

DECLARATION

I, the undersigned, hereby declare that the content of this dissertation is the result of my own independent research and that neither this dissertation, nor any part thereof, has previously been submitted to another institution by any other person or myself in order to obtain a degree.

Signature | Date

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1. CHAPTER 1: INTRODUCTION AND RESEARCH DESIGN

1.1 INTRODUCTION

South Africa is one of the most urbanised countries in the Sub-Saharan Africa region barring the small states of Reunion, Gabon and Djibouti. According to a recent survey conducted in 2013 by the South African Institute of Race Relations (SAIRR) in Johannesburg, about 62.0% of the population lives in the urban areas of the country (Turok, 2012; SAinfo reporter, 2013). This percentage has increased by 10.0% over the last two decades; the prominent reasons for such urbanisation being the post-apartheid free movement of people and higher economic growth in the urban areas, attracting people in search of jobs (Turok, 2012; SAinfo reporter, 2013). In turn, this urbanisation has created conditions for concentrated economic activity. Although the South African urban centres are perceived as the dominant areas of economic activity and employment, attracting most foreign investment, it is also realized that they are not performing to their potential or reaping the benefits of agglomeration because of shortages in energy and water infrastructure and shortfalls in education and skills. These – among other factors as well – have fuelled ills such as crime and have brought about social tension as well as environmental and health risks. Besides the challenge of provision of civic services, urbanisation also poses the challenge of solving traffic problems such as traffic congestion and crashes on the roads of the urban areas (Ndebele, 2013; Turok, 2012).

The South African cities are predominantly characterised by low-density suburb-oriented developments. This form of development has favoured road-based transportation, particularly by private cars and minibus taxis. In addition, the increase in urban functions – including service activities – has created a higher demand for intra-city vehicular movement in the cities and in the absence of adequate public transportation systems, this resulted in the phenomenon of a one-man-one-car system in most of the country's urban areas. Simultaneously it is also observed that as in many other developing countries, a number of South African cities are experiencing a change from almost single modes of travel in self-driven cars to a multimodal system with the gradual introduction of public transportation by bus and the increase in two wheelers and goods vehicles in addition to the predominance of individual-driven cars. Consequently, there is a pressure on the roads of the cities.

Prior to the 2010 Football World Cup, road improvements featured in many cities of the country, which included expansion of the provincial road network through freeway widening, building new roads, upgrading interchanges, and installing traffic management systems (cameras and electronic signs) as well as an automated toll system. However, vehicle sales and the consequent traffic in the cities are also increasing rapidly. The enhanced vehicular movement as a result of increased urban functions (particularly economic activities); the rise in volume of vehicles; the use of private vehicles in the absence of public transportation facilities; and a growing multi modal system, have all given rise to traffic congestion on the roads in urban areas – particularly during peak hours on the roads leading towards city centres.

Most of the South African cities have a designated Central Business District (CBD). These CBDs usually perform multifarious functions that include commercial, administrative and other civic activities. They are accessible by vehicles and major arterial roads pass through them. As a result, the CBD areas are under pressure in terms of traffic congestion and inadequate parking facilities, and therefore need attention to alleviate these problems.

Thus, traffic congestion has become a major disturbing problem in many cities in South Africa bringing a range of undesirable consequences, which include negative economic impact and environmental pollution (Rao and Rao, 2012; Sorensen et al, 2008; Wang, Gao, Xu, Sun, 2014).. Specifically the central business districts (CBDs) of many large and medium sized cities of the country are severely affected by it. For instance, the city Kimberley in the Northern Cape Province experiences typical traffic congestion challenges in its CBD area because of its unique physical, spatial and economic characteristics and road network which has to accommodate heavy vehicles in addition to the normal city traffic –, particularly during the peak hours. Therefore it is essential to assess the level of traffic congestion and the influence of the imperative solutions, which could assist in evolving strategies to meet these challenges. To realise the aim a study was conducted by considering Kimberley city as a case study.

1.2 PROBLEM STATEMENT

Kimberley is a diamond mining city located at the intersection of two national roads, the N8 and N12. It is linked to Johannesburg by the N12 North-East, to Cape Town by the N12 South-West and to Mangaung (Bloemfontein) by the N8 South-East (please refer map 1 in annexure VII). The city is developed around a diamond mine (the big hole), therefore the central area of the city (CBD) is located very close to the big hole. The mining activities have created risks of instability in and around the CBD area, including the big hole. Although the mining activities were stopped in the year 1914, the decision to open a combined treatment plant (CTP) to retreat the dumps in the area, has extended the life of mining in the city up to the year 2023. However, because of the risk of instability and the possibility of roads and the area surrounding the big hole caving in due to the vibrations of heavy vehicular traffic, the Bultfontein road – which is closest to the big hole and in the proximity of the CBD – was closed by the Sol Plaatje Municipality (municipality governing Kimberley city) in the year 2008.

It is observed that currently heavy motor vehicles transporting mine products in the province, pass through the city on the R64 and then join the N8 connection to Bloemfontein. Similarly, buses and heavy motor vehicles carrying cargo pass through Kimberley city on the N12 connection to Cape Town. Besides, most of the vehicles travelling from the Kimberley Township (Galeshewe) and surrounding areas, as well as heavy vehicles from the industrial areas situated on the North-Eastern side of the city, and also the vehicles travelling from Johannesburg on the N12 are forced to pass through the CBD area to their various destinations outside the city. This scenario of traffic movement, combined with the intra-city traffic and closing down of the Bultfontein road, has resulted in heavy pressure on the roads passing thorough the CBD area of the city. Consequently, heavy congestion, disrupted traffic flow and increase in travel time (particularly during peak hours) are experienced on these roads. In addition, occurrence of accidents, damage to the roads, an unfriendly pedestrian environment and the negative environmental impact of noise and pollution have also been observed. In spite of having provided alternative roads for heavy vehicles sporadically, the problems seem to remain unchanged. Moreover, the generation of multimodal and pedestrian traffic because of the newly established Sol Plaatje University close to the CBD, is also expected to add pressure on the roads of the Kimberley CBD area. Thus, challenges of traffic congestion on the roads in and around the roads of CBD area of the city are observed, which warrant an investigation to comprehend the level of challenges of traffic congestion, the factors that cause traffic congestion and evolve apposite policy/ strategic interventions to reduce the traffic congestion and enable smooth and efficient traffic movement in the CBD area.

1.3 PURPOSE OF STUDY

1.3.1 Research aims of the study

The main aim of the study is to examine the current traffic system, the extent of traffic congestion, plausible causes of traffic congestion on the roads in and around the Kimberley CBD area, and to explore how the traffic system in the city and in the CBD area can be re-engineered so that safe and efficient vehicular mobility can be achieved without compromising accessibility to the CBD area of the city.

1.3.2 Objectives of the study

To achieve the aims mentioned in section 1.3.1 above, the following set of specific was framed for this investigation:

- To assess the current transportation and traffic system in the Kimberley city in general and in the CBD area in particular;
- To analyse the existing traffic movement system, including the movement of heavy vehicles in the city and through the CBD area;
- To identify the major control parameters influencing the traffic congestion in and around the CBD area;
- To assess the traffic congestion level in terms of Level of Service (LOS), travel time index, segment delay in the roads and queue length at the junctions in and around the CBD area by using empirical models;
- To simulate the traffic congestion level in and around the CBD area under various scenarios of policy interventions in the current scenario and also in the future projected year 2025.
- To formulate strategic guidelines to re-engineer the traffic system for efficient traffic movement in the CBD area.

1.4 HYPOTHESIS

Based on the analytical work in the present investigation, the following two plausible hypotheses were formulated and tested:
(a) Segregation of traffic (modal split) will appreciably reduce traffic congestion in terms of improved LOS, improved speed and less travel time on the roads of the CBD.; and
(b) Appropriate traffic assignment (diversion to alternative roads) will significantly reduce traffic congestion in terms of improved LOS, improved speed and less travel time on the roads of the CBD.

1.5 SCOPE OF THE STUDY

The scope of the investigation is limited to re-engineering of the road transportation system in and around the CBD area of the city Kimberley, South Africa. The design of a new transportation infrastructure or major alteration of the existing system is excluded from the scope of this investigation. The investigation was conducted by collecting data from a limited number of selected roads and suburbs in the city through sample surveys. The traffic congestion scenario was analysed and intervention measures developed by the application of existing empirical models suitable for this purpose as the development of new empirical models were not considered in this study. It is believed that should the recommendations of the present investigation be implemented, traffic congestion in the Kimberley CBD area would be appreciably alleviated.

1.6 RESEARCH DESIGN

Figure 1.1 presents the outline of the research methodology followed for the conduction this investigation. The detailed research design is discussed in the following subsections.

1.6.1 Methodology of the study

This investigation followed a systematic methodology (Figure 1.1) which comprises of the following steps:

a) The identification of problems

b) Relevant literature review

c) The formulation of objectives

d) Delineation of study area and selection of samples (users and roads) for survey

d) The collection of data,

d) The analysis and identification of control parameters,

e) The application of empirical models,

f) The development of simulated scenarios,

g) The drawing of inferences,

h) Policy analysis and

i) Evolving a set of strategic guidelines and recommendations.

Since the investigation requires field data and road users' perception, a survey research method followed by quantitative analysis by use of statistical and empirical mathematical models suitable for analysing the traffic scenarios on the roads in and around the CBD area of city are observed to be most relevant (Kadiali, 2008). Therefore, this investigation was conducted by following survey research method and quantitative analysis as shown in Figure 1.1.

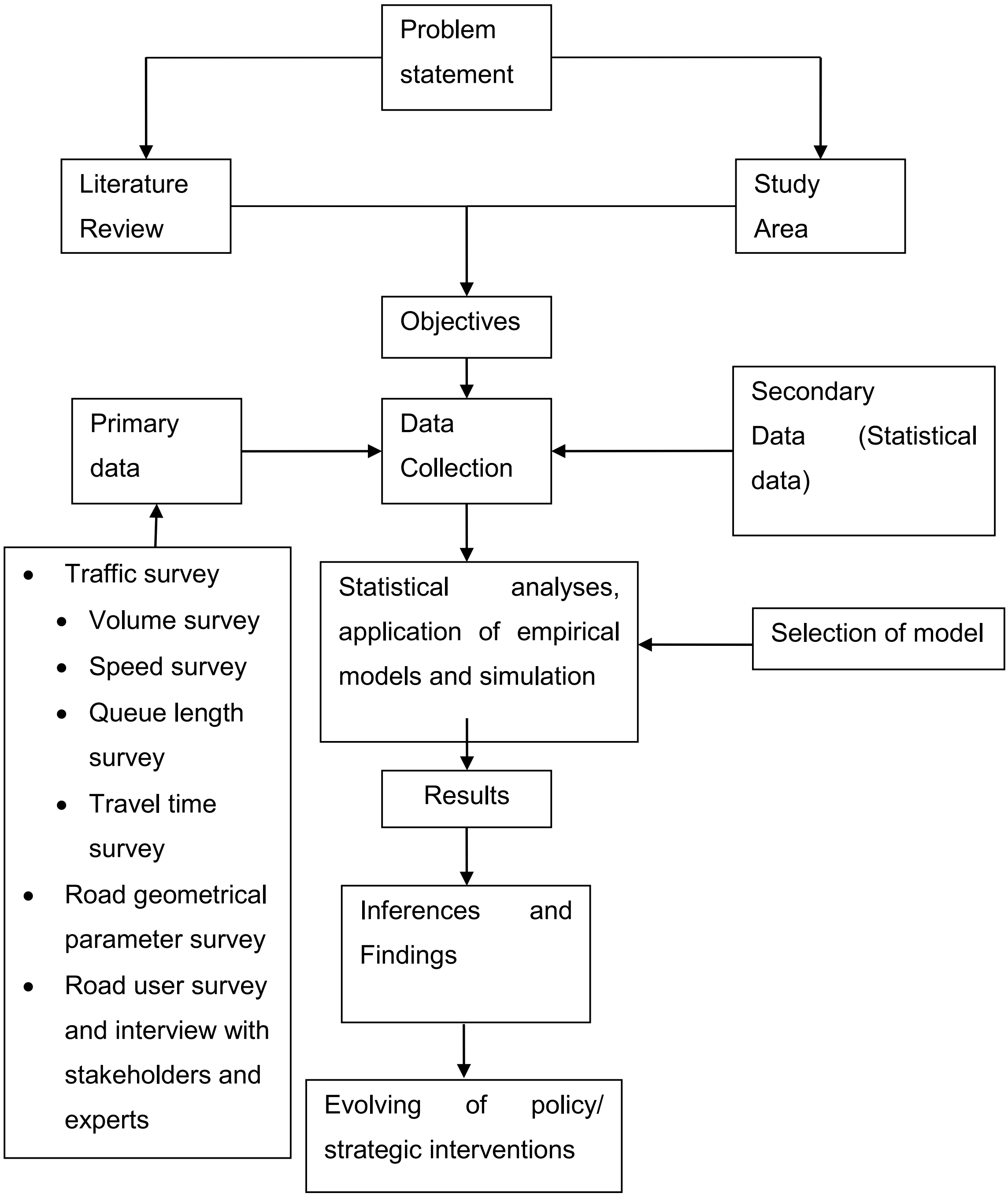

Figure 1.1: Methodology outline adopted in the study

1.6.2 Data Collection

Data were collected from primary and secondary sources and then employed in the investigation. The primary date on various aspects of traffic scenario and road user perceptions were collected by using survey methods relevant to the respective aspects and using questionnaire and standard templates (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012). Also, reconnaissance survey and pilot survey were conducted before finalising the sites, templates and questionnaire to be used for the survey.

1.6.2.1 Primary Data

The primary data were collected from road user survey conducted in the city, physical and geometrical parameter surveys of the road and traffic survey. The surveys were conducted by using established survey methodology applicable for transportation and traffic planning and design purposes (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012; Nardo, Saisana, Saltelli, Tarantola, Hoffman, Giovannini, 2005; Saltelli, 2007). The collection of data from primary sources was essential because structured and up-to-date statistical data of important parameters with regard to traffic scenarios in the study area were not available. Moreover, the perception of road users and the opinion of stakeholders are essential for the development of strategies and policy interventions for alleviation of traffic congestion and efficient and smooth flow of traffic.

1.6.2.2 Selection of sites for survey

A number of relevant variables were taken into consideration for identification of suitable sites to conduct different types of surveys in the Kimberley City. Traffic surveys that included volume, speed, queue length at traffic junctions; travel time; delay time and speed changes of traffic were conducted at different locations on the important roads passing through and around the CBD area (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012, Nardo, et al., 2005; Saltelli, 2007). The criteria used for selection of these roads include the importance of the road, its proximity and influence on the CBD and associated urban functions, volume of traffic, traffic flow pattern, speed of vehicles, congestion level and safety level. Based on these parameters, traffic surveys were conducted on the following roads: Long Street, Barkley Road, Bishop`s Road, Carter`s Road, Schmidtsdrift Road, Transvaal Road impacted by Pniel Road, Barkley section 2 impacting Transvaal Road, Main Street, Memorial Road, Du Toitspan Street, Lyndhurst Street, North Circular Street, South Circular Street and Cecil Sussman Street (refer map 1 annexure VII). The physical and geometrical road parameter survey was also conducted on the same roads. The queue length survey was conducted on the important traffic junctions located on these roads, namely the Long Street – Bultfontein Road junction (J1), the Bishop-/Lyndhurst Street– Delham

Street/Bultfontein Road junction (J2), the Transvaal Road –Cecil Sussman Street junction (J3), the Du Toitspan Street – Lennox Street junction (J4), the Transvaal Road – Old Main Street junction (J5) and the North Circular Street – Pniel Street junction (J6).

1.6.2.2.1 Road geometrical parameters survey

Data pertaining to physical road geometrical parameters were collected at important road sections located on the identified major roads namely Long Street, Barkley Street, Bishop`s Road, Carter`s Road, Schmidtsdrift Road, Transvaal Road impacted by Pniel Street, Barkley section 2 impacting Transvaal Road, Main Street, Memorial Road, Du Toitspan Street, Lyndhurst Street, North Circular Street, South Circular Street and Cecil Sussman Street. The various existing road-geometry related parameters which were measured at each road section, include the road traffic system (one- or two-way), road width, number of lanes, width of each lane as well as the total width of all lanes heading in one direction, the presence of service lanes, gradient, curvature, shoulder width, sight distance, type of kerbing, median width, type of road surfacing, type of parking facilities available on the side of the road, etc.

1.6.2.2.2 Speed survey

Speed survey (spot speed) data were collected at the road sections that were identified for the survey by employing standard templates (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012). The data were collected by conducting a survey over a period of one week (which includes five week days and two weekends) for 13 hours a day (i.e. from 6.00 a.m. to 7.00 p.m.) continuously. The other periods of the day were not considered because of the very meager volume of traffic observed during the pilot survey. The survey was conducted in parallel at all the selected road sections.

The survey in speed changes was conducted by driving vehicles between adjacent junctions during the peak periods and documenting the speed changes, distance covered, time lapse between speed changes and number of speed changes (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012).

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1.6.2.2.3 Traffic volume survey

Surveys to investigate the volume of traffic and its implications on the traffic congestion in each road were conducted at the most important intersections as well as at sections located on the following identified important roads: Long Street, Barkley Road, Bishop`s Road, Carter`s Road, Schmidtsdrift Road, Transvaal Road impacted by Pniel Street, Barkley section 2 impacting Transvaal Road, Main Street, Memorial Road, Du Toitspan Street, Lyndhurst Street, North Circular Street, South Circular Street and Cecil Sussman Street. The intersections selected for the traffic volume surveys were the Long Street – Bultfontein Road junction (J1), the Bishop-/–Lyndhurst Street – Delham Street/Bultfontein Road junction (J2), the Transvaal Road – Cecil Sussman Street junction (J3), the Du Toitspan – Lennox Street junction (J4), the Transvaal Road – Old Main Street junction (J5), and the North Circular Street – Pniel Street junction (J6). Selection of these intersections was based on their importance in the movement of traffic, such as type of intersection, the number of legs of the intersection, its proximity to the CBD area, the composition of different modes of traffic passing through the junction and observed congestion.

The traffic volume surveys were also conducted by using a standard template which includes various modes of transport such as cars, goods trucks, motorcycles, delivery vehicles, buses, taxis and other vehicles entering a specific intersection or road section per hour, as well as the direction of the traffic flow, number of vehicles, etc., (Kadialli, 2008; Richardson, Ampt, 1995; Talpur, Napiah, Chandio & Khahro 2012).

1.6.2.2.4 Road user surveys

Road user surveys were conducted at the nodal points of the city to comprehend the perceptions of the road users regarding traffic system, road and traffic infrastructure, origin and destination, challenges they are facing with regards to traffic system in the study area as well as to find out their perceptions regarding the level of challenges, and possible strategic intervention measures that would be suitable to alleviate the challenges of traffic congestion (Lambsdorff, 2006; Kadiali, 2008; Nardo., Saisana, Saltelli, Tarantola, Hoffman, Giovannini, 2005; Richardson, Ampt, 1995; Saltelli, 2007; Talpur, Napiah, Chandio & Khahro 2012). To conduct the road user surveys, a list of nodal points located in the city was collected. From these nodal points, the following important nodal points where significant urban functions and vehicular activities were observed, were selected for the survey: the bus terminus, the taxi rank, the Sol Plaatje Municipality office area, the Northern Cape University area and the city centre (CBD). (refer map 1 annexure VII). A total of two-hundred-and-forty (240) road users were surveyed, with the number of road users selected for the survey at each nodal point varying between 40 and 50. However, of the 208 samples returned, 202 were found to be useful for further analysis. The sample size was decided on the 1 in 50 (1:50) (maximum numbers) passing though the city per hour at different parts of the city. The adequacy was confirmed by comparing it with and established norms (Kadiali, 2008) and literature available on similar studies (Emuze and Das, 2015; Nardo, et al., 2005; Saltelli, 2007). Table 1.1 presents the demographic characteristics of the sample surveyed. 63.36% of the road users surveyed was males and 36.64% were females. About 48.03% of the road users surveyed belongs to age group 15-24 years and 43.07% of them to the age group 35-64 years. About 71.78% of the road users surveyed were drivers. The majority of the road users (76.24%) predominantly travel around inside the city and about 23.76% of the road users generate external traffic. The survey was conducted by employing a random sampling process, using pretested survey schedules comprising various parameters relating to road user perception regarding traffic congestion related issues. The various parameters include purpose of the trip, number of trips, origin and destination, types of vehicles use, time of the trip, distance travelled during the trip, perceptions regarding available road and traffic related infrastructure, traffic congestion, traffic accidents, parking availability, road condition, challenges being faced with and perception of improving the traffic congestion scenario.

In addition to the above, discussions with police and traffic officials, municipal officials as well as employees in the transportation sectors were conducted through a semi-structured interview process.

Table 1.1: Composition of survey sample for road user survey

Gender	Sample size in age groups			Total sample size	Drivers	Non Drivers	Predominantly internal city movement	Predominantly external city movement
	15-34	35-64	>65					
Number of males	59 (29.22%)	56 (27.72%)	13 (6.43%)	128 (63.36%)	97 (48.02%)	31 (15.35 %)	92 (45.55%)	36 (17.82%)

Number of females	38 (18.81%)	31 (15.35%)	5 (2.47%)	74 (36.64%)	48 (23.76%)	26 (12.87%)	62 (30.69%)	12 (5.94%)
Total sample size	97 (48.03%)	87 (43.07%)	18 (8.90%)	202 (100%)	145 (71.78%)	57 (28.22%)	154 (76.24%)	48 (23.76%)

1.6.2.3 The significance of data collected

First-hand data at grassroots level are essential to understand the existing scenario in the study area. The data collected are highly significant as they are linked to the specific objective(s) of the investigation. The surveys of traffic volume, speed, queue length and travel time, as well as the measurement of the geometric parameters are essential to understand the existing scenario and its implications on traffic movement and the occurrence of traffic congestion in the study area. Data on the perception of road users collected through road user surveys provided insight in the travel behaviour of road users, the road challenges they have to face and their perceptions regarding the available infrastructure as well as how to improve the scenario.

1.6.2.4 Secondary Sources of Data

Statistical data were collected from various secondary sources pertaining to the study which include published and unpublished literature and documents of relevant organisations at city level as well as at provincial and national level (such as the Sol Plaatje Municipality and the Department of Transport, Safety and Liasion of Northern Cape Province, Statistics, SA). The data collected include the demographics and socio-economic profile of the study area, vehicle and traffic volume reports and programmes and policies for future development of the city.

1.6.2.5 Ethical consideration in data collection

All protocol and ethical consideration have been followed while collecting data. Due consent from the road users and relevant organisations was obtained before collecting any data. During the road user survey, the road users were first informed about the type, purpose and content of survey. Due confidentiality of the responses and anonymity of the identity of the respondents were kept. During the physical road geometry survey, the organisations such as Sol Plaatje Municipality and road traffic departments were informed about the survey. Precautions such as visibility of the survey personnel through use of florescent vest jackets, and placing of appropriate information signs were taken.

Care has been taken to not to harm any living elements such as people or animals, put anybody under unwarranted stress and duress, and damage any natural and artificial elements.

1.7 DATA ANALYSES

After compilation, the data were controlled for comprehensiveness and correctness. Errors or biased returns were eliminated by crosschecking and subsequently carefully transferred to excel code sheets for computer analysis. The data collected were statistically analysed by the use of descriptive statistics, tabulation and significance tests. The determination of traffic congestion indicators such as traffic transmission index (Q index), LOS, travel time index (TTI), segment delay time (Ds), Queue Length at junctions (Ni), signaling cycle length at junctions (Co) and percentage traffic diversion (P) were done by applying the empirical models. Forecasting of traffic and simulated scenario analyses were then conducted with the aim to develop policy/ strategic interventions. The details about the various tools and techniques and models used in the analyses are described below.

1.8 ANALYTICAL TOOLS AND TECHNIQUES

1.8.1 Analytical Tools

Relevant analytical tools which include code sheets and software (SPSS, EXCELL, etc.) were used for data processing, analysis and application of empirical models.

1.8.2 Analytical Techniques

Relevant statistical techniques, such as tabulation, development of a perception index, significance tests and applicable empirical models were employed according to the requirements of the present investigation.

1.9 APPLICATION OF EMPIRICAL MODELS

The model being used for the perception index is presented in Equation 1 (Eq1, section 1.9.1) and empirical models used for the analysis of the traffic scenario in the CBD area are presented in Equations 2 to 8 in section 1.9.2. The relevance and implication of these models are discussed in detail in the chapter 2 (please refer section 2.7).

1.9.1 Perception index

Using the values assigned by the respondents as obtained from the road user survey, a perception index (PI) of the road users was developed by employing a weighted average index method (Lambsdorff, 2006; Nardo, et. al., 2005; Saltelli, 2007). The variables were grouped under four categories, namely land use and urban functions, urban pattern, road geometry and other urban development related parameters. The influence of each variable was assessed according to a scale of 0 to 1. Based on the perceptions and / or direct and indirect experience of respondents regarding transportation and traffic systems, urban movement challenges and traffic congestion scenarios, they were asked to assign a value in a scale of 0 to 1 to each variable which influences the occurrence of traffic congestion. While developing this index, care was taken to exclude irrelevant, subjective and uncertain responses. The model used for the development of the perception index is presented below.

Perception weighted average index= (PI) =$\frac{\sum Pi*Ni}{\sum Ni}$ ……………………………. (Eq. 1)

Where, Ni = number of respondents, PI = index values provided by the respondents in a scale of 0 to 1 as obtained from the road user survey.

1.9.2 Empirical models for congestion level analysis

1.9.2.1 Segment delay time (Ds)

Segment delay (Ds) has been calculated by equation 2 (Eq. 2) (Lomax, Turner, Shunk, Levinson, Pratt, Bay. and Douglas, 1997; Rao and Rao, 2012).

Ds = (TTac – TTap)*Vp ……………………………………………….. (Eq. 2)

Where: TT_{ac} = actual travel time (minutes)

TT_{ap} = acceptable travel time (minutes)

V_p = vehicle volume in the peak period (number of vehicles)

1.9.2.2 Travel Time Index (TTI)

Travel Time Index (TTI) has been calculated by equation 3 (Eq. 3) (Rao and Rao, 2012; Schrank and Lomax, 2005).

TTI= Peak period travel time/Free flow travel time

= Free flow travel speed/ Peak period travel speed……………… (Eq. 3)

1.9.2.3 Traffic transmission index (Q index)

Traffic transmission index (Q index) has been determined by equation 4 (Eq.4) (Levinson and Lomax, 1996; Rao and Rao, 2012).

Q = KS/(Âs.f)…………………………………………………………(Eq.4)

Where:

Q = Quality of traffic transmission index,

K = 1000 - constant,

S = average speed (mph),

Âs= absolute of speed changes per mile, and

f = Number of speed changes per mile.

1.9.2.4 Queue length at junctions (Ni)

Queue length (Ni) is calculated by equation 5 (Eq.5).

Ni= (Di*Qi)/3600 ....(Eq.5)

Where:

Di = Average delay of vehicles in lane i in units of seconds/vehicle, excluding acceleration and deceleration delay

Qi = Arrival flow rate in lane i in units of vehicles/hour/lane (Traffic Signal Design Volume 3, section 2.4.6, Road Traffic Signs Manual, South Africa, 2012)

1.9.2.5 Level of service (LOS)

LOS has been determined by equation 6 (Eq. 6) (HCM, 1985, 2000).

LOS = V/C or AADT/C …………………………………………… (Eq. 6)

Where:

V= total volume of vehicles on the road (lane)

AADT=Average annual Daily Traffic

C= Capacity of the roads (lanes)

1.9.2.6 Percentage traffic diversion (P)

The percentage traffic diversion (P) has been determined by equation 7 (Eq. 7) (Kadialli, 2008).

$P = 100/\ (1+t_R^6)$ ………………………………………………… (Eq. 7)

Where:

t_R = travel time ratio = Time on new system/ Time on old system

1.9.2.7 Signal cycle length (Co)

Signal cycle length at junctions has been determined by equation 8 (Eq. 8) (Kadialli, 2008; Traffic Signal Design Volume 3, section 6.13.4, Road Traffic Signs Manual, South Africa, 2012).

$Co = (1.5L+5)/\ (1-Y)$……………………………………………… (Eq. 8)

Where:

L= Total lost time

Y = Ymax1+ Y2max

Ymax = q / s = (Design hour flow (q) in PCU s/hour) / (Saturation flow(s) in PCUs/hour)

1.9.3 Forecasting of traffic volume (PCU)

Relevant models were used to forecast the traffic volume and congestion level on the roads in the CBD area under different scenarios based on variations in modal split and traffic assignment. The forecasting of traffic volume on various roads is essential for the development of remedial measures and policy interventions that will alleviate traffic congestion challenges. Therefore, forecasting of the traffic volume in terms of PCU has been conducted by using a dynamic forecasting method and employing the algorithm as presented in equation 9 (Eq. 9) below:

$V_{(t)} = V_{(i)} + \int_{to}^{t} \mathrm{V(i)}(r1 + r2 - r3).dt$…………………...................(Eq. 9).

Where: $V_{(t)}$= Predicted traffic volume at time t

$V_{(i)}$= Initial traffic volume at time t_0 (Base year 2015)

r1 = average annual normal rate of increase in traffic volume (1.5% per year)

r2= average annual rate of increase in traffic volume due to the establishment and operation of the Sol Plaatje University in Kimberley City (0.5% per year)

r3 = average annual rate of decrease in traffic volume because of reduction in mining activities (0.25% per year)

t= Projected period of 10 years (Projected year 2025)

t_0= Base year (2015)

1.10 RESULTS AND DISCUSSION

Results were obtained from all types of analyses which encompass the road user perception survey, the road geometrical parameter survey, the traffic surveys, traffic congestion level analysis and the simulated scenarios, have been discussed in detail to arrive at plausible findings.

1.11 INFERENCES

Plausible inferences were drawn for the development of a set of feasible policies.

1.12 STRATEGIES AND RECOMMENDATIONS

Based on the results, discussions, and inferences of this investigation, a set of policy/strategic guidelines has been prepared and recommended, for the reduction of vehicular accidents and the enhancement of road safety in the study area.

1.13 LIMITATIONS

One of the limitations of this study is that it cannot be generalised because the findings of the study are applicable only to the specific scope of study and thus need further investigation. In addition, only 240 road users could be surveyed for the following reasons:

- Time constraints (M.Tech. research is time-based)
- Limited availability of manpower for conducting the survey (personal conduction of investigation at grassroots level yields more advantages)
- Limited survey conduction time (The survey could be conducted during the daytime and evenings only)

Another major limitation of this investigation has been the limited availability of secondary data pertaining to the study area.

1.14 CHAPTER SCHEME

Chapter 1: Introduction, the statement of problems and the objectives, scope, concept, research methods and limitations of the research.

Chapter 2: Literature review.

Chapter 3: Profile of the study area with respect to its background, demographics, socio-economic factors, basic infrastructure, transportation and traffic management systems.

Chapter 4: Data analyses, results and discussions, simulated scenario analyses and hypotheses testing.

Chapter 5: Findings, re-engineering concept, policy analysis, policy recommendations and conclusion.

2. CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

In recent years extreme automobile dependence has been one of the major aspects of urban travel in modern cities (Meyer and Miller, 2001). In any travel, choice of mode or vehicle and choice of route are the two most basic requirements. Route selection and choice of mode of travel by an individual in an urban area depend on various factors. Among others, the most important ones are the location of urban functions, purpose of the trip, time and distance relationship, availability of different modes of travel, paying capacity of the commuter, affordability, road traffic conditions, ease of driving and movement, lifestyle and weather conditions. While the location of the origins of trips and destination of commuters impact the trip distribution in an urban area, route selection and choice of mode influence the traffic assignment on different routes (or roads). The whole process of mode choices, trip generation, route choices and purpose of trip, develops a traffic flow on the roads of the urban areas. However, if the capacity of the roads are inadequate, or if the roads are not appropriately designed according to required road characteristics to accommodate the traffic generated or if the urban functions in or around those roads are not appropriately planned, then traffic congestion and vehicular accidents may occur. As mentioned long ago by Miller (1972), one of the most visible manifestations of higher travel needs of people and movement of goods, is the generation of traffic and this extreme dependence on automobiles causes congestion on the roads in urban areas. Consequently, congestion has become a major urban transportation problem in most of the cities of the world (Downs, 1992; Litman, 2004). Occurrence of congestion leads to loss of time and money in addition to other psychological and physical problems that a commuter may experience. It is therefore essential to understand the various factors that cause traffic congestion as well as the impact of traffic congestion. Furthermore, it is necessary to understand not only the methods/models that need to be employed to predict the occurrence of traffic congestion but also the various intended policy interventions/ solutions available to reduce such traffic congestion on urban roads and advance fast and safe movement in the urban areas.

Given this premise, a sound theoretical background was developed for this investigation by reviewing, analysing, and synthesising the aspects of traffic congestion in urban areas that have been intensively investigated by various scholars. In this context, the various aspects being considered include the definition of traffic congestion, the impact of traffic congestion, factors influencing traffic congestion, indicators that measure traffic congestions, models/ methods used to measure traffic congestion and various intended policy interventions to reduce traffic congestion. The detailed literature review, synthesis and findings from the literature are presented in the following sections.

2.2 DEFINING TRAFFIC CONGESTION

There is no single definition for traffic congestion and the problem can be interpreted in different ways, although in general it is a situation in which demand for road space exceeds the supply (ECMT, 2007; Lascano Kezic, Durango-Cohen, 2012; Talukdar, 2013). Traffic congestion occurs when traffic is delayed due to the presence of an excess in number of vehicles on the same portion of the roadway at a particular time, resulting into slower than the normal or "free flow" speeds (Dft, U.S., 2005, p. 1; Link et al. 1999, p. 9). There will be long queues of vehicles moving on a constant start-and-stop basis because the number of vehicles traveling on the road exceeds the design capacity of the road. Consequently, it results in the delay in traffic movement and the traveller cannot move in a desirable manner as well (ECMT, 1999; Goodwin 2004; Levinson et al., 1997; Lomax, 1990; Lomax, Turner and Schunk, 1997; Taylor, 2002; p. 94; Weisbrod, Vary, et al. 2001, p. 1). Thus, traffic congestion can be described in two ways: (1) a high vehicle concentration moving at low flow speed, and (2) the number of vehicles on the road is close to or exceeds the maximum capacity of the road, causing an imbalance between travel demand and transport system supply (Hon, 2005, p. 24; Talukdar, 2013). Congestion is generally categorised into recurrent congestion, non-recurrent congestion and a pre-congestion state (Brownfield et al, 2003). Recurrent congestion occurs mainly when there are too many vehicles at the same time, consequently reducing traffic speed and increasing commuting time, which may relate to rapid growth in population, urbanization and growth in car ownership and use. It occurs typically during peak hours, but can also occur during off peak hours. However, non-recurrent congestion is associated with random conditions or special and unique conditions, including traffic incidents (ranging from disabled vehicles to major crashes), work zones which slow down traffic, weather and special events. A pre-congestion state occurs where free-flow conditions break down but full congestion has not yet occurred (Banjo, 1984; Brownfield et al, 2003; Chakwizira, 2007; HCM, 2000). However, these definitions can be broadly classified into three groups: (i) capacity demand related, (ii) travel time delay related, and (iii) cost related (Aftabuzzaman, 2007). A summary of the definition of congestion as observed from research in literature is presented in Table 2.1.

Table 2.1: Summary of alternative definitions of traffic congestion

Parameter	Definition	Sources
Capacity demand related	Traffic congestion occurs when travel demand exceeds the existing road system capacity.	Rosenbloom, 1978
	Congestion is a condition in which the number of vehicles attempting to use a roadway at any time exceeds the ability of the roadway to carry the load at generally acceptable service levels.	Rothenberg, 1985
	Congestion is a condition that arises because more people wish to travel at a given time than the transportation system can accommodate: a simple case of demand exceeding supply.	The Institute of Civil Engineers, 1989 cited in Miller and Li, 1994
	When vehicular volume on a transportation facility (street or highway) exceeds the capacity of that facility, the result is a state of congestion.	Vuchic and Kikuchi, 1994; Vuchic, 2005.
	Congestion is the impedance vehicles impose on one another due to the speed-flow relationship in conditions where the use of a transport system approaches its capacity.	ECMT, 1999
	Congestion may be defined as a state of traffic flow on a transportation facility characterized by high densities and low speeds, relative to some chosen reference state (of low densities and high speeds).	Bovy and Salomon, 2002

Travel time delay related	Congestion is an imbalance between traffic flow and capacity that causes increased travel time, cost and modification of behaviour.	Pisaraski, 1990 cited in Miller and Li, 1994
	Traffic congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.	Lomax et al, 1997
	Traffic congestion is a condition of traffic delay (when the flow of traffic is slowed below reasonable speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them.	Weisbrod, Vary and Treyz, 2001
	Congestion is the presence of delays along a physical pathway due to the presence of other users.	Kockelman, 2004
	Congestion can be defined as the situation when traffic is moving at speeds below the designed capacity of a roadway.	Downs, 2004
	In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time, resulting in speeds that are slower – sometimes much slower – than normal or "free flow" speeds.	Cambridge Systematics and TTI, 2005
Cost related	Traffic congestion refers to the increment in costs resulting from interference among road users.	VTPI, 2005

2.3 FACTORS INFLUENCING TRAFFIC CONGESTION

According to the Department of Transportation, United States (2005, pp.1-2), there are primarily seven reasons for traffic congestion. These seven reasons are generally grouped into three broad categories, namely traffic influencing events, traffic demand and physical road features. Traffic incidents (such as vehicular crashes, breakdowns, debris in travel lanes, events that occur on the shoulder or roadside, etc.), work zones (such as construction activity on the roadway) and weather (such as reduced visibility; bright sunlight on the horizon; presence of fog or smoke; wet, snowy or icy road way) are regarded as traffic influencing events. Traffic demand includes fluctuations in normal traffic, such as day to day variability in demand and special events. Physical highway features include physical and geometrical roadway characteristics, poor traffic control devices and physical bottlenecks (capacity) of the road (Talukdar, 2013).

2.3.1 Factors influencing traffic congestion in the CBD area

The concentration of trip destinations in a small area – particularly the central area (CBD) of the cities – poses the challenge of providing large transportation capacity in a limited physical space while preserving the historical, political, cultural, economic and environmental heritage/values of the areas. It has been observed that a larger percentage of trips are made to city centres (CBD - a defined and pre-eminent central area in cities) and that the total number of trips grows exponentially with the size of the city (Levinson, Lomax, & Turner, 1997; Turok, 2012. In addition, city centres are characteristically areas of high concentration of activities, where space is scarce and vehicular dependence. However, the quantum of road infrastructure like the number, width and vehicle manoeuvring facilities are often found to be constrained in comparison to their demand in the CBD areas. So these factors coupled with large scale vehicular operation and high traffic volume cause traffic congestion in the CBD areas. Therefore some scholars' proclaim that there exists a dichotomy of high demand for transportation capacity in a geographic environment where space is limited (Lascano Kezic, Durango-Cohen, 2012; Levinson, Lomax, & Turner, 1997; Turok, 2012).

2.4 IMPACT AND IMPLICATION OF TRAFFIC CONGESTION

The various apparent impacts of congestion were discussed by Department for Transport in United Kingdom (DfT, 2001) as part of the qualitative findings. As reported by DfT (2001), and corroborated by other investigations (Rao and Rao, 2012; Sorensen et al, 2008; Tiwari, Cervero, and Schipper, 2011; Wang, Gao, Xu, Sun, 2014), these impacts seem to be

- Competitive or aggressive driving.
- More difficult or tiring driving
- Limited freedom of action or ability to travel where and when drivers wish
- Increased risk of accidents or mishaps
- Intensified pollution

- Increased fuel consumption
- A major source of driver stress causing frustration, anger, anxiety, confusion and/or exhaustion

These impacts are also consistent with other research findings, such as that of the European Union (EU, 2003; Grant-Muller and Laird, 2007).

The overall implication of congestion could include a negative impact on the economy in terms of reduction in productive hours, impacting the Gross Domestic Products (GDP), and an increase in environmental pollution, fuel consumption and consequent carbon emissions and other polluting matters (Rao and Rao, 2012; Sorensen et al, 2008; Tiwari, Cervero, and Schipper, 2011; Wang, Gao, Xu, Sun, 2014).

2.5 INDICATORS FOR MEASURING TRAFFIC CONGESTION

A wide variety of indicators have been developed to measure traffic congestion (Dijker, Piet, Bovy, and Vermijs, 1998; Grant-Muller, 2005). However, literature suggests that only a few indicators form the basis for regular monitoring of the road network, and that more concrete indicators are needed to measure congestion at a practical level (Grant-Muller & Laird, 2006). One of the major and most favoured indicators, is the total amount of delay encountered, calculated across all traffic from the difference between the actual speed encountered and free flow speed (Dft, 2000, 2000b; Dodgson, Young, and van der Veer, 2002). This leads to the measurement of the average delay encountered by a vehicle travelling per kilometre. It was believed to be advantageous in providing a better picture of how changing traffic levels and different policy packages can affect the time lost to congestion, even though delays are measured purely in terms of vehicle journey time and no allowances are made for differences in occupancy rates, values of time, or for additional factors such as additional operating or environmental impacts that congestion can generate. Similarly, simple measures relating to speed are also used to indicate congestion, particularly for a motorway environment (Grant-Muller, 2005) as mentioned in Table 2.2. These indicators include mean journey times, variability of journey times, throughput (total number of vehicles per time interval that pass a point on the carriageway), queue lengths, speed differential between lanes and delay per hour/day (Graham and Glaister, 2004; Grant-Muller, 2005; Grant-Muller & Laird 2006; Noland and Polak, 2002). Besides, the congestion reference flow (a quantified measure of congestion for a junction link must be considered separately) and the level of service

(LOS) are other basic congestion measures that are widely applied in some countries like the USA and Scotland (Highways Agency, 1997; State-wide Planning Scenario Synthesis, 2005).

Table 2.2: Indicators of congestion

Sl No	Indicator	Explanation
1	Mean journey times	Mean journey time on link by link basis, from time to time for a specified time period. These journeys need to be combined into meaningful journeys.
2	Variability of journey times	Standard deviation (variance) in journey times on a link by link basis and route basis, within day variability basis and between day variability.
3	Throughput	Total number of vehicles that pass through a point during a time interval on the carriageway.
4	Total time: speed less than 40 km/ hour (25 m/hour) and 80 km/ hour (50 km/hour)	Total time during which the average speed drops below 40/80 km/hour per predefined time interval between specified section and junctions.
5	Number of occurrences of speed less than 40/80 km/ hour	Total number vehicles below average speed drops below 40/80 km/hour per predefined time interval between specified section and junctions.
6	Queue length	Queues because of flow breakdown, Queues formed at exit slip roads, Queues on on-slips, Queues that join the section,
7	Speed differential between lanes	Difference in mean speeds between each of the lanes per section, plus difference in extreme distribution.
8	Delay per hour/ day	Measure of delay per hour/day, where delay is measured as the difference between time in free flow and actual journey time.

(Source: Grant Muller, 2005; Grant-Muller and Laird, 2007)

2.6 TRAFFIC CONGESTION SCENARIO IN SOUTH AFRICA

Several transportation policy studies in South Africa suggested that road traffic congestion is a problem in cities of South Africa (Kumar & Barrett 2008; Bob, Roberts, Pillay, and Dimitrov Laverne, 2010). According to a South African Social Attitudes survey focusing on transportation conducted in 2008 road traffic congestion is one of the main disadvantage, and the third highest ranked concern in cities (about 10% of respondents of the survey identified it as the major concern) (Bob, et al., 2010). It was found that the causes of traffic congestion in South Africa cities could range from poor management of traffic flow, to growing motorisation, to inadequate parking, inadequate planning and weak enforcement (Roger, 2004, 2005). It was suggested that the trip to work travel activities take considerably longer (by between 14 to 23 minutes) per trip and on an average consumes about 5% of daily personal time amounting up to 72 minutes in 24 hours (Rogers, 2004, 2005). Besides, in a recent survey conducted by TomTom has found that 78% of the 3.8 million drivers on Johannesburg roads stuck in a severe traffic jam every day. In the year 2011 alone, about 10% (342000) of commuters cancel their meetings, and more than 40% of employees reach late in their work due to traffic jams. It is also revealed that about one third of the drivers spend 45 minutes more in traffic nationally. This provides ample evidence of critical nature of the traffic congestion challenges in the cities of South Africa (TomTom Survey, 2011).

The traffic congestion and crises in the transport system demands urgent investment and adequate policy interventions (Donaldson, 2015; Turok and Veassen, 2000). Thus, to meet the challenges efforts are being made to develop policies and strategies over the years. The earliest institutionalised exposition of such efforts took the form of guidelines prepared for urban, movement networks in 1976 by the South African Institution of Civil Engineers (SAICE, 1976). Followed by government-commissioned guidelines were prepared by the CSIR and by a Committee of Urban Transport Authorities (CUTA) on behalf of the National Department of Transport in the mid-1980s and until the end of millennium (Rogers, 2005, Turok and Veassen, 2000).

Consequently the key features of the guidelines developed to manage urban movement networks include: (1) 1.5 – 2-km-square cells of collector and access road networks, closed to through traffic and contained within delimiting grids of limited-access arterials and freeways, and introverted in terms of public facility and amenity, (2) hierarchical classification of roads into 'freeways', '(major and minor) arterials', '(major and minor) collectors' and 'local streets'; the spacing of arterials at 2-km intervals, and the spacing of freeways at 5 – 8-km intervals; (3) provision of limited-access points onto bordering arterials to minimise through traffic within townships and to create least interference to arterial traffic flow; the use of crescents, non-continuous connecting roads and cul-de-sac within townships to reduce collector and local road traffic speeds; (4) minimisation of the number of intersections in collector and local road networks, and a preference for tee intersections; (5) minimisation of the number of pedestrian street crossings, and the direction of vehicular flow outwards to bordering arterials and the direction of pedestrian flow inward (5) the provision of limited-access points onto bordering distributors to exclude through traffic from 'neighbourhood cells'; (6) minimisation of the number of intersections in access road networks, with preference for right-angled tee intersections where signalisation is not warranted; (7) minimisation of internal vehicular flow by placing land uses which attract vehicular traffic on local distributors and at or near the periphery of the area; the avoidance of at-grade pedestrian crossing of class 1 – 3 distributors (CSIR, 2000; SAICE, 1976).

However, despite these guidelines and efforts to manage traffic in cities of South Africa, traffic congestion is rising unabated. Therefore, looking at the challenges, particular at critical places including CBD area of cities, several policy interventions are suggested, which include, staggering of working hours, increasing and upgrading road infrastructure, encouraging non-motorised movement such as walking and pedestrianizations, implementation of congestion tax and carbon emission tax, introduce other forms of transport, lanes dedicated to public transport (e.g. for buses and taxis), decentralisation of offices, industries and shops, park-and-ride facilities, outer ring roads and bypasses, more efficient public transport system (e.g. Gautrain and Rea vaya), one-way streets, underground transport, subsidising of the cost of public transport, encourage lift clubs and so on (Learn Extra Live 2014; Tiwari, et. al., 2009). However, literature revealed that studies relating to congestion challenges and particularly regarding to re-engineering measure in South African cities are limited, which therefore, warrants investigation.

2.7 EMPIRICAL METHODS AND MODELS TO MEASURE AND ANALYSE TRAFFIC CONGESTIONS AND THEIR IMPLICATIONS

The various relevant empirical models available and generally used to analyse the traffic congestion are presented in Table 2.3. The implications and relevancy of these models with respect to the analysis of the traffic scenario in CBD area are discussed as below:

2.7.1 Traffic transmission index (Q index)

Traffic transmission index (Q index) measures congestion on the basis of speed. Thus congestion is considered as a function of the reduction in speed, which is the direct cause of loss of time that essentially leads to increased vehicle operating costs, fuel consumption, and emissions of air pollutants and greenhouse gases (GHGs) (Dft, 2001; Hon, 2005, p. 24; Talukdar, 2013. In addition, the setting of a threshold that is directly related to travel speed, is most appropriate. This method differs from conventional planning by making use of LOS which compares volumes with capacity and does not explicitly account for speed. Thus, a speed based threshold accounts more for the impacts of congestion than would a threshold based on capacity (Levinson and Lomax, 1996; Rao and Rao, 2012). However, the range of speed and number of speed changes and the absolute quantum of change in speed in the study area may be difficult to comprehend, which reduce the applicability of the model (Levinson and Lomax, 1996; Rao and Rao, 2012).

2.7.2 Travel Time Index (TTI)

According to Rao and Rao, (2012) and Schrank and Lomax, (2005), a time-based congestion measure such as TTI provides a different view on congestion. It offers guidance on identifying major concerns, enables policy makers to address the problems more efficiently and to evolve solutions that are more likely to have a greater impact. TTI has the advantage of expressing traffic congestion in terms of both space and time. Therefore, it is easy to understand the main concept of this index. However, it requires separation between recurring- and incident delays, and measurement of non-recurring data can be difficult – particularly in the CBD area of a city. In spite of this limitation, TTI offers a stronger basis for more generalized conclusions (Rao and Rao, 2012; Schrank and Lomax, 2005).

2.7.3 Segment delay time (Ds)

Segment delay is considered as the additional time taken by a road user in comparison to the free flow travel or the acceptable travel time in a particular segment of the road (Department of transportation U.S., 2005, p. 1; Link et al. 1999). It is measured in terms of relative delay. Delay rate can also be used to estimate the difference between actual system performance and performance expected of those system elements (Lomax et al., 1997). By employing relative delay rate which reflects the condition of flow travelers relate to their travel experience (Hamad and Kikuchi, 2002). Similarly, total delay offers the possibility to estimate how any improvements within a transportation system could affect a particular corridor or the entire system. Although total delay shows the effect of congestion in terms of the amount of lost travel time, relative delay is very difficult to comprehend, as congested travel- or congested roadway length does not represent the different magnitudes of congestion (Hamad and Kikuchi, 2002).

2.7.4 Level of Service (LOS)

Level of service is defined as the volume to capacity ratio of traffic (V/C) on a road segment (HCM, 1985, 2000). One of the advantages of using LOS to measure congestion is that it can be comprehended easily as it is based on two variable which can be easily measured and. It is also widely used since it is very easy to collect the data required for computation. Although the Highway Capacity Manual, USA (HCM, 1985, 2000) provides fairly detailed norms for measurement of different levels of congestion, critics argue that LOS cannot provide a continuous range of values of congestion as it does not offer any distinction between different levels of congestion once congested conditions have been reached. In addition, it could only be applicable to a location-specific congestion phenomenon and does not reflect overall or regional congestion conditions (Byrne and Mulhall, 1995).The use of a stepwise LOS measure can sometimes be misleading, especially when the condition is near a threshold (Hamad and Kikuchi, 2002). However, since traffic flow in and around CBD areas represent similar characteristics, arguments have emerged that LOS can be more useful for measuring congestion (HCM, 1985, 2000) on the roads of such locations.

2.7.5 Lane-mile duration index

The lane-mile duration index (LMDI) measures the extent and duration of freeway congestion. It is considered to be more relevant than LOS measures, particularly in freeway conditions. However, the limitation of this model is that it cannot reflect the effect of traffic congestion on highways having different functions (Cottrell, 1991; Rao and Rao, 2012). It can also provide poor results as traffic data are not collected from all the freeway segments in an area. Its application in a CBD area is limited, unless the road segments and the traffic have characteristics similar to those of freeways (Cottrell, 1991; Rao and Rao, 2012).

2.7.6 Percentage traffic diversion

The percentage traffic diversion is not a direct measure of congestion but one of the frequently used assignment techniques to divert traffic through bypasses or diversion curves (Kadiali, 2008). Its empirically derived relationships show the proportion of traffic that is likely to be diverted either on a new facility being under construction (such as a bypass, expressway, arterial street, etc.) or on the old facility and the extent would remain serviceable while new facilities are being created or even when traffic management measures are considered without creation of additional facilities. Such empirical relations can be developed, using a variety of variables such as travel time saved, distance saved, travel time ratio, distance ratio, travel time and distance saved, distance and speed ratio, and travel cost ratio. Thus, this model has more relevance in cases when solutions, such as traffic diversion or re-routing measures are considered to ease the traffic congestion in CBD areas (Kadiali, 2008).

Table 2.3: Empirical models generally used for traffic congestion analysis

Parameter	Model	Nomenclature	Applicability	References
Traffic Transmission Index (Q index)	Q = KS/(ÂsÃf)	Q = quality of traffic transmission index, K = 1000 - constant, S = average speed (mph), Âs= absolute of speed changes per mile, and f = number of speed changes per mile.	Based on speed and speed changes. Applicable to urban roads and higways.	Levinson and Lomax, 1996; Rao and Rao, 2012.
Level of Service (LOS)	LOS = V/C or AADT/C	V= total volume of vehicles AADT=Average annual daily traffic	Based on volume and capacity of roads, Useful for urban roads, roads in and around CBD	HCM, 1985,2000

			areas and highways.	
Travel Time Index (TTI)	TTI= (Peak period travel time/Free flow travel time) = (Free flow travel; speed/ Peak period travel speed)		Based on travel time and speed. Applicable for highways and urban roads.	Rao and Rao, 2012; Schrank and Lomax, 2005
Segment Delay Time	Ds = (TTac – TTap)*Vp	TT_{ac} = actual travel time (minutes) TT_{ap} = acceptable travel time (minutes) V_p = vehicle volume in the peak period (vehicles)	Based on relative delay in terms of lost time. Relative delay is very difficult to comprehend, as congested travel- or congested roadway length does not represent the different magnitudes of congestion.	Lomax, Turner, Shunk, Levinson, Pratt, Bay. and Douglas, 1997; Rao and Rao, 2012.
Lane-Mile Duration Index	LMDIF = _ $\sum^{m}{}_{1}$[Congested Lane − Miles* Congestion Duration (hours)]	Where i equals an individual freeway segment and m equals the total number of freeway segments in an urban area.	Based on congestion mile and congestion duration. It is more suitable for free ways. However, it cannot reflect the effect of traffic congestion on highways having different functions and urban roads	Cottrell, 1991; Rao and Rao, 2012.
Percentage Traffic Diversion	$P = 100/(1+t_R^6)$ t_R =Time on new system/ Time on old system	t_R = Travel time ratio	It is based on travel time or speed. It is useful for deciding diversions (by-passes)	Kadialli, 2008.

			and traffic assignment on different roads.	

2.7.7 Other relevant models for measuring traffic congestion

According to Dft (2000), the Commission for Integrated Transport (CfIT 2000) advised that a measure be used which is based on the total amount of delay encountered, calculated across all traffic from the difference between the actual speed encountered and the free flow speed. This formed the basis of the National Model Forecasts (2003) in the UK. Alternative delay measures were also used, such as the total delay of volume of traffic being divided into the average amount of delay encountered by a vehicle per kilometer (Dft 2005). Besides, the Highway Agency (1997), as mentioned in Levinson, Lomax, & Turner, (1997) recommended the following model to measure the congestion on a road segment or link.

CRF= Capacity*NL*Wf*100/PkF*100*PkD*AADT*AAWT

Where: Capacity = maximum hourly lane throughput

NL= Number of lanes per direction

Wf = A width factor

PkF= Proportion of total daily flow (two way) that occurs during peak hours

PkD = Directional split of the peak flow

AADT = Average annual daily traffic flow on the link

AAWT= Average annual weekly daily traffic flow on the link

Leonardo (1993), as mentioned in Levinson, Lomax, & Turner (1997), also suggested the following model that can be used to measure congestion for a wider area than just a link as well as for comparative purposes in urban areas:

CI=∑ (ti+di)/ti

Where CI= Congestion index

ti = Free flow travel time

di = excess travel time

This model can be applied for all vehicle journeys or for flow in a single link or corridor. Where links are summed separately, a flow weightage can be applied, thus modifying the model to:

CI=∑fa*(ta+da)/ ∑fa

Where CI= Congestion index

Ta = Free flow travel time on link a

Da = Excess travel time on link a

fa = Flow along a link

Besides, advanced computational methods such as a fuzzy neural approach for urban traffic flow predictions (Yin, Wong, 2002) have also been attempted in limited cases.

2.8 APPROACHES TO ADDRESS THE PROBLEMS OF TRAFFIC CONGESTION

The various approaches to address the problems of congestion in urban areas (particularly in the city centres), fall in three broad categories: supply management, land use management and transportation demand management**.** Supply management includes all measures taken to increase the number of people and trips served by the transportation system in order to accommodate as much demand as possible. This includes added capacity for vehicles, transit, bicycles, pedestrians and multi-mode facilities (Gao and Song, 2000; Yang and Bell, 1998; Zanjirani Farahani et al., 2013; Meyer, 2003) as well as optimization of traffic signal timing (Ceylan and Bell, 2004; Stevanovic et al., 2013). However, according to critics of this method, the majority of traffic jams are caused by accidents and events and not because of a lack of capacity (STPP, 2001). Adding capacity to alleviate the problems also becomes controversial in view of the argument of induced demand and the environmental and health effects of additional travel and land consumption (Gifford, 2005). In addition, supply management methods do little to mitigate congestion caused by non-recurring incidents. Land-use management has also been advocated. It describes the use of growth management, planning, and zoning to promote local density that will encourage transit. Transit oriented development and high-density land use are both examples of this type of management (Taylor, 2002). However, critics of land-use management measures cite two major challenges these measures pose, namely increased congestion created by high-density development and the long time it takes to change land-use patterns and behaviours. They also have their doubts regarding the connection and causality between land-use management and traffic congestion (Taylor, 2002). Similarly, Transportation Demand Management (TDM) is a strategy of instituting largely financial incentives and disincentives to encourage motorists to use alternate routes, times and modes, or to defer trips entirely in order to reduce the demand for traffic facilities. TDM arises out of a desire to consider alternative measures to the "supply-side" measures because of the negative effects of induced demand on the community. Such alternative measures include: congestion pricing, park-and-ride lots, high-occupancy-vehicle lanes, high-occupancy-toll lanes, employer commute option programs, telecommuting, alternative work schedules and traffic calming measures. Of all the measures, congestion pricing and raising of taxes tend to be both most effective and politically legitimate as a funding source (Gifford, 2005); however, due to the cost it places on drivers, it is one of the hardest methods to implement (Bass, 2008; Thynell, Mohan & Tiwari, 2010). This approach has also been criticised (e.g. Goodwin, 2004) as not being particularly useful from a policy perspective, as any policy associated with alleviating congestion will have a cost associated with it. Additionally, any reduction in congestion will reduce the impediment of travel and result in an increase in travel demand and average trip length – which will not only increase the environmental, accident and maintenance burden but may also lead to an increase in congestion above the zero congestion level. The total cost of congestion measures is also criticised for the arbitrariness of its baseline (Bass, 2008; Goodwin, 2004; Thynell, Mohan & Tiwari, 2010).

Other ways of reducing traffic congestion include meticulous traffic design and the use of advanced technology such as the intelligent traffic system (ITS), the Global Positioning System (GPS), inter vehicle communication and vehicle simulator, variable message signs and smart mobility approaches (Alterkawi, 2006; Emuze and Das, 2015; Das, 2014; Chen, Yu, Zhang, Guo, 2009; Furth, Muller, 2009; Hardjono, 2011; Salicru, Fleurent, Armengol, 2011; Rao and Rao, 2009; Santos, Coutinho-Rodrigues, Current, 2008; Toral, Vargas , and Barrero, 2009a; Yin, Lam, Miller, 2004). It is also argued that a balance between use of automobile and public transport can ensure a desired level of efficient mobility (Owen, 1992). Efficient vehicle routing, punctuality of routes and diversion of vehicles are also considered as other options to alleviate traffic congestion, particularly in the congested urban areas (Das and Keetse, 2015; Emuze and Das, 2015). However, the heart of the problem of vehicle routing lies at distribution management because not only do conditions vary from one setting to other, but also the objectives and constraints encountered in practice are highly variable. In spite of some research being done in this area, the focus is limited to a number of prototype problems. There is also not much literature available on the effect of a combination of the parameters such as travel time, vehicle routing (traffic assignment), segregation of vehicular traffic (modal split), appropriate traffic assignment on different alternative roads and reengineering of the traffic system at the local level, and the impact thereof on the congestion on a road network (Cordeau, Laporte, Savelsbergh, Vigo, 2007).

Overall, the studies and practices which deal with the mitigation of traffic congestion, either include increasing of road infrastructure supply or decreasing of travel demand, or both. Current studies have however demonstrated that increasing the size of infrastructure could be only part of the answer (OECD, 2013) as many measures are intrinsically interactive and may need to be addressed jointly. As a result of increased growth of traffic flow, it is crucial to develop cost-efficient policies which would alleviate traffic congestion and address negative externalities in terms of environmental impact and cost to the economy (Watling, Milne, Clark, 2012).

2.9 SYNTHESIS AND CONCLUSION

Every commuter has the right to select his/her preferred mode of travel and route. The selection of a route or mode of travel by an individual in an urban area depends on various factors such as the location of the urban functions, the purpose of the trip, the physical distance and time relationship, the road and traffic conditions, ease of driving and movement, etc. On the other hand, the individual's selection of a route or mode of travel also has an influence on the traffic distribution of that area in general. This whole process of movement and route selection may alter or fix a route for a commuter’s daily commuting and may influence the occurrence of traffic congestion.

Traffic congestion is an important challenge encountered particularly in cities. Traffic congestion is essentially expressed as the high concentration of vehicles moving at a low flow speed. The number of vehicles on the road being close to – or exceeding the maximum capacity of the road, causing an imbalance between travel demand and supply of the transport system. Traffic congestion is categorised into a recurrent, non-recurrent congestion, and pre-congestion state. Recurrent congestion occurs when there are too many vehicles at the same time, consequently reducing traffic speed and increasing commuting time. Recurrent congestion may relate to rapid growth in population, urbanization and growth in car ownership and use thereof. It occurs typically during peak hours, although it can also occur during off-peak hours. Non-recurrent congestion is associated with random conditions or special and unique conditions, including traffic incidents. Pre-congestion state essentially relate to the period during which or state of the road on which the scenario of flow of vehicles are building up to turn to a congested state.

The occurrence of congestion on a road segment, at a junction or overall road network depends on the need for travel, purpose of trip – in essence trip generation, mode choices, route choice, etc. which in turn develop a flow of traffic on the roads of urban areas. Traffic congestion occurs when traffic is delayed due to the presence of an excess in number of vehicles on the same portion of the roadway at a particular time, which results into slower than the normal or "free flow" speeds. Inadequate road capacity, inappropriately designed roads according to the required road design characteristics for accommodating the traffic generated, and inappropriate urban functions in or around those roads, can cause traffic congestion and vehicular collisions. Besides, the extreme dependence on automobiles is observed to be another cause of traffic congestion on roads of the urban areas. Additionally, it is argued that the limited space, higher concentration of activities, and automobile dependence in the central area of cities are responsible for occurrence higher congestion in the CBD area of the cities.

Traffic congestion is associated with certain negative impacts on the economy as well as the environment. It can cause travel delay which in effect increases fuel consumption, increases cost of travel and also reduces the effective working hours, which negatively impacts the GDP and productivity. Similarly, it causes intensified emission of carbon and other polluting matters to the atmosphere resulting to air pollution. As evident air pollution has severe human health and environmental implications. Besides, it leads to competitive or aggressive driving, harder or tiring driving, and limited freedom of action increasing the risk of traffic accidents.

Several indicators have been suggested to measure congestion, which include difference in speed during free flow and actual speed, mean journey times, variability of journey times, throughput (total number of vehicles per time interval that pass a point on the carriageway), queue lengths, speed differential between lanes, delay per hour/day, etc. These indicators can be grouped into three broad categories, namely traffic influencing events (traffic incidents, work zones and weather), traffic demand (fluctuations in normal traffic) and physical road features (physical and geometric characteristics of the road, poor traffic control devices and physical bottlenecks (capacity) of the road).

A number of empirical models such as segment delay index, travel time index, queue length, lane mile duration index and LOS are suggested by the Highway Agency (1997), and Dft (2003, 2005). However, these models have advantages and limitations with regard to applicability in different contexts. So there is a necessity to identify appropriate models to analyse congestion scenario on a road, or in a road network, in a city or in a particular area like CBD of a city. The models applicability and limitations need to be evaluated with respect to the context (i.e., locations, type of functions in the locations and type of roads) and availability and possibility and ease of collection of data.

Several approaches to alleviate the challenges of congestion have also been proposed. Measures to reduce traffic congestion can be categorised into supply management, land use management and transportation demand management. The measures under these three broad categories range from meticulous traffic design, application of ITS, efficient vehicle routing, punctuality of routes and diversion of vehicles, congestion pricing, park-and-ride lots, high-occupancy-vehicle lanes, high-occupancy-toll lanes, employer commute option programs, telecommuting, alternative work schedules, to traffic calming measures. It is also argued that increase in infrastructure could only partially address the problem. Thus, in the wake of increased traffic flow, development of cost-efficient policies which would alleviate traffic congestion and address negative externalities in terms of environmental impact and cost to the economy, is of paramount importance.

The literature reviewed above forms the basic framework for this analytical investigation of traffic congestion in the study area and devising traffic congestion reduction measures.

3. CHAPTER 3: STUDY AREA PROFILE

3.1 INTRODUCTION

An investigation of the study area is essential to understand the socio-economic-, spatial- and environmental characteristics, the prospects and problems of the area for successful development of planning guidelines for an efficient transportation system as well as for taking measures to alleviate traffic related challenges, including traffic congestion. In this chapter, an attempt is made to investigate and understand the various attributes of the study area which influence the road transportation system in general and the occurrence of traffic congestion in the study area. The attributes being discussed include the demographic and socio-economic parameters of the study area such as industrial-, mining- and tourism resources; spatial features and land use; the social- and physical infrastructure; the road network and various road transportation related challenges faced by the study area under the existing scenario.

3.2 BACKGROUND OF STUDY AREA

The area in and around the central business district (CBD) of Kimberley City is considered as the study area for this investigation. Kimberley City is situated on the latitude 28.7419°S and longitude 24.7719° E. Kimberley is the provincial capital of Northern Cape having a combined urban population of more than 236000 (Census, SA, 2011). It has a total of 49 suburbs (districts and townships included) and a designated CBD. Although it is one of the 21 secondary cities of the country, it is the largest urban area in the Northern Cape. More importantly it is the historical site of the first major mineral discoveries in South Africa and is primarily known for its diamond mining activities. Kimberley is connected to various major cities of the country such as Johannesburg, Pretoria, Cape Town and Bloemfontein by national roads. As Kimberley is situated at an average distance of 800 km each from some of the major cities in South Africa such as Cape Town, Polokwane, Nelspruit and the town of Springbok, it seems from the road network point of view that the city is the central point of the country. In recent years however, the economic functions of the city have been changing because of the reduced mining activities.

The city has considerable historical significance. The first significant diamond in South Africa, *The Star of Africa,* was discovered here in 1866. This discovery resulted in the arrival of the British De Beer brothers and the consequent new rush to the area. On the 5th of July 1973 (Roberts, 1976) , the name New Rush was by proclamation changed to Kimberley in honour of the Earl of Kimberley, British Secretary of State for the Colonies. Kimberley was besieged at the beginning of the Second Boer War on 14th October 1899. Though lifted on 15 February 1900, the war continued until May 1902. The British had built a concentration camp at Kimberley to house Boer women and children during that period. In 1912 the separately administered boroughs of Kimberley and Beaconsfield amalgamated to form the City of Kimberley.

Though a considerable degree of urban segregation already existed before the Apartheid era, the Group Areas Act was implemented in the city during this era. As a consequence communities were divided according to legislated racial categories, namely European (White), Native (Black), Coloured and Indian. Residential segregation was enforced in a process which saw the creation of new townships at the Northern and North-Eastern edges of the expanding city.

With the establishment of 9 provinces in South Africa in 1994, the Northern Cape became a province with Kimberley as its capital. From that time onwards the city underwent considerable development, as administrative departments were set up and housed for the governance of the new province and renamed as Sol Plaatje Municipality by the city council (Figure 3.1).

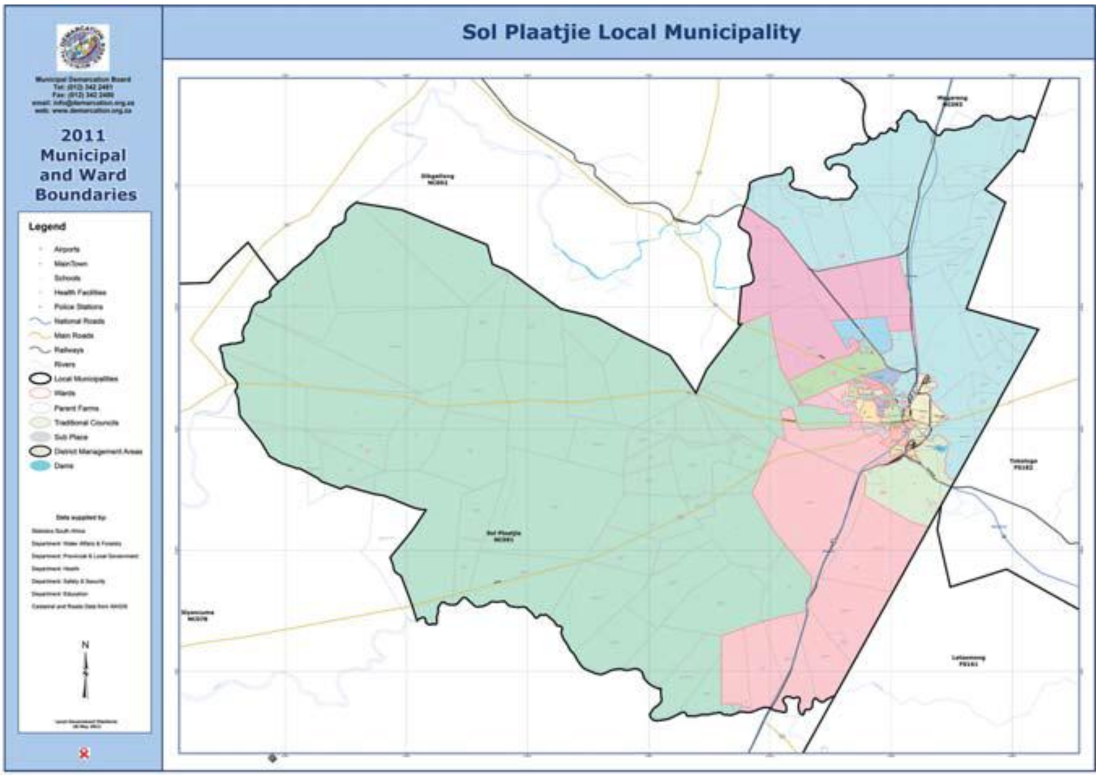

Figure 3.1: Boundaries of the city Kimberley (Source: SolPlaatje Municipality, 2015)

3.3 SPATIAL PROFILE

The Spatial Development Framework (SDF) of a city provides development rationale for promoting sustainable urban development within a defined urban area. The city Kimberley has the following five spatial layers (IDP, Sol Plaatje Municipality 2012-2017):

- Suburbs and townships
- The urban edge
- The road system: Transport corridors and routes
- Open space systems: Heritage and sensitivity
- A hierarchy of activity nodes

3.3.1 Suburbs and Townships

Kimberley has a designated CBD and 49 suburbs (including townships) which are presented in Table 3.1. These suburbs are mostly residential areas in which the majority of the city's population reside.

Table 3.1: Suburbs and townships of the city Kimberley

Sl. No	Suburbs/ Townships	Sl. No	Suburbs/ Townships	Sl. No	Suburbs/ Townships
1	Albertynshof	18	Hadison Park	34	Mint Village
2	Ashburnham	19	Herlear	35	Moghul Park
3	Beaconsfield	20	Heuwelsig	36	Monument Heights
4	Belgravia	21	Hill Crest	37	Newton
5	Carters Glen	22	Homelite	38	New Park
6	Cassandra	23	Homestead	39	Platfontein
7	Colville	24	Homevale	40	Rhodesdene
8	De Beers	25	Kenilworth	41	Riviera
9	Diamant Park	26	Kestellhof	42	Roodepan/ Pescodia
10	Du Toit's Pan	27	Kimberley North	43	Royldene
11	El Torro Park	28	Kirstenhof	44	Roylglen
12	Ernestville	29	Klisserville	45	Southridge
13	Floors/ Florianville	30	Labram	46	Squarehill Park
14	Galeshewe incl "Old No 2"	31	Lindene	47	Vergenoeg
15	Gemdene	32	Malay Camp	48	Verwoerd Park
16	Greenpoint	33	Minerva Gardens	49	West End
17	Greenside				

3.3.2 The urban edge

An urban edge has been introduced in the city to halt the urban sprawl and to develop a compact city and intensified activities in accessible locations along the public transport routes. It also assists in protecting naturally sensitive areas of the city.

3.3.3 The road system

The city has a hierarchical road system. The roads are classified as arterial or collector roads (U3-arterials, and U4- local collector roads) (COTO, 2012). The movement system in the city is based on the creation of a ring road system that dissects strategically with spokes radiating from the central axis (inner City) and connects the outer areas (refer map 1 annexure VII).

3.3.4 Nodes

A hierarchical system of existing and proposed activity has been identified in the city. The nodes are delineated on the city map by means of a nodal boundary. Any land use within the delineation has certain rights and/or constraints. The purpose is to contain any business activity and/or area outside the demarcated and identified nodes. The municipality delineated the nodes based on factors such as:

- Levels of accessibility (existing and in line with proposed new links) which inform the order of the node
- Existing level of activity, including a mix and range of services available
- Areas of proximate developable land
- Surrounding land uses and other opportunities, which give direction regarding the (potential future) nature and role of the node (IDP, Sol Plaatje Municipality 2012-2017)

3.3.5 Open space system: Heritage and sensitivity

Ecology and protection of natural elements such as diversity in plant and animal life are the most important considerations for the creation of open space systems in the city. The various open space systems or ecologically sensitive areas near Kimberley include Kamfers Dam which – whilst impacted by human activity is particularly unique in the local natural system; water rich areas draining from Galeshewe and Ashburnham towards the Kamfers Dam pan; and watercourses coming from the West End running towards the dam north of the Legislature building and Wit Dam.

3.3.6 Urban pattern and land use

The city has a central inner city known as the CBD. Arterial roads radiate from the city centre and major roads pass through it, representing a concentric radial pattern (Figure 3.2). The largest part of the city is comprised of residential areas with most of the major commercial and administrative activities located in and around the CBD. The mining areas are located in and around the city. The largest open diamond mine in the world excavated by hand known as The Big Hole, is located in the proximity of the CBD.

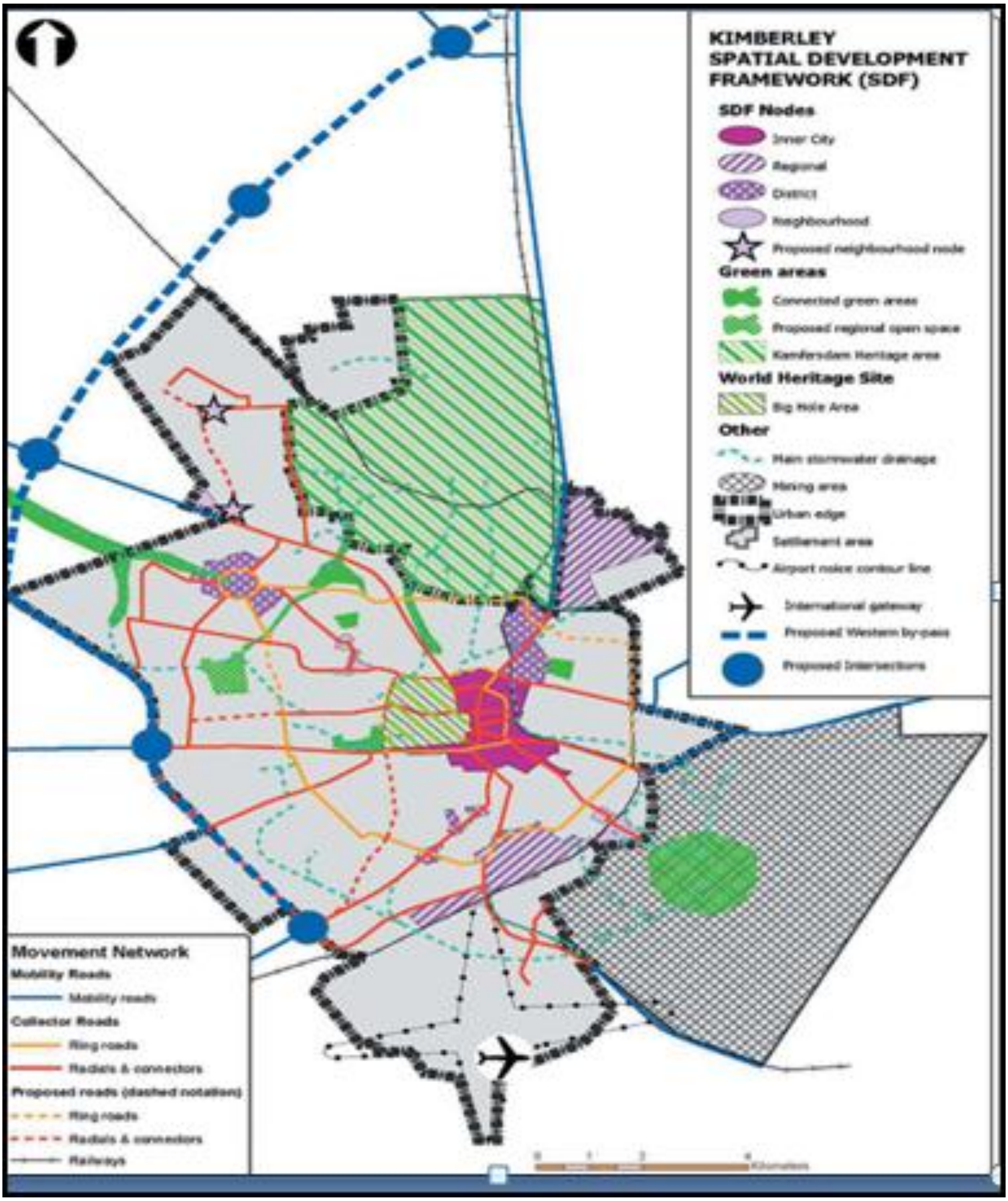

Figure 3.2: Land use and spatial development framework of the city Kimberley

(Source: Sol Plaatje Municipality, 2015)

3.4 DEMOGRAPHIC PROFILE

3.4.1 Population

The population of Kimberley city in 2011 was just over 236000 (Statistics, SA, 2011), which is about 20% of the total population of the Northern Cape for the same year. As seen in Figure 3.3, the growth in the population of Kimberley has followed a similar trend to that of both the Northern Cape Province and South Africa over the same period of time. The average population growth rate of Kimberley over the last decade (1.18%) is observed to be higher than the national average (0.98%) and marginally lower than that of the Northern Cape Province (2.26%). The population density of Kimberley city is 1439.23 persons/ sq. km, which is much higher than the average population density of the Northern Cape (3.1 persons/sq.km) and the national average (43.39 persons/sq. km). This implies that Kimberley is the most dominant city in the province. The number of households in the city were 62946 in 2011 and it follows the same trend than that of population growth (Figure 3.4). The average family size is observed to be 3.86, which has remained almost constant over the last decade.

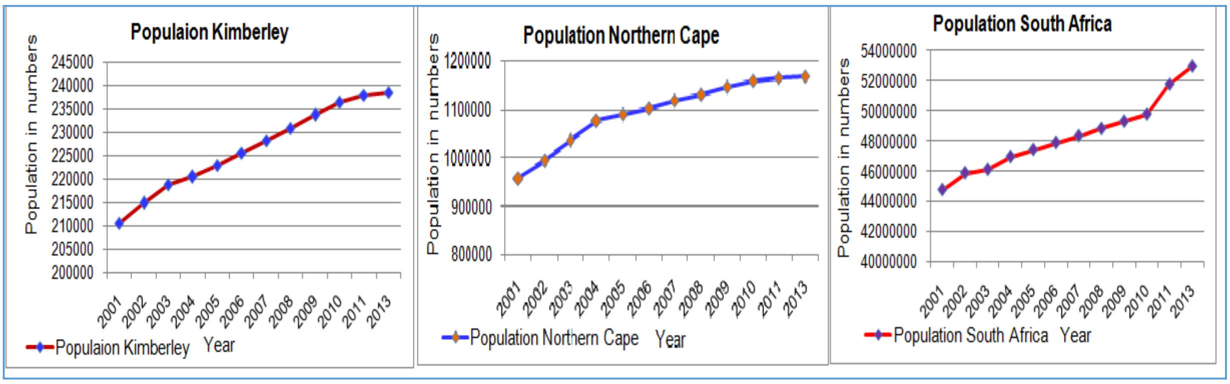

Figure 3.3: Population of the city Kimberley, the Northern Cape Province and South Africa for the years 2001 to 2013 (Source: IDP, Sol Plaatje Municipality, 2012)

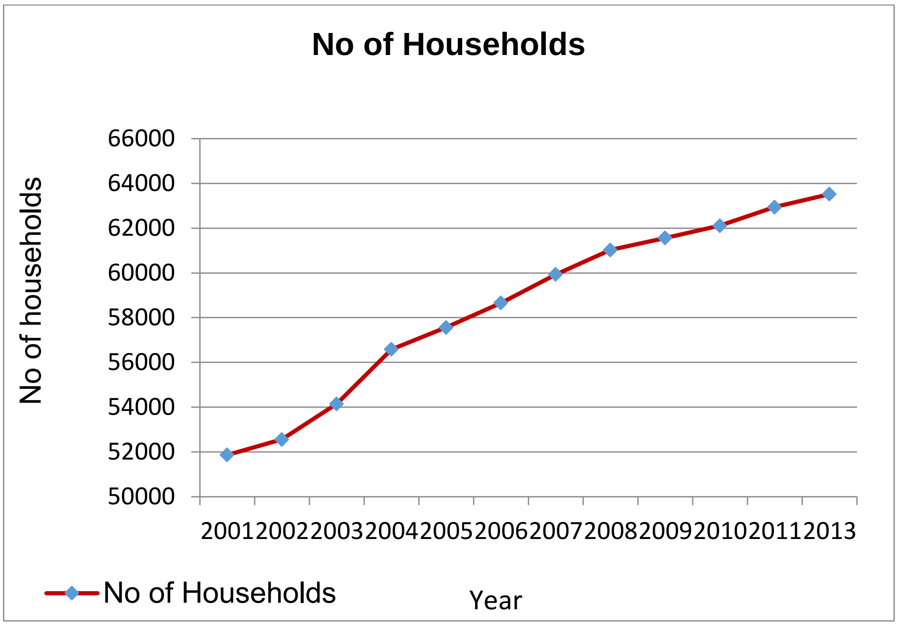

Figure 3.4: Number of households in the city Kimberley (Source: SA Census, 2011; IDP, Sol Plaatje Municipality, 2012)

3.4.2 Gender demographics (Age-gender Structure)

Figure 3.5 presents the age-gender structure of Kimberley City and of South Africa. Not only can it be observed that the age gender structure of the city Kimberley is similar to that of the country, but also that most of the population (about 36% of the total population) fall within the age categories 15 - 34 years, indicating presence of large young groups. Similarly, 68% of the population fall within the categories 15 - 65 years, indicating a large employable population which needs movement facilities in the city. However, the population pyramid of the city Kimberley has a narrower base (age group between 0-14 years) and a wider middle portion (age group between 15-64 years) than the national population pyramid (SA Census, 2011). This implies that there is higher migration to the city and a consequent larger urbanisation (IDP Sol Plaatje Municipality, 2012). Also, presence of significant size of population belonging to young group working group indicates that there is a need for significant vehicular transportation to cater to the daily travel needs of people.

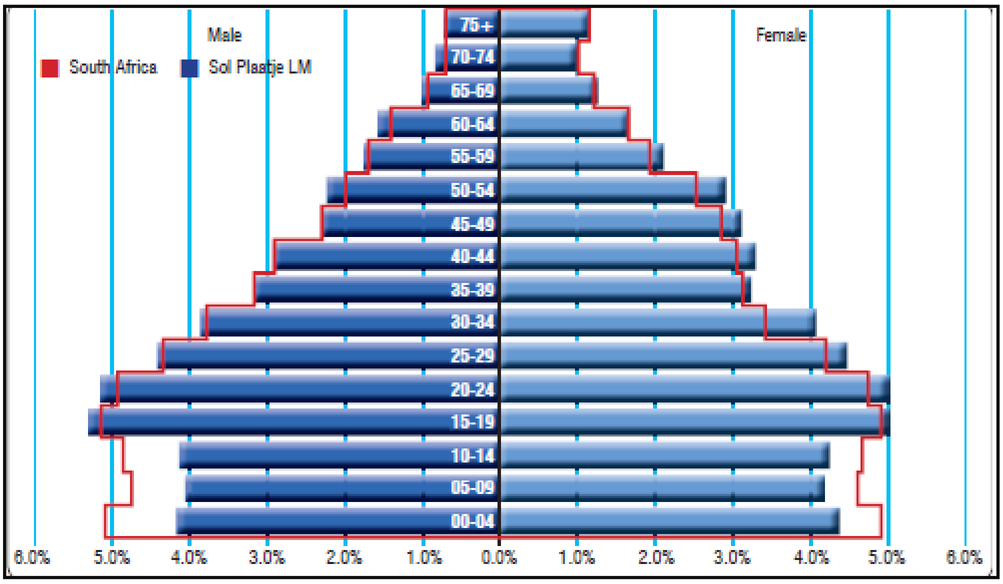

Figure 3.5: Gender demographics of the population Kimberley city, 2010

Source: IDP Sol Plaatje Municipality, 2012.

3.5 SOCIO-ECONOMIC PERSPECTIVE OF THE CITY

3.5.1 Economic sectoral composition

It is observed that the economy of Kimberley constitutes all three sectors of the economy, namely primary, secondary and tertiary sectors. Figure 3.6 presents the composition of the economic sectors in Kimberley City. The tertiary sector, which is primarily concentrated in the community and government services sub-sector, largely dominates the economy of the city, constituting about 82.60% thereof. In contrast to the primary sector (9.50%), the contribution of the secondary sector is the lowest (7.90%). Community services (33%), followed by the financial sector (24%), are the major tertiary sector activities contributing to the economy of the city. Public administration (13.9%), education (6%), health and social work (6.6%) and other community services (6.2%) are observed to be the major constituents of the community services economy of the city (IDP Sol Plaatje Municipality, 2012).

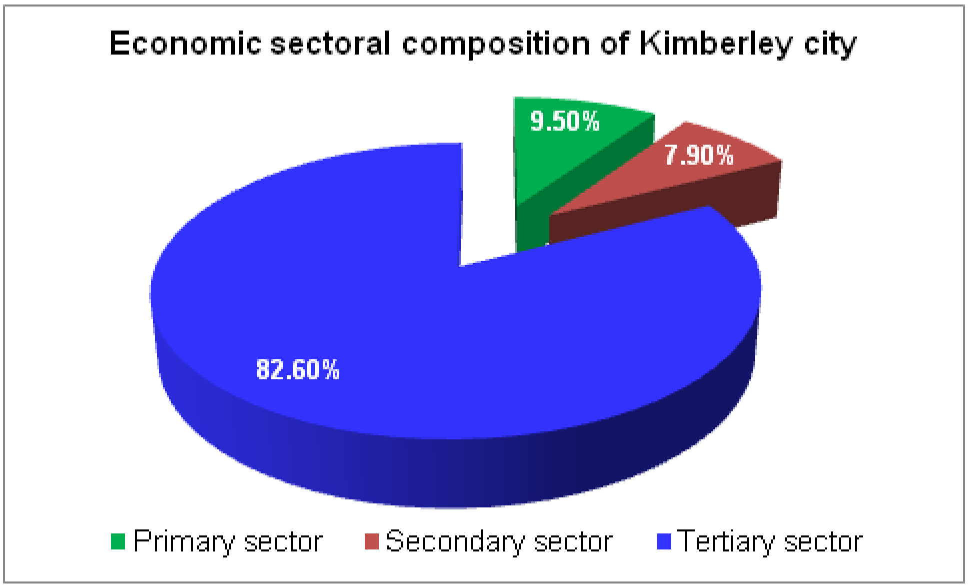

Figure 3.6: Sectoral composition of the economy of Kimberley

The location quotients of the various subsectors of the economy (Figure 3.7) show that community services, finance and transport have higher location quotients – even higher than the national average. This indicates that these three subsectors are more concentrated in the city, having dominant presence. Whereas trade has average presence and construction, mining, electricity and agriculture less than average presence, manufacturing has the minimal presence in the city.

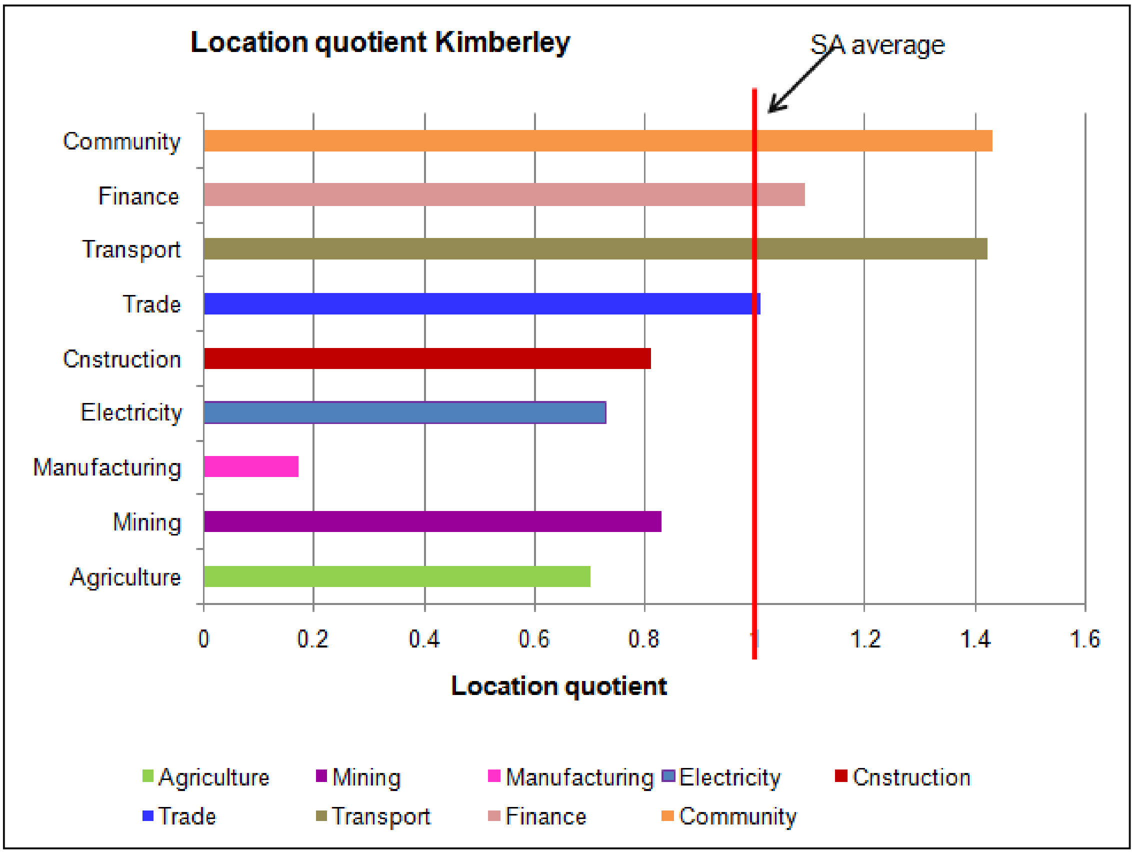

Figure 3.7: Location quotient of various economic activities

Source: Calculated based on statistical data from Sol Plaatje Municipality and Statistic SA, (2011)

3.5.2 GDP of the city

The GDP contribution of Northern Cape Province is about 2.4% of the national total. However, Kimberley City contributed one third (29.7% of the GDP) to the Northern Cape Province economy in the year 2010 and 0.7% to the National GDP (Statistics SA, 2010; IDP Sol Plaatje Municipality, 2012-2017) (Figure 3.8). In absolute monetary terms, it amounts to R18.9 billion in current prices. As seen in Figure 3.9, after experiencing ups and down during the middle part of the last decade (from 2004 to 2008), the GDP growth in Kimberley follows a classical "V"-shape from 2008 onwards, reaching the nadir (-2.1%) in the year 2009. However, it recovered gradually, attaining a growth rate of 5.3% in the year 2011. Although the average GDP growth rate during the last 8 years (between 2004 and 2011) is about 2.75%, the scenario indicates that the GDP is on the path of recovery (Statistics SA, 2010; IDP Sol Plaatje Municipality, 2012).

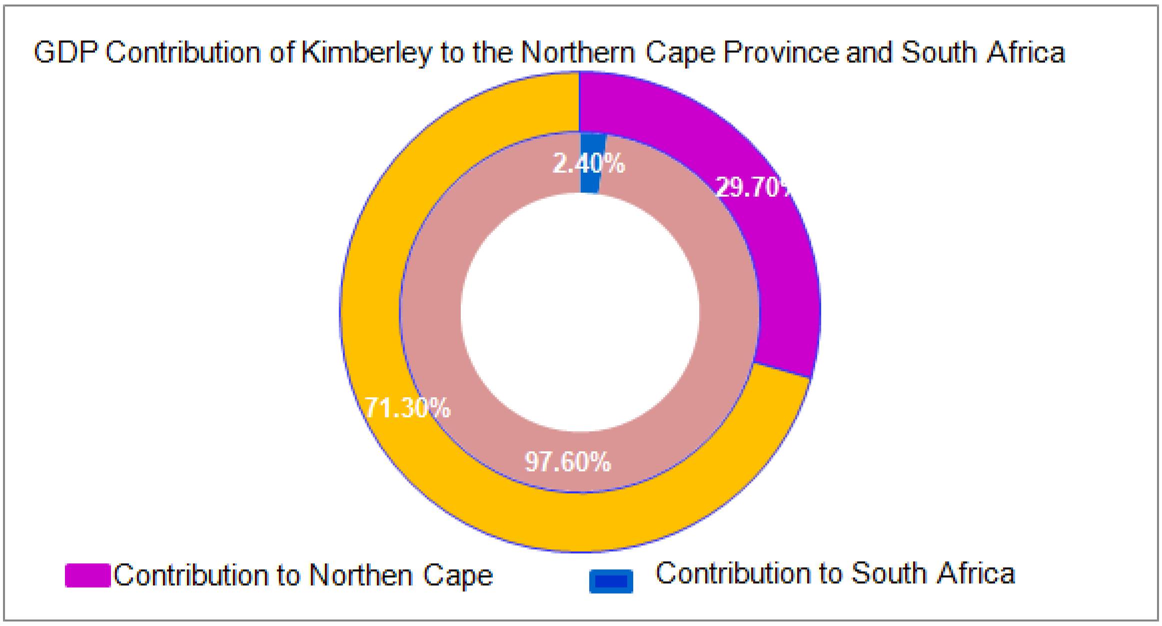

Figure 3.8: GDP contribution of the city Kimberley to the Northern Cape Province and South Africa

Source: Based on statistical data from Sol Plaatje Municipality and Statistic SA, (2011)

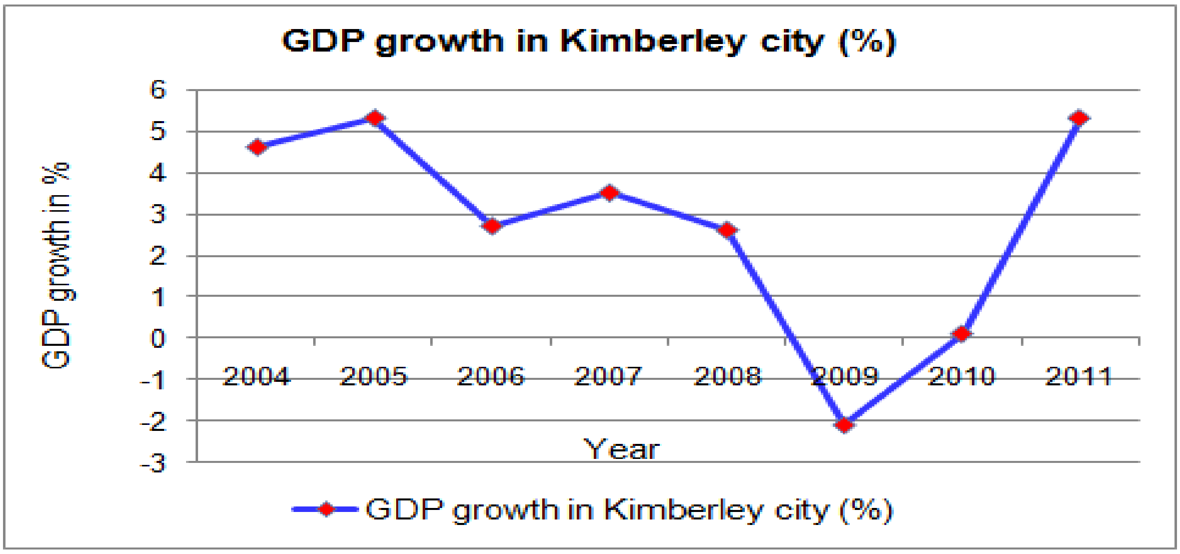

Figure 3.9: GDP growth in the city Kimberley

Source: Based on statistical data from Sol Plaatje Municipality and Statistic SA, (2011)

3.5.3 Employment active population (EAP) and employment

Figure 3.10 shows the yearly variations in the employment active population **(**EAP) of the city Kimberley from the year 2004 to 2011. It is observed that in the year 2011 more than 35.0% of the population of the city Kimberley were economically active (EAP), which in absolute terms of number is a population of 80500, although according to demographic characteristics of the city about 65% people can work. It has reached its highest (83500) during the year 2008.

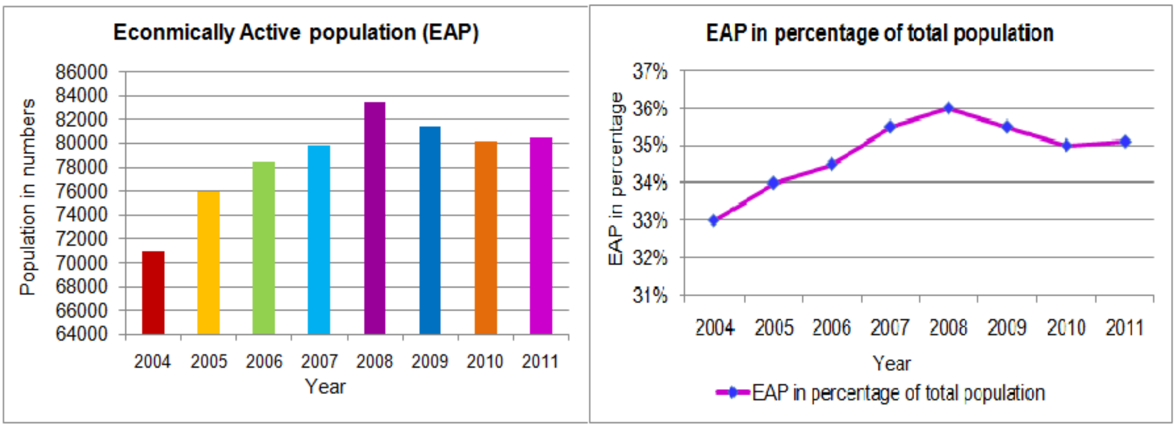

Figure 3.10: Economically active population in the city Kimberley (Statistics SA, 2011; IDP Sol Plaatje Municipality, 2012)

3.5.4 Sector wise occupation

Figure 3.11 shows a sector wise presentation of occupations in the city. It can be observed that community services (35.0%), and trade (23.0%) have the largest percentage of employees in the city. Household activities followed by finance are the next subsectors which employ a significant number of people. Construction and manufacturing fill a segment of about 5% each of the total employment, which seems to be higher in terms of their contribution to the GDP. Mining and agriculture employ only about 3.0% respectively of the total number of employees and the electricity subsectors a very meagre 0.6% (Statistics SA, 2011; IDP Sol Plaatje Municipality, 2012). It indicates that a significant section of the people and activities in manufacturing and other industries warrant significant vehicular travel needs in the city.

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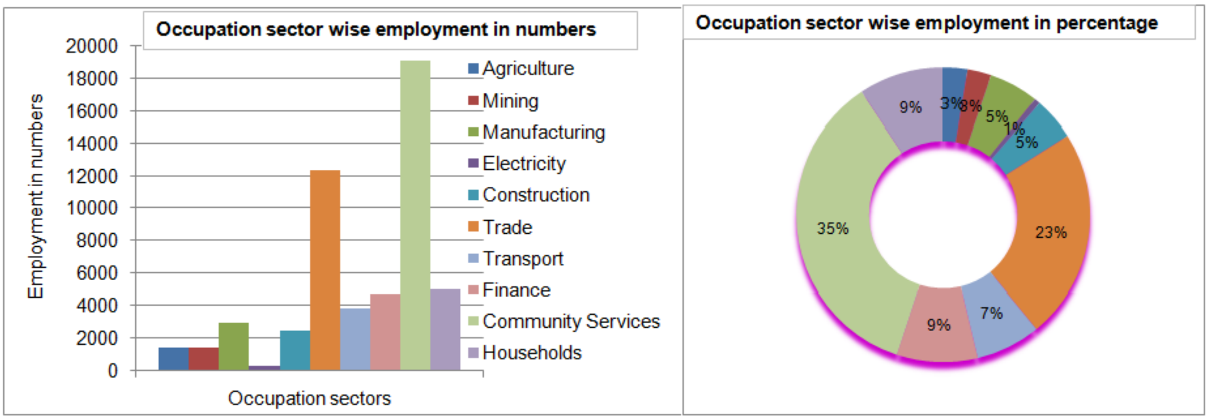

Figure 3.11: Sector wise presentation of occupations and their employment in numbers in Kimberley (Statistics SA, 2011; IDP, Sol Plaatje Municipality, 2012)

3.5.5 Income and Expenditure

An analysis of households per income category (Figure 3.12) indicated that the numbers of households in the lowest income category were showing a declining trend from the year 2004 to 2010. Where more than half (57%) of the households in the city belonged to the lower income category (ZAR 0-72000) in the year 2004 and it has declined to about 43% in the year 2010. However, the number of households in the lower middle and middle income group (72001-360000) has increased to about 46% in the year 2010 as against the 37% in the year 2004. On the other hand the number of households in the higher middle and higher income groups (360001-2400000 and >240000) have also increased from 6% in 2004 to 11% in 2010. This implies that the income of the households has increased significantly over the last decade and currently the majority of households belong to the middle income groups in the city. It can also be seen in According to IDP, Sol Plaatje municipality (2012), the annual per capita income of the city Kimberley for the year 2010 has been estimated at R40500, which was significantly higher than the provincial average of R30200. The Gini coefficient (0.65) is also relatively high, indicating an unequal distribution of income in the city as shown in Figure 3.12. The unequal income distribution occurs because of the diversity in occupation pattern seen in the city, for example people working in agriculture or community service have lower incomes than the people working in the manufacturing sector or mining sector.

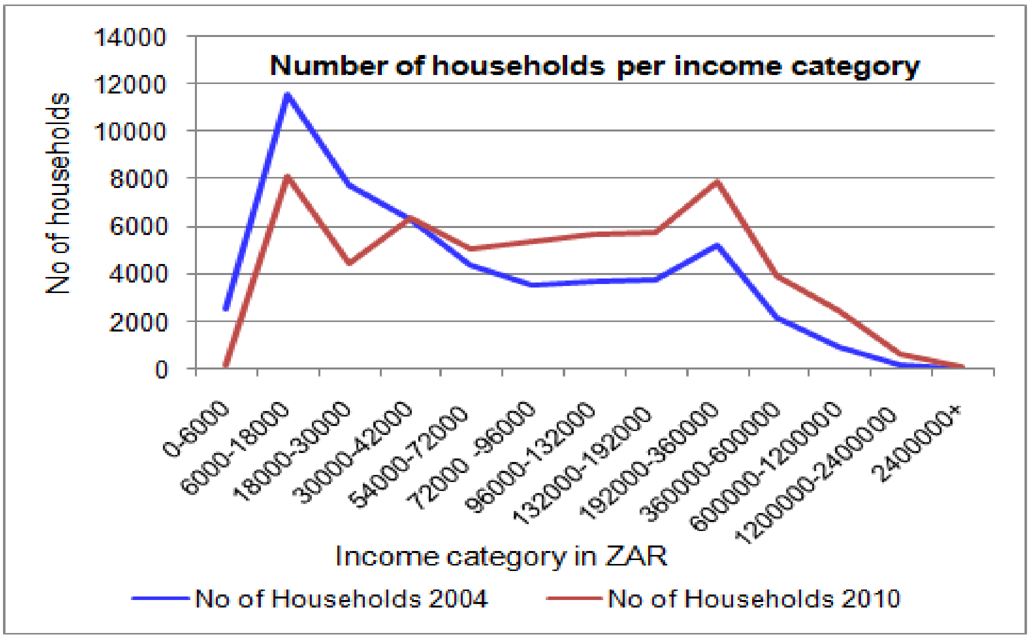

Figure 3.12: Number of households per income category in Kimberley

Source: (Statistics SA, 2011; IDP, Sol Plaatje Municipality, 2012-2017)

The expenditure pattern (Figure 3.13) in the city shows that more than one third of the income (more than 34.0%) is spent on basic services such as food (16.67%), accommodation (13.69%) and clothing (3.34%). Transportation accounts for 12.81% of the expenditure and taxes for 13.27%. Where the expenditure on medical schemes and finances is 6.44% and 5.57% respectively, a meagre 3.0% - 3.5% each is spent on alcoholic beverages, education and personal care. About 21.0% of the expenditure is found to be unaccounted for. It is thus clear from this figure that people in the city spend a significant amount on basic services and transportation.

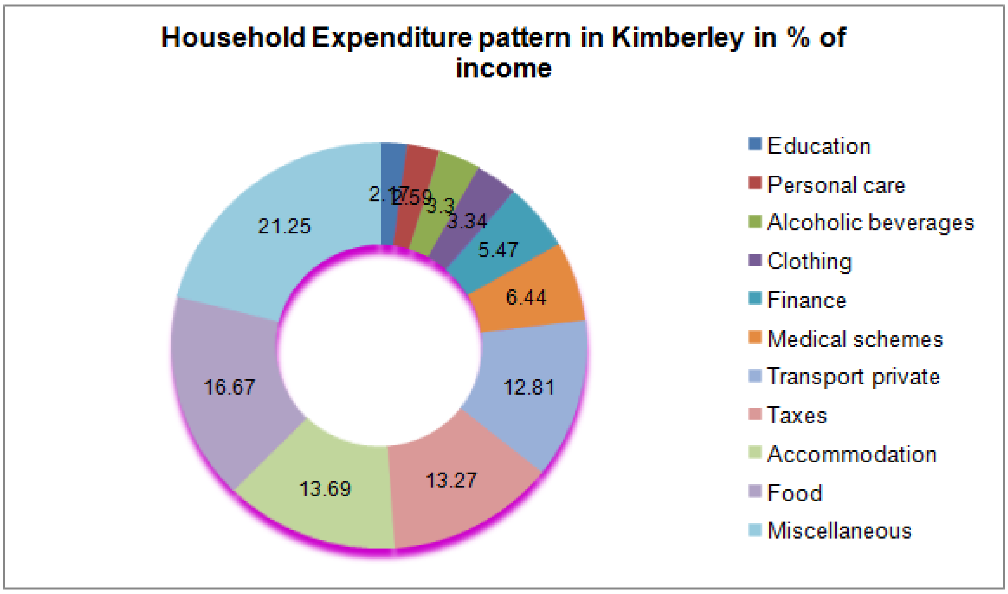

Figure 3.13: Household expenditure pattern in the city Kimberley in % of income (Statistics SA, 2011; IDP, Sol Plaatje Municipality, 2012-2017)

3.5.6 Education and Health

In the year 2010 about 86.4% of the population in the city were functionally literate, which is 3.6% higher than the year 2004. Of these, about 48.0% have an education level lower than a matric certificate and about 14.0% having obtained a pass in their matric certificate without any further education (Statistics SA, 2011). This implies that the city has a significantly higher literacy rate, which is associated with higher levels of urbanisation and higher access to schools. Kimberley also has a number of hospitals and clinics in the private sector in addition to hospitals in the government sector. These hospitals are located in the important roads such as Du Toitspan Road which is close to the CBD area and thus impact traffic movement on the roads in and around the CBD of the city.

3.5.7 Civic facilities and utilities

About 64.0% of the households have access to piped water in their dwellings whereas about 30.0% of the households have access to water supply in their yards. About 6% of the households have no formal water supply system and depend on various other sources (Data from Sol Plaatje Municipality, 2015). It is evident that the percentage households having piped water supply has increased over the years, but a major concern is that simultaneously the number of households having no formal water supply has also increased significantly in the last decade (Data from Sol Plaatje Municipality, 2014).

About 90.0% of the people have flush toilets, whereas 7.4% and 1.6% of the households have pit toilets and a bucket system respectively and about 1.1% of the households do not have any toilets at all. While the scenario of flush toilets has remained more or less same, the number of pit toilets has significantly increased from 2.2% in 2004 to 7.4% in the year 2010. This occurred because of the conversion of bucket type toilets to pit toilets. The number of households with bucket type- and no toilets has decreased marginally in the last decade. The majority of households have access to solid waste collection and refuse disposal (Data from Sol Plaatje Municipality, 2015).

The majority of households (86.0%) were connected to electricity for lighting and other household activities in the year 2010, which is a significant increase since the year 2004. In 2010 only 4.0% of households used electricity for lighting only, which is significantly less than the 12.0% in the year 2004. The number of households without any electricity is about 10.0% which has remained almost constant over the last decade (Data from Sol Plaatje Municipality, 2015).

It can thus be concluded that the scenario of civic facilities and utilities in the city Kimberley is encouraging. It is clear that most of the households have access to water supply and that a high percentage of households have access to electricity, sanitation and a solid waste disposal system.

3.6 TOURISM

Kimberley City projects itself as a significant tourist destination. The city has a diversity of museums and visitor attractions. It also acts as a gateway to other Northern Cape destinations which include the Mokala National Park, nature reserves and numerous game farms or hunting lodges, as well as historic sites of the region. It is noticed that the number of tourist trips to the city has increased at an average annual rate of 1.8% since 2004 and the total number of tourist trips amounts to 130,829 in 2011 (Department of Tourism, Northern Cape province, 2012). Holidays, leisure and visits to relatives and friends dominate the tourism scene in the city, but there is a meagre presence of business tourism in the city.

3.7 CENTRAL BUSINESS DISTRICT (CBD)

Kimberley city has a designated Central Business District (CBD) (Figure 3.14) which performs important urban functions of the city and provides facilities for both commercial and administrative activities. Spatially, it is bounded by Quinn Street in the East, Cecil Sussman/Quinn Street in the North, Cecil Sussman/Bultfontein road in the West, and Lennox Street in the South. The N12 and N8 national roads intersect in the area (Figure 3.15). The arterial roads which generally influence traffic movement in the CBD area, are Long-, Barkley, Bishop-, Carter-, Schmidtsdrift-, Memorial- and Transvaal roads (Phakamile Mabija Road).

Figure 3.14: Arial photo of the CBD of Kimberley City (Source: www.google.com Google earth, 2015)

Figure 3.15: Location of the CBD of Kimberley City (Source: www.google.com Google earth, 2015)

3.8 TRANSPORTATION

Kimberley City is connected to various parts of the country and the Northern Province by all three modes of transportation, namely road, railway and aviation. Kimberley Airport connects the major cities of the country such as Johannesburg and Cape Town with regular scheduled flights. Railway has had significant presence in the city since early years. Under the management of the Cape Government Railways, the railway line connecting

Kimberley to the cities along the Cape Colony's coastline began in 1872and the railway line from Cape Town to Kimberley was completed in 1885, accelerating the transport of both passengers and goods (Burman, 1984; Worger, 1987). The railway reticulation also linked Kimberley with Port Elizabeth, Johannesburg, Durban and Bloemfontein. Since the 1990s onwards there has been a decline in the use of railway and in recent years passenger train services to and from Kimberley are provided by Spoornet's Shosholoza Meyl, which connects Cape Town and Port Elizabeth in the South and Johannesburg in the North. The luxury Blue Train and Rovos Rail also ply through the city. Although two major national roads, the N12 and N8, intersect each other in the city, the central arterial route to the North, the N1 from the Cape to Johannesburg, passes through Bloemfontein and not Kimberley.

3.8.1 Road transportation network and vehicle population

Kimberley City has a well-established hierarchical road network system. As discussed earlier, two of the major national roads, the N 12 connecting Johannesburg in the North-East and Cape Town in the South-West and the N8 connecting Mangaung (Bloemfontein) in the South-East and Grobershoop in the South-West, intersect close to the CBD in Kimberley City. In addition, regional roads such as the R 31, R 64 and the R 357 connect the city with other parts of the country. The R 31, which starts at the Reitfontein border post at the Namibian border, ends at the N12 West of Kimberley City. Similarly, the R 357 which starts at the R77 at Nieuwoudsville, crosses the R 31 and ends at the N8 in Kimberley. Moreover, the R 64 South-East of Kimberley, connects the city with Bloemfontein City in the Free State. One of the peculiarities of the road network system is that the portion of the N8 passing through the city transforms to city arterial roads known as Schmidtsdrift Road, then Long Street closer to the CBD. The portion of the R 64 in the city is known as Lennox Street, which after crossing the N12 becomes Regiment Way. Lennox Street almost overlaps the N12 and R 64 in the city. Similarly, Bultfontein Road in the city overlaps both the N8 and N12. On entering the city, the R 357 regional road is identified as Carters Way. Although it seems that the major roads radiate from the city centre, the road network system in the city has a grid iron pattern. According to COTO (2012), the internal roads are classified as U3 urban minor arterial roads. One of major characteristics of the road network system in the CBD area is that the portion of Bultfontein Road near the Big Hole has been closed down because of the risk of instability and caving in of the road in the surrounding area. This has forced the majority of the heavy vehicles carrying mined products from the mining areas in and around the city, other cargo vehicles travelling to various destinations outside the city and vehicles coming from Johannesburg, to pass through the other arterial roads in the CBD area. Consequently, the roads in an around the CBD area are under heavy pressure because of the combined movement of heavy vehicles in and out of the city and normal inter- and intra-city traffic, which also results in inefficient traffic movement.

Figures 3.16 and 3.17 show the major arterial roads passing though the CBD area of the city. Some of the major roads are Schmidtsdrift Road, Long Road (N8), Transvaal Road (Phakamile Mabija Road - N12), Barkley Road, Pniel Road, North Circular Road, South Circular Road, Bultfontein Road (closed near the Big Hole area), Carters Way, Memorial Road, Main Road, Memorial Road, Du Toitspan Road, Lyndhurst Road, Carrington Road and Oliver Road.

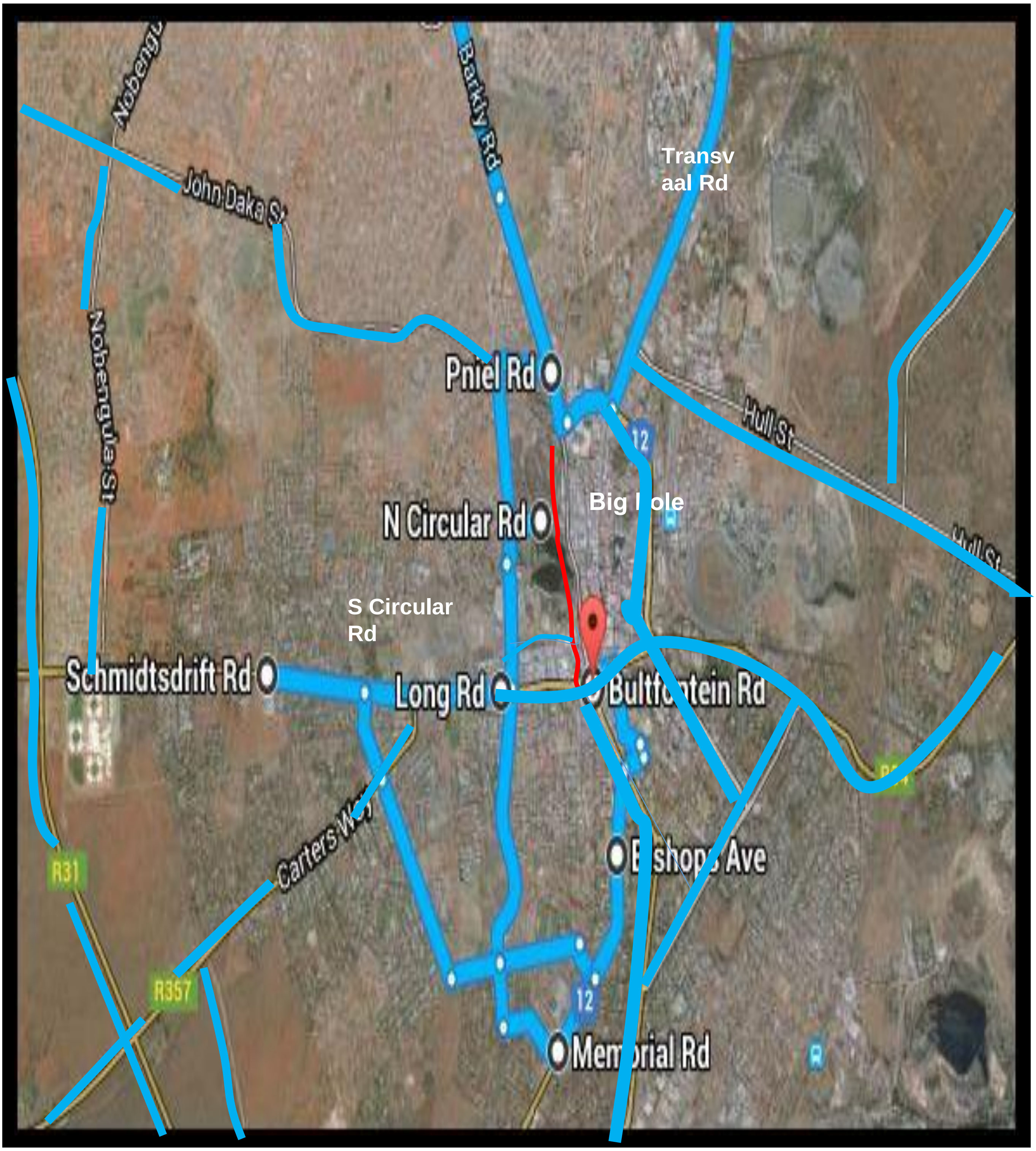

Figure 3.16: Major roads in and around the Kimberley CBD (Source: Sol Plaatje Municipality, 2015)

Figure 3.17: Internal road network of the Kimberley CBD area (Source: www.google maps.com, 2015)

3.8.2 Nodal transfer points

The various nodal points on the road network are bus stations, bus stops, taxi ranks, etc. and the location of these nodal points is presented in Figure 3.16. The smaller circular dots indicate the two main bus stops that serve as the origin points for the other bus stops. All the major roads, except on a few isolated routes, are used regularly by all modes of vehicles throughout the day.

3.8.3 Types and number of vehicles

Figures 3.18a and 3.18b present the number and composition of vehicles (modal split) in Kimberley City and the Northern Cape Province respectively. It is observed that the total number of licensed vehicles in Kimberley City amounts to 63579, which constitutes about 23.6% of the total number of vehicles registered in the Northern Cape Province. Both Kimberley and the Northern Cape Province register similar trends in vehicular growth and in the last five years the number of vehicles in Kimberley and the Northern Cape Province has been increasing at an annual rate of 2.79% and 3.47% respectively. It is also observed that about 58.0% of vehicles in Kimberley City are passenger cars as opposed to the 45.0% of passenger cars in the province. However, the percentage of light load vehicles (30.0%) and heavy load vehicles (2.0%) in the city is significantly lower than the 39.0% and 6.0% for corresponding vehicles in the province. There is not much difference in the percentage motor cycles in the city and the province – 4.0% and 3.0% respectively, as well as the percentage buses and mini passenger vehicles in the city and province– 3.0% and 2.0% respectively (Department of Transport, Northern Cape, 2015). It is thus clear from the findings that in comparison to the province, passenger cars in Kimberley City are the more dominant vehicle type. However, the province has more light and heavy load vehicles. The trend of buses, mini passenger vehicles and motor cycles are similar in both cases.

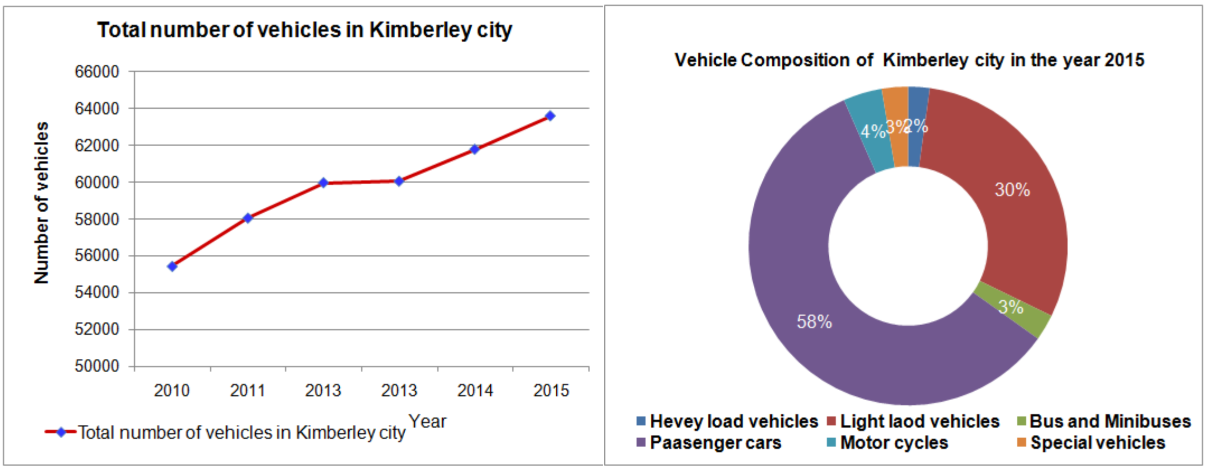

Figure 3.18 (a): Number of vehicles and vehicle composition in the city Kimberley
(Source: Department of Transport, Safety and Liaison, Northern Cape, 2015)

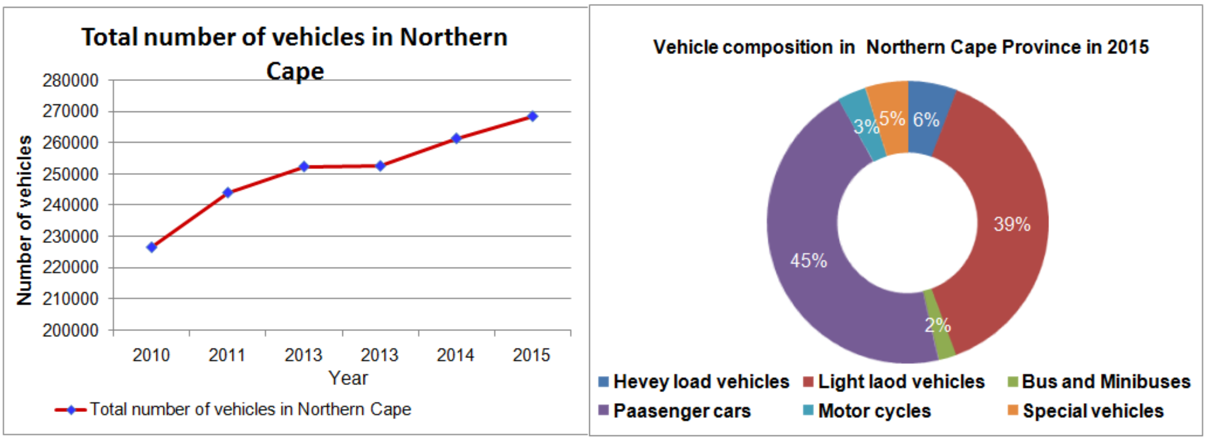

Figure 3.18 (b): Number of vehicles and vehicle composition in the Northern Cape Province (Source: Department of Transport, Safety and Liaison, Northern Cape, 2015)

3.8.4 Public transportation system (Mini-buses and Buses)

Public transportation service in Kimberley City is generally provided by public taxis operating on different routes and connecting various suburbs and nodal points in the city. Taxis offer transportation services both inside the city for short distance travelers and outside the city for long distance travelers. After the discontinuance of Trams in the city in 1947, no further intra-city public transportation service either by bus or tram has been available. However, the city offers historical vintage tram services to tourists who can ride the trams around the Big Hole area. Besides, the city is connected to other parts of the province and the country by long distance bus services offered by transportation companies such as Translux, Greyhound, City to City, SA Roadways and similar companies. The bus terminal is located on the other side of Bultfontein Road at the Kimberley civic centre vicinity, South Africa.

3.8.5 Traffic Management Systems

The traffic management systems of Kimberley, which are almost similar to those of other cities in the country, have the following characteristics (Source: physical road and traffic system survey, 2015 conducted by the investigator):

- Intersections with no control: There are some junctions in the city that have no traffic control or management system such as signalling of any sort. However, this system is limited to only minor junctions and is hardly used inside the city.

- Intersections with a stop control on the minor road crossing a major road: This system is used to access a major road from a minor road. The vehicle must stop before entering or crossing the major road.
- Intersections with a yield control on the minor roads: This system is used to access a major road from a minor road. The vehicle must yield (give way) to traffic on the major road before entering or crossing the major road.
- Intersections with traffic signal controls: The signal will control the traffic in such a way that the one direction will stop while the other direction is allowed to drive. Different phases can be implemented to control directional flow of the traffic. The majority of the junctions, particularly in the inner parts of the city, are signalised either by isolated or synchronous signalling systems. The major junctions are also provided with right-turn signals and pedestrian facilities.
- Intersections with an all-way stop: This controls the traffic by means of requiring all vehicles to stop at the intersection. The driver that stops first departs first. Some of the junctions of the study area are provided with this system.
- Roundabouts: This is a circular intersection with a median situated in the middle. It works on a yield function and is not used for high traffic volumes. There are several such junctions in Bloemfontein City, particularly at the entrance to suburban areas.
- Road pavement marking: All the pavements of roads in the city are properly marked according to rules and regulations provided by the South African National Road Agency Limited (SANRAL) G2 manual.
- Signage: This refers to speed control, directional flow, yielding, stopping, etc. The roads of the city are provided with the proper signage systems according to the requirements.
- Speed traps: These may be fixed cameras or stationed radars and are situated at random points within the city.
- Parking systems: Both on-street and off-street parking systems are found in the city. Such parking may be paid or free parking in the different parking areas. On-street parking is a problem when the road width is insufficient.

3.8.6 Some examples highlighting the traffic management system in the study area

Figures 3.19-3.23 present examples of traffic scenarios and traffic management systems in Kimberley City. Figure 3.19 shows the traffic scenario in the morning hours (about 9.00 am) on the roads close to the CBD of Kimberley City. It is evident that traffic is composed of mixed modes of vehicles such as cars, pick-up vans and heavy vehicles such as trucks, though the majority of vehicles are cars.

Figure 3.19: Traffic scenario on the roads of the city Kimberley

(Source: physical road and traffic system survey, 2015 conducted by the investigator)

The traffic signaling system is shown in Figure 3.20. The signal constitutes of a three phase system (green, amber and red) and is provided as the standards recommended by the Road Traffic signs manual, Traffic Signal Design Volume 3, section 6.12, South Africa, 2012.

Figure 3.20: Traffic control facilities (signaling and pedestrian crossings) at the junctions in the Kimberley CBD area
(Source: physical road and traffic system survey, 2015 conducted by the investigator):

Also, as seen from the Figure 3.20 certain portion of the roads in the CBD area do not have adequate sidewalks or pedestrian pavements, although they are present in majority of the roads. The pavement markings observed on the roads of Kimberley City are presented in Figure 3.21. It is observed that relevant markings such as lane demarcation, no crossing lines and direction signs have been made on the roads of Kimberley City.

Figure 3.21: Traffic control facilities (pavement marking and lane demarcation) at the junctions in the Kimberley CBD area

(Source: physical road and traffic system survey, 2015 conducted by the investigator):

Figure 3.22 presents pavement markings that include lane demarcation, on-street parking facilities for cars and for heavy vehicles for off- and on loading, and pedestrian walkways (roadside pavements) on the roads passing through the CBD area of Kimberley City.

Figure 3.22: Pavement markings showing on-street parking facilities and lane demarcation on the roads in the Kimberley CBD area

(Source: physical road and traffic system survey, 2015 conducted by the investigator):

3.9 IMPLICATION OF SOL PLAATJE UNIVERSITY ON THE TRANSPORTATION SCENARIO OF KIMBERLEY CBD AREA

The Sol Plaatje University is located very close to the CBD area of the city. Although the university is partly in operation, it is expected to be fully operational very soon. According to the National Plan on Higher Education and the Green Paper for Post-School Education and Training, an increase of 20.0% by 2016 and 23.0% by 2030 respectively is envisaged in enrolment for higher education. . Thus the new university will not simply take over existing academic programmes run by other institutions, but will add an array of new courses. It is envisaged that over a period of time the institution will develop as a multi-campus institution, starting with the main campus designed for an initial student population of 5000. Besides accommodation facilities, cultural and social spaces will be located within a walking distance from the university campus. Approximately 5000 students are estimated to use the campus by 2022. A residency factor of approximately 80% is anticipated and the staff component is expected to be approximately 500 members. In addition to increase in pedestrian and bicycle traffic, the university is expected to contribute an increase of about 0.25% to the traffic volume annually.

3.10 CONCLUSION

Kimberley City, located almost in the centre of South Africa, is in addition to its function as the administrative capital of the Northern Cape Province, essentially a mining operation oriented city. Two national roads, the N8 and N12, pass through the city and intersect close to the designated CBD area of the city, resulting in most of the external traffic – in addition to the internal traffic –passing through the city on the roads of the CBD. Some of the major roads such as Long Street and Transvaal Road carry a significant amount of traffic passing through the CBD. It is also observed that adequate traffic control measures such as automated signalling and pavement markings have been provided on the roads of the city. The location of Sol Plaatje University is expected to add to the traffic challenges of the city. Besides, the demographic, social and economic profile that includes mining activities of the city seemingly engender significant amount of vehicular traffic, which results traffic congestion on the roads in and around the CBD of the city. However, a detailed analysis of the various factors relating to traffic congestion challenges and levels of congestion in the city are discussed in chapter 4.

4. CHAPTER 4: ANALYSIS AND RESULTS

4.1 INTRODUCTION

The data collected through various surveys and secondary sources were compiled and statistically analysed. In this chapter the results of all relevant analyses are discussed under the following headings:

- Physical and geometric characteristics of roads
- A traffic scenario analysis
- Perception of the public regarding the variables influencing traffic congestion
- A current traffic congestion analysis
- Forecasting of future traffic
- Simulated traffic congestion analyses and application of re-engineering methods to reduce traffic congestion.

4.2 PHYSICAL AND GEOMETRIC CHARACTERISTICS OF ROADS

A physical road survey was conducted with the assistance of students engaged in studying Civil Engineering on various roads in and around the CBD area of the study area to determine the physical and geometric characteristics of these roads (refer map 1, annexure VII). The various physical and geometric parameters surveyed, were road width, lane numbers, lane width, availability of pedestrian/ bicycle lanes, kerbs, median width, sight distance, radius of curvature, road surface, pavements/ footpaths/ shoulders, control and signalling systems, and availability and type of parking facilities. The results of the survey were then compared to the physical and geometric characteristic design standards recommended by the South African National Road Authority Limited (SANRAL, G2 manual, 1-304) and Guidelines for Human Settlement Planning and Design, Roads: Geometric design and layout planning (Chapter 7, p1-41) to observe the discrepancies in the current road system (if any) and in order to establish whether any relationship exists between physical and geometric aspects of the roads and the occurrence of traffic congestion in the study area.

Table 4.1 presents the results of the physical and geometric characterises of the roads in and around the CBD area of Kimberley City, and Table 4.2 presents the recommended physical and geometric design standards of the roads (SANRAL, G2 manual, 1-304; Guidelines for Human Settlement Planning and Design, Roads: Geometric design and layout planning (Chapter 7, p1-41).

It has been established that Long Street, Transvaal Road (Phakamile Mabija Road), Carter Road, Schmidtsdrift Road, Barkley section 2 (impacting Transvaal) Road, Memorial Road and Main Street are U3 minor arterials and that other roads such as Bishop`s Road, Barkley Road, North Circular Road, South Circular Road, Du Toitspan Road, Lyndhurst Street, and Cecil Sussman Road can be categorised as U4 local collector roads. All the roads have at least two lanes in their road segments, which in general transform to three lanes near the junctions to facilitate left- and right turns.

The width of the roads varies between 5.9m (narrowest) and 9.3m (widest). As a result the lane widths vary between 2.95m to 4.65m. A comparison with the recommended standards indicated that lane widths and consequent road widths of all the roads except Barkley Road section 2 (impacting Transvaal Road) are less than the recommended standards and therefore do not conform to the design standards. The lane widths of Carter Road (3.65M), Transvaal Road (influenced by Pniel Road) (3.55M), Du Toitspan Road (average 3.6m) and Cecil Sussman Road (average 3.5m) are within the acceptable range of 3.5 m to 3.75m. However, Long Street, Bishop`s Road, Barkley Road, Memorial Road, Main Street, Lyndhurst Street, North Circular Road and South Circular Road have inadequate road lane widths.

All the roads surveyed – except Barkley Road and Schmidtsdrift Road – have pedestrian pavements or shoulders, but no bicycle lanes or bicycle movement facilities are available. The pedestrian facilities or pavements of roads such as Long Street, Carter Road, Barkley Road section 2 (impacting Transvaal), Du Toitspan Road and Lyndhurst Street are fully paved and in a proper condition. However, the pavements and pedestrian facilities of other roads such as Bishop`s Road, Main street, Memorial Road, North Circular Road, South Circular Road, and Cecil Sussman Road are either partially paved or in some places not well maintained. The pavement widths vary between 1.0m to 7.0m and are in most cases more than 1.5m. There are kerbs on the roadsides of all the roads except Barkley Road as it does not have any pavement facilities.

Medians are found in Long Street, Schmidtsdrift Road, Toitspan Road and Main Street. The widths of medians in these streets vary between 1.0m and 1.2m. There are no medians in any of the other roads, but the roads are divided by continuous pavement markings (lines) in order to divide the roads into separate ways.

No sharp curves were observed in any of the roads. The curves on the roads are more or less gentle with a larger radius of curvature than the recommended 210m. The sight distance measured in different sections of the roads is more than 100m and at some places even more than 150m to 200m, which is much higher than the recommended sight distance of 41m (calculation based on the allowable speed of 60km/h in urban roads).

The gradient of the roads, measured at different sections in all the roads in the CBD area, is found to be within the range of 1.0% to 2.0%, which is less than the acceptable gradient limit of 6.0%.

All the roads observed are sealed. The road surface condition of Carter Road, Memorial Road, Transvaal Road (Phakamile Mabija Road), Main Street, Lyndhurst Street, and Du Toitspan Road is good, whereas the road surface condition of all other roads is acceptable. No potholes – except for occasional lines and cracks – are found on these roads.

All the junctions on these roads are controlled by automated traffic signalling systems with a cycle time varying between 70 seconds to 140 seconds during the peak hours.

On-street parking systems in the form of parallel parking are available in some segments of Long Street, Memorial Road, Schmidtsdrift Road, Du Toitspan Road, Main Street and Transvaal Road (Phakamile Mabija Road). All other roads do not have any kind of parking system. It has also been observed that the on-street parking facilities available on the road sections except Long Street and Transvaal Road (Phakamile Mabija Road) passing though the CBD do not interfere with the traffic movement on the roads.

However, on street parking on Long Street and Transvaal Road (Phakamile Mabija Road) is found to be a cause of concern with regards to traffic congestions, particularly during peak hours.

4.2.1 Summary of findings of the physical survey

- The roads are either national, regional, minor arterial (U3) or local (U4) roads.
- The major roads such as Long Street, Bishop`s Road, Barkley Road, Memorial Road, Main street, Lyndhurst Street, North circular Road, South circular Road, have inadequate lane widths and consequent road widths, which is a cause of concern with regard to traffic congestion.
- The majority of the roads do not have physically built median structures and the roadways are divided by road marking (lines). In the CBD area this may cause challenges in traffic movement because of the interference of oncoming traffic.
- There are kerbs on the roadsides of almost all roads except Barkley Road which does not have any pavement facilities.
- Adequate pavements for pedestrians are available on the road sides of all the roads except Barkley Road. While the pavement facilities of a number of roads are permanently paved, the pavements on the sides of a significant number of the roads are either partially paved or remain unpaved. However, pavements do not seem to interfere with the traffic movement and do not influence the congestion on the roads.
- On-street parallel parking facilities are available in certain segments of Long Street, Transvaal Road (Phakamile Mabija Road), Carter Road, Main Street, Schmidtsdrift Road and Du Toitspan Road. The parking facilities available on these road sections do not interfere with the traffic movement in general. The on-street parking facilities provided in Long Street and Transvaal Road are a cause of concern with respect to traffic congestion – particularly during the peak hours.
- The surface conditions of all roads are either acceptable or good. No apparent challenges such as potholes or broken sections which could interfere in the smooth traffic movement were observed.
- All the roads have adequate sight distance.
- The curves on the roads are gentle and the gradient of the roads are within acceptable limits.

Table 4.1: Physical and geometric characteristics of the roads in the Kimberly CBD

Name of the roads	Road type (N/R/ Arterial/ local street, etc.)	Road width	Number of lanes	Lane width (m)	Availability of pedestrian/ bicycle lane(Y/N) P/UN/ B	Pavements/ footpaths /shoulders width (m)	Kerbs (Y/N)	Median width (m)	Sight distance (m)	Radius of Curvature	Gradient (%)	Type of Road surface	Condition of road surface	Availability of traffic control system	On-street parking type Right angle/ inclined/ parallel
Long (N)	U3	6.7	2	3.35	Y(PD/P)	2.8	Y	1.1	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	Y (Parallel)
Long (S)	U3	6.8	2	3.4	Y(PD/P)	2.8	Y	1.1	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	Y (Parallel)
Barkley (Two way)	U4	9.3	2	4.65	N	-	N	-	>200	Gentle	1.0-20	Sealed	Acceptable	Automated signalling	NO
Bishop (N)	U3	6.1	2	3.05	Y (PD/UN)	1.6-6.0	Y	N	<150	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO
Bishop (S)	U3	6.2	2	3.1	Y (PD/UN)	1.65	Y	N	<150	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO
Carter (N)	U3	7.3	2	3.65	Y(PD/P)	2.5-5.5	Y	N (Line)	>150	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Carter (S)	U3	7.3	2	3.65	Y(PD/P)	1.5-5.5	Y	N (Line)	>150	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)

Schmidtsdrift (N)	U3	6.1	2	3.05	N	-	N	1.0	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	Y (Parallel)
Schmidtsdrift (S)	U3	6.0	2	3.0	Y (PD/UN)	1.5	Y	1.0	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	N
Barkley section 2 (impacting Transvaal) (N)	U3	7.5	2	3.75	Y (PD/P)	2.2	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	N
Barkley section 2 (impacting Transvaal) (S)	U3	7.5	2	3.75	Y (PD/P)	3.1	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	N
Memorial (N)	U3	6.3	2	3.15	Y (PD/UN)	6.1	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	N
Memorial (S)	U3	6.5	2	3.25	Y (PD/UN)	5.8	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Transvaal (influenced by Pniel) (N)	U3	6.5	2	3.55	Y (PD/P)	2.4	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Transvaal (influenced by Pniel) (S)	U3	7.1	2	3.55	Y (PD/P)	2.3	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Du Toitspan (N)	U4	7.1	2	3.55	Y (PD/P)	1.0-4.0	Y	1.0	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)

Du Toitspan (S)	U4	7.3	2	3.65	Y (PD/P)	1.0-1.5	Y	1.0	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Main Street (N)	U3	6.9	2	3.45	Y (PD/UN)	3.9	Y	1.2	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	Y (Parallel)
Main Street (S)	U3	7.1	2	3.55	Y (PD/UN)	5.0-7.0	Y	1.2	>200	Gentle	1.0-2.0	Sealed	Good	Automated signalling	NO
Lyndhurst Road (N)	U4	6.2	2	3.1	Y (PD/P)	2.8	Y	N (Line)	>100	Gentle	1.0-2.0	Sealed	Good	Automated signalling	NO
Lyndhurst Road (S)	U4	5.9	2	2.95	Y (PD/P)	3.3	Y	N (Line)	>100	Gentle	1.0-2.0	Sealed	Good	Automated signalling	NO
North circular Road (N)	U4	6.2	2	3.1	Y (PD/UN)	2.9-3.1 (both sides)	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO
North circular Road (S)	U4	6.2	2	3.1	Y (PD/UN)	2.9-3.1 (both sides)	Y	N (Line)	>200	Gentle	1.0-1.5	Sealed	Acceptable	Automated signalling	NO
South Circular Road (N)	U4	6.2	2	3.1	Y (PD/UN)	3.0	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO
South Circular Road (S)	U4	6.2	2	3.1	Y (PD/UN)	3.0	Y	N (Line)	>200	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO
Cecil Sussman Road (N)	U4	7.2	2	3.6	Y (PD/P)	1.0-2.4	Y	N (Line)	>100	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO

Cecil Sussman Road(S)	U4	6.8	2	3.4	Y (PD/UN)	0.5-1.3	Y	N (Line)	>100	Gentle	1.0-2.0	Sealed	Acceptable	Automated signalling	NO

(Source: Physical and geometrical parameter survey of roads, 2015)

(N) = North (To the inside the city)

(S) = South (Towards outside the city)

PD- Pedestrian facilities, B- Bicycle, P- Paved, UN- Unpaved, Y- Yes, N- No

Table 4.2: Design standard and specifications of physical and geometric characteristics of roads

Name of the roads	Type of road	Minimum lane width (m)	Sight distance (m)	Gradient (%)	Radius of curvature (m)	Speed (Km/h)
Long (N)	U3	3.7	41	6	210	60
Long (S)	U3	3.7	41	6	210	60
Barkley (N)	U4	3.7	41	6	210	60
Barkley (S)	U4	3.7	41	6	210	60
Bishop (N)	U3	3.7	41	6	210	60
Bishop (S)	U3	3.7	41	6	210	60
Carter (N)	U3	3.7	41	6	210	60
Carter (S)	U3	3.7	41	6	210	60
Schmidtsdrift (N)	U3	3.7	41	6	210	60
Schmidtsdrift (S)	U3	3.7	41	6	210	60
Barkley section 2 (impacting Transvaal) (N)	U3	3.7	41	6	210	60
Barkley section 2 (impacting Transvaal) (S)	U3	3.7	41	6	210	60
Memorial (N)	U3	3.7	41	6	210	60
Memorial (S)	U3	3.7	41	6	210	60
Transvaal (influenced by Pniel) (N)	U3	3.7	41	6	210	60
Transvaal (influenced by Pniel) (S)	U3	3.7	41	6	210	60
Du Toitspan (N)	U4	3.7	41	6	210	60
Du Toitspan (S)	U4	3.7	41	6	210	60
Main (N)	U3	3.7	41	6	210	60
Main (S)	U3	3.7	41	6	210	60
Lyndhurst (N)	U4	3.7	41	6	210	60
Lyndhurst (S)	U4	3.7	41	6	210	60
North Circular (N)	U4	3.7	41	6	210	60
North Circular (S)	U4	3.7	41	6	210	60
South Circular (N)	U4	3.7	41	6	210	60

South Circular (S)	U4	3.7	41	6	210	60
Cecil Sussman (N)	U4	3.7	41	6	210	60
Cecil Sussman (S)	U4	3.7	41	6	210	60

4.3 TRAFFIC SCENARIO ANALYSIS

4.3.1 Traffic Volume on road sections

Table 4.3 and Figure 4.1 present the traffic volume scenario in the major roads in and around the CBD area of the study area. The traffic hours are categorised into normal (off peak) hour- and peak hours. The duration of day from 6h30 – 8h30 is considered as peak hour 1 and from 16h00 – 17h30 is considered as s peak hour 2. All other hours of the day are considered as normal hours (or off-peak hour). The traffic volume is analysed in terms of average hourly traffic volume (normal hours) and peak hourly traffic volume in equivalent passenger car units (PCU). The traffic is also divided into two categories, namely traffic towards the CBD or city (N) and traffic away from the CBD or city area (S). It has been observed that the average hourly traffic volumes of different roads vary between a minimum of 132.50 PCU/hour in North Circular (away from CBD) to a maximum of 2826.60 PCU/hour on Transvaal Road (influenced by Pniel) travelling towards the CBD. The average traffic volume in normal and peak hours both towards and away from the CBD on Long Street, Transvaal-, Bishop- and Barkley section 2 Roads is significant, whereas the average traffic volume during normal hours is found to be not so high on other roads such as Barkley Road, Memorial Road, Main street, Carter Road, Schmidtsdrift Road, Du Toitspan Road, Lyndhurst Street, North circular Road, South circular Road and Cecil Sussman Street.

The average peak hour traffic volume on the different roads of the study area ranges between a minimum of 164.30 PCU/ hour to a maximum of 3912.30 PCU/h. The highest peak hour traffic has been observed on Transvaal Road, Long Street, Barkley section 2 Street, Bishop Road, Carter Road and Schmidtsdrift Street, among which the heaviest traffic during the peak hours is on Long Street and Transvaal Road influenced by Pniel Road.

The percentage peak hour traffic of all the roads vary between 31.0% and 37.0% (Table 4.3). Long Street and Transvaal Road carry respectively about 35.0% of their total daily traffic during peak hours and Du Toitspan Street carries about 36.0% of its total daily traffic during peak hours. However, roads like Main Street and North Circular Road carry about 32.0% and 33.0% respectively of their total daily traffic during peak hours. The ratio of peak hourly traffic volume to average hourly volume on various roads varies between a minimum of 1.24 to a maximum of 1.48. Considerable traffic volume during peak hours has been observed in some of the streets such as Long Street (ratio varying between 1.37-1.41), Transvaal Road (1.38), Carter Road (ratio varying between 1.37 - 1.39), Schmidtsdrift Road (ratio varying between 1.37-1.41), Du Toitspan Road (ratio varying between 1.42 - 1.48), Memorial Road (ratio varying between 1.35-1.42), Cecil Sussman Road (ratio varying between 1.39-1.41) and Barkley section 2 impacting Transvaal Road (ratio varying between 1.39-1.40). Peak hour traffic volume on all the other roads, namely Bishop`s Road, Barkley Road, Lyndhurst Street, Main Street, North Circular Road and South Circular Road is relatively less.

The modal split of the traffic volume (Table 4.4) indicates that Long Street and Transvaal Road carry a significant amount of heavy vehicles (12.00% and 15.00% respectively) in contrast to the 2.0% and 6.0% on other roads. Barkley section 2 impacting Transvaal Road, Cecil Sussman Street and Memorial Road each carry 6.0% heavy vehicles, whereas Bishop Road and Carter Road each carry about 4.0% heavy vehicles. About 2.0% heavy vehicles ply on Schmidtsdrift Road, Du Toitspan Road, North Circular Road and South Circular Road, whereas Barkley Road carries 3.0% heavy vehicles. This indicates that the modal split on majority of the roads except the Long Street, Transvaal Road, Barkley section 2 impacting Transvaal Road, Cecil Sussman Street and Memorial Road more or less comply to the design standards (norms) of urban roads in South Africa cities (COTO, 2012).

Table 4.3: Traffic volume scenarios in and around the CBD area of Kimberley

Roads	Direction	No of lanes	Average hourly traffic volume (V in PCU)	Peak hourly traffic volume (Vp in PCU)	Ratio of peak hourly traffic volume to average hourly volume	Ratio of peak hour traffic volume to total traffic volume
Long	N	2	2611.90	3682.50	1.41	0.35
	S	2	2542.90	3490.60	1.37	0.34
Barkley	N	2	449.30	599.60	1.33	0.33
	S	2	415.90	564.90	1.36	0.34
Bishop	N	2	1531.50	2082.70	1.36	0.34
	S	2	1503.40	2024.59	1.35	0.34
Carter	N	2	988.10	1370.80	1.39	0.35
	S	2	995.50	1367.30	1.37	0.34
Schmidtsdrift	N	2	977.50	1373.40	1.41	0.35
	S	2	967.60	1324.10	1.37	0.34
Barkley section 2 impacting Transvaal	N	2	1084.70	1512.90	1.39	0.35
	S	2	1052.80	1477.30	1.40	0.35
Memorial	N	2	607.60	860.10	1.42	0.35
	S	2	586.78	792.30	1.35	0.34
Transvaal influenced by Pniel	N	2	2826.80	3912.30	1.38	0.35
	S	2	2804.80	3879.70	1.38	0.35
Du Toitspan	N	2	476.70	676.90	1.42	0.35
	S	2	433.40	642.60	1.48	0.37
Main	N	2	246.40	305.50	1.24	0.31
	S	2	224.20	296.60	1.32	0.33

Lyndhurst	N	2	288.20	381.90	1.33	0.33
	S	2	268.80	356.40	1.33	0.33
North Circular	N	2	182.30	244.60	1.34	0.34
	S		132.50	164.30	1.24	0.31
South Circular	N	2	176.70	248.80	1.41	0.35
	S		168.40	226.40	1.34	0.34
Cecil Sussman	N	2	527.80	734.40	1.39	0.35
	S	2	498.60	702.60	1.41	0.35

Note: N: Towards the CBD (to the city); S: Away from CBD (from the city)

Source: Traffic survey, 2015

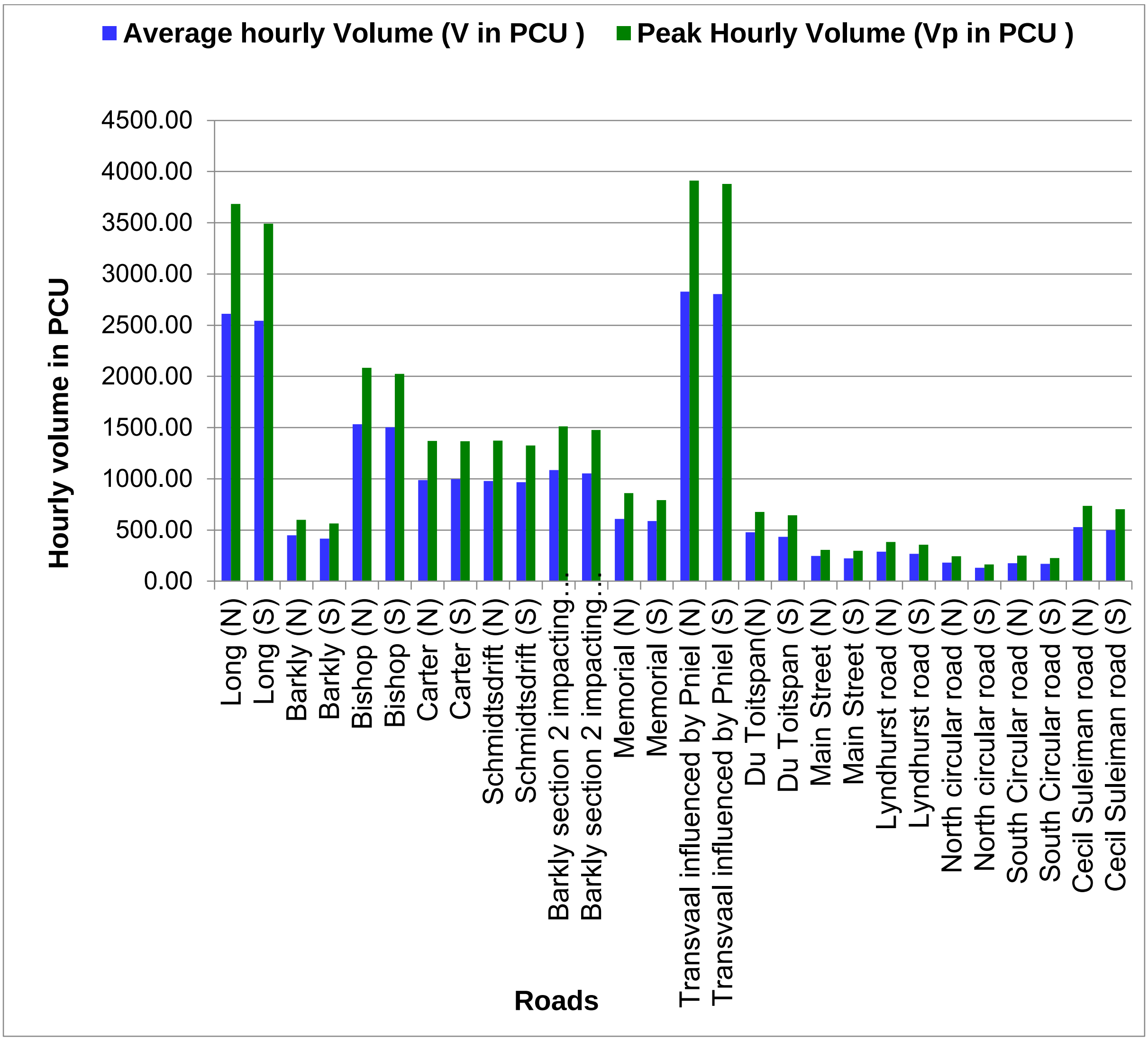

Figure 4.1: Average and peak hourly volume in PCU on the roads in and around the Kimberley CBD area

Table 4.4: Modal split (composition of vehicles) in terms of volume in PCU on the roads in and around the Kimberley CBD area

Roads	Direction	% of cars to total traffic volume in PCU	% of heavy vehicles to normal cars in PCU	Average hourly traffic volume (Cars in PCU)	Average hourly traffic volume (Heavy vehicles in PCU)	Peak hourly traffic volume (Cars in PCU)	Peak hourly traffic volume (Heavy vehicles in PCU)
Long	N	88.00	12.00	2611.9	313.43	3482.5	417.9
	S	88.00	12.00	2542.9	305.15	3490.6	418.87
Barkley	N	97.00	3.00	449.3	13.48	599.0	17.97
	S	97.00	3.00	415.9	12.48	564.9	16.94
Bishop	N	96.00	4.00	1531.5	61.26	2082.7	83.30
	S	96.00	4.00	1503.4	60.14	2024.59	80.98
Carter	N	96.00	4.00	988.1	39.52	1370.8	54.83
	S	96.00	4.00	995.5	39.82	1367.3	54.69
Schmidts drift	N	98.00	2.00	977.5	19.55	1373.4	27.46
	S	98.00	2.00	967.6	19.35	1324.1	26.48
Barkley section 2 impacting Transvaal	N	94.00	6.00	1084.7	65.08	1512.9	90.77
	S	94.00	6.00	1052.8	63.17	1477.3	88.63
Memorial	N	94.00	6.00	607.6	36.46	860.1	51.60
	S	94.00	6.00	586.78	35.21	792.3	47.53
Transvaal influenced by Pniel	N	85.00	15.00	2826.8	424.02	3912.3	586.84
	S	85.00	15.00	2804.8	420.72	3879.7	581.95
Du Toitspan	N	98.00	2.00	476.7	9.53	676.9	13.53
	S	98.00	2.00	433.4	8.67	642.6	12.85
Main	N	99.00	1.00	246.4	2.46	305.5	3.05

	S	99.00	1.00	224.2	2.24	296.6	2.96
Lyndhurst (N)	N	98.00	2.00	288.2	5.76	381.9	7.63
	S	98.00	2.00	268.8	5.38	356.4	7.12
North Circular	N	98.00	2.00	182.3	3.65	244.6	4.89
	S	98.00	2.00	132.5	2.65	164.3	3.28
South Circular	N	98.00	2.00	176.7	3.53	248.8	4.97
	S	98.00	2.00	168.4	3.37	226.4	4.52
Cecil Sussman	N	94.00	6.00	527.8	31.67	734.4	44.064
	S	94.00	6.00	498.6	29.92	702.6	42.156

Figure 4.2 presents the hourly traffic variation on the traffic flow in the roads in and around the CBD area of Kimberley. The hourly analysis of traffic flow on five major roads indicated that there are two clear peak hours: 6h30 –8h30 and 16h00 – 17h30. Traffic flow during other hours is observed to be relatively low and somewhat constant.

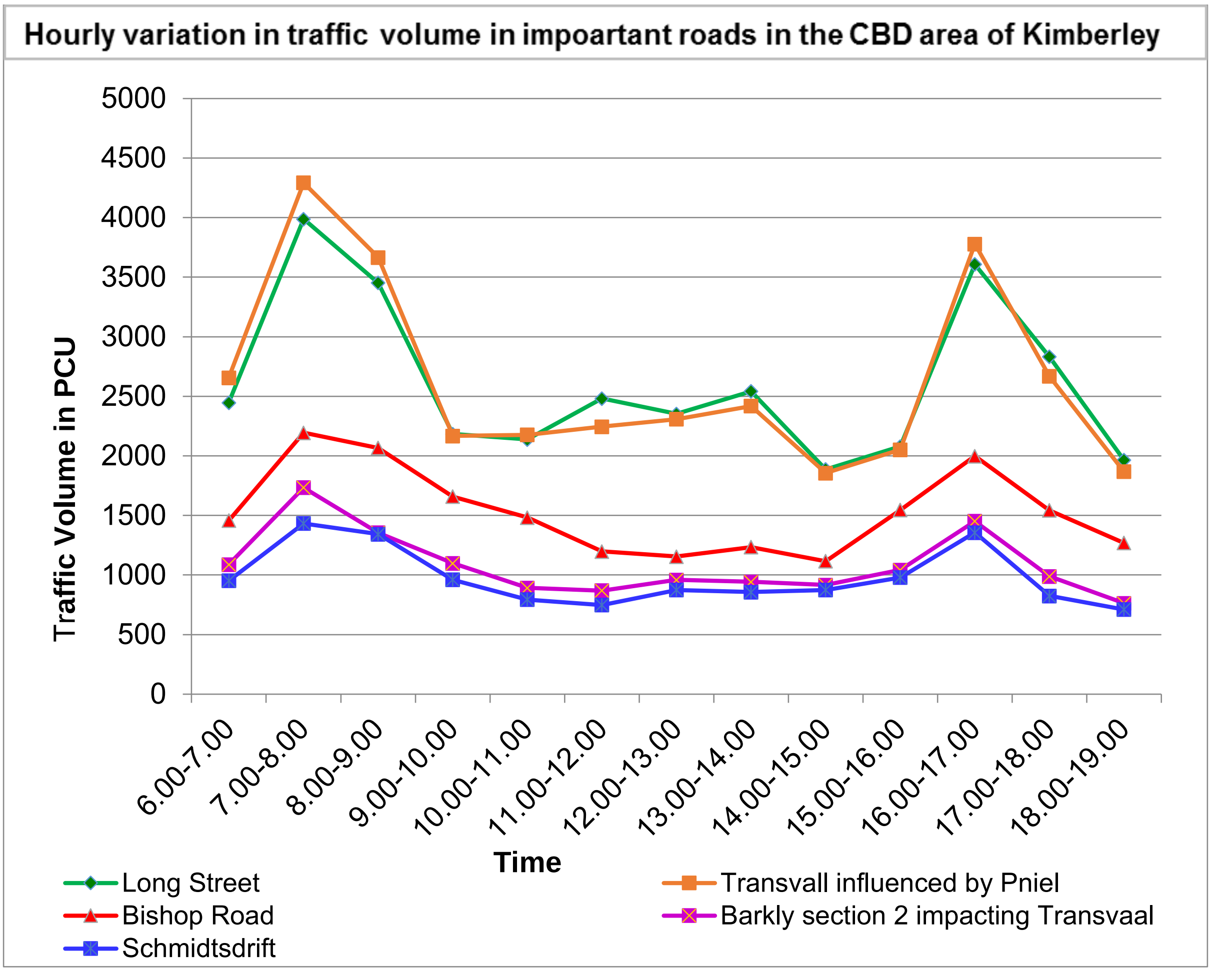

Figure 4.2: Hourly variation in traffic volume on various roads in the Kimberley CBD area

4.3.2 Traffic volume at junctions

Figure 4.3 to Figure 4.8 present the traffic volume and queue length of vehicles at different junctions during peak hours. The six important junctions being considered are: the Long Street – Bultfontein Road junction (J1); the Bishop–/Lyndhurst Street – Bultfontein Road/Delham Street junction (J2); the Transvaal Road – Cecil Sussman Road junction (J3); the Du Toitspan Street – Lennox Street junction (J4); the Transvaal Road – Old Main Street junction (J5); and the North Circular Road – Pniel Road junction (J6). The arrows in the figures indicate the direction of flow and the numbers in the box indicate the traffic flow per hour during peak hours. The traffic flow is divided into left turning-, straight moving- and right turning vehicles. The maximum queue length (Ni) (actual) on any of these lanes during the red phase of the traffic signal is also mentioned in addition to the traffic flow.

Figure 4.3 shows the traffic flow during peak hours at the junction joining Long Street and Bultfontein Road. It is observed that left turning (35%) and straight traffic (57%) on both these roads are quite significant. The volume of vehicles turning right is relatively low. The queue length during the red phase of the signal is also highly significant as it indicates that both the roads carry a significant amount of traffic, creating opportunities for traffic congestion.

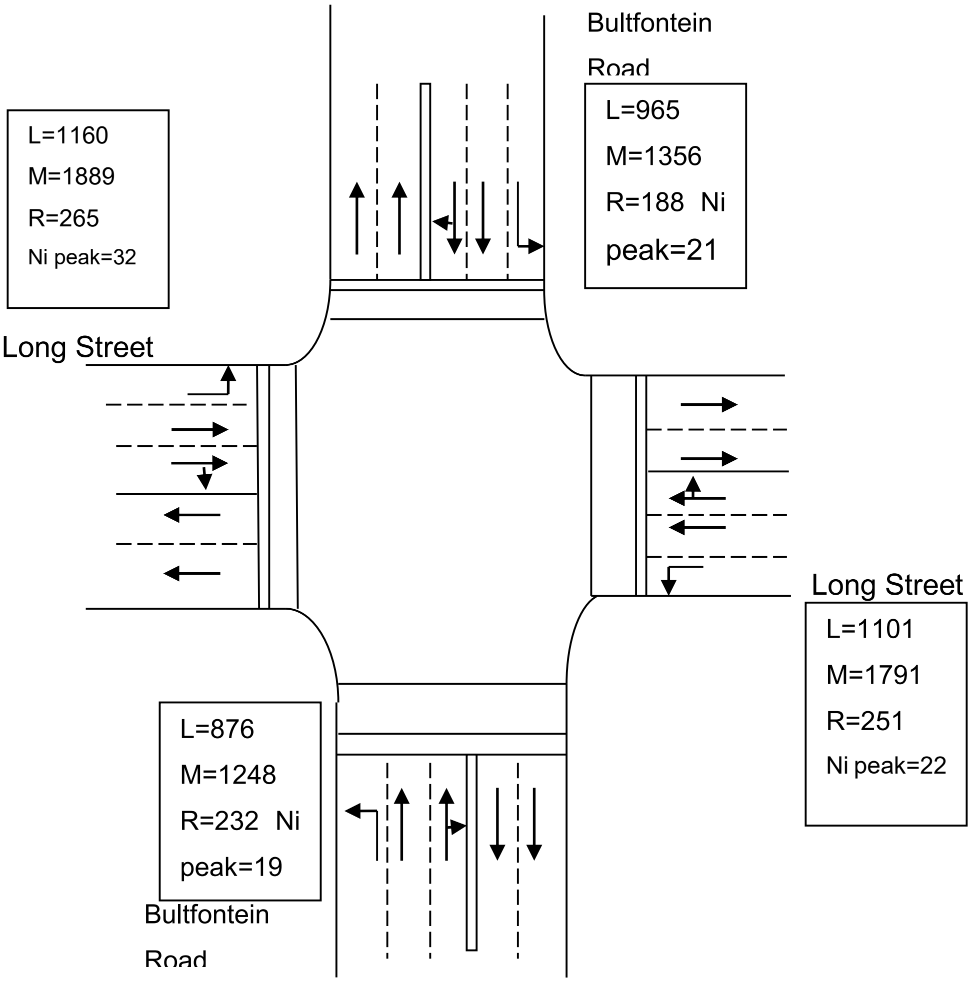

Figure 4.3: Schematic diagram of traffic flow in the junction joining Long Street and Bultfontein Road

Figure 4.4 presents the traffic flow during peak hours at the junction joining Bultfontein–Delham and Bishop–Lyndhurst Roads. It is observed that the Bultfontein- Delham Roads carry about 38.0% left turning-, 59.0% straight moving- and 9.0% right turning traffic. The Bishop–Lyndhurst Roads carry 40.4% left turning-, 53.5% straight moving- and about 5.0% right turning traffic. The maximum queue length is also quite appreciable on both the Bultfontein- and Bishop Roads, whereas the queue lengths on Lyndhurst- and Delham Roads are low. This indicates that there is high traffic pressure on both Bultfontein- and Bishop Roads; whereas the Lyndhurst- and Delham segments of the roads are relatively free of traffic.

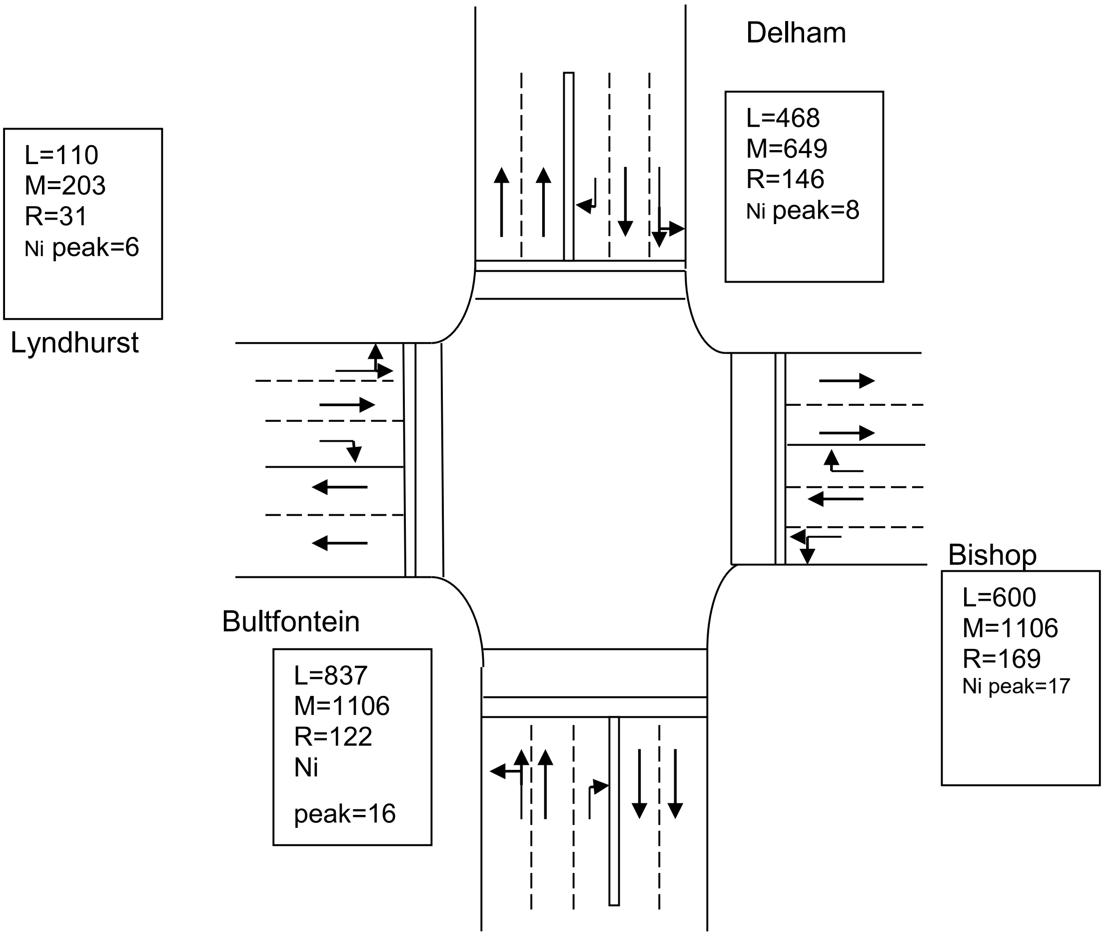

Figure 4.4: Schematic diagram of traffic flow in the junction joining Bultfontein - Delham and Bishop-Lyndhurst Roads.

The traffic flow at the junction joining Transvaal Road and Cecil Sussman Road is presented in Figure 4.5. It is noted that Transvaal Road carries significantly more traffic than Cecil Sussman Road. About 31.0% of the traffic in Transvaal Road turns left and 57.0% of the traffic continue to move in the same direction. However, the right turning traffic (12.0%) is also significant compared to the right turning traffic on other roads. The left turning-, straight moving- and right turning traffic on Cecil Sussman Road are 35.0%, 57.0% and 8.0% respectively. It has also been observed that Cecil Sussman Road receives a significant amount of traffic from Transvaal Road and the downstream traffic on the Cecil Sussman Road at the junction is also appreciable. The maximum queue lengths on Transvaal Road on both sides of junction are 28 and 24, which seems to be significant.

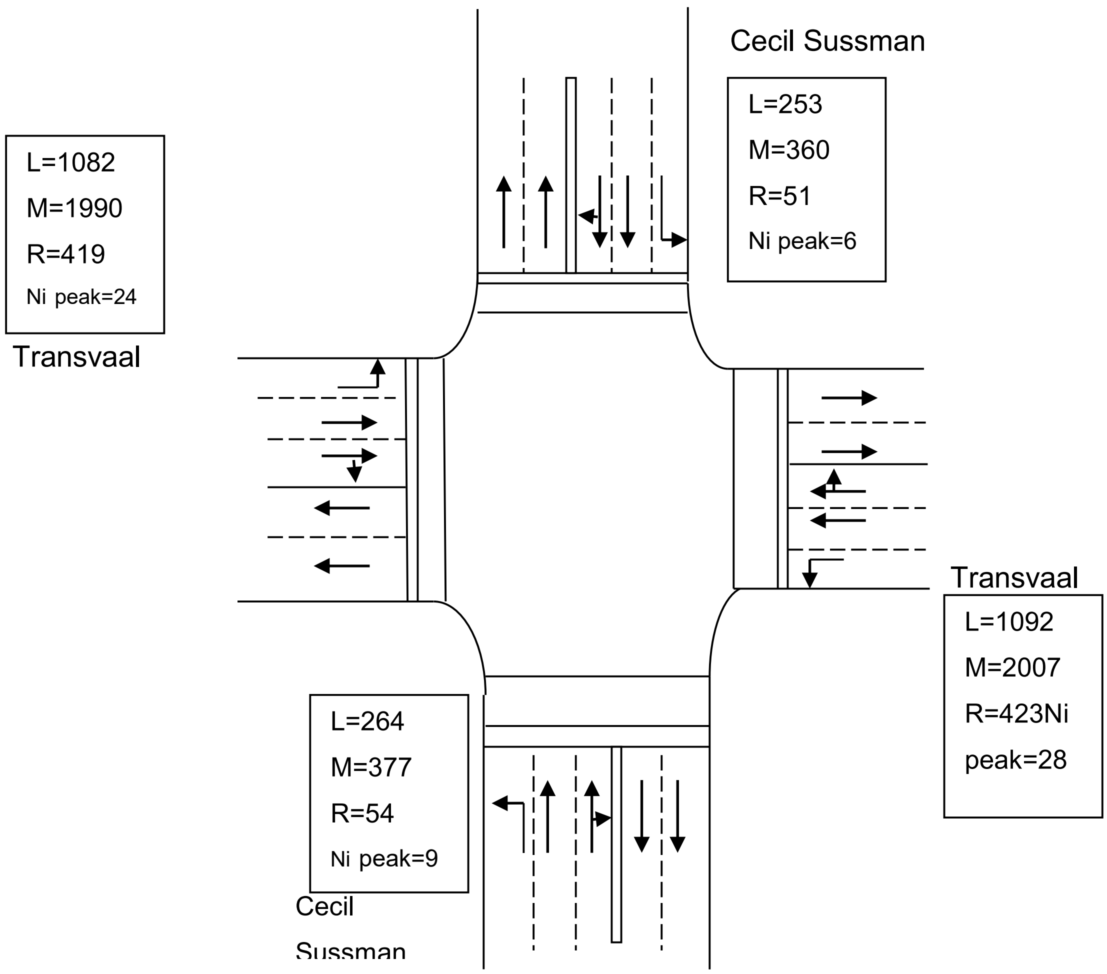

Figure 4.5: Schematic diagram of traffic flow in the junction joining Transvaal Road and Cecil Sussman Road

Figure 4.6 presents the traffic flow during peak hours at the junction joining Du Toitspan Road and Lennox Street. Du Toitspan Road carries about 33.0% left turning-, 56.0% straight moving- and 11.0% right turning traffic and Lennox Street carries 35% left turning-, 57.0% straight moving- and 8.0% right turning traffic. However, the volume of traffic is considerably low and the maximum queue length observed is 8, which is also insignificant. The junction seems not to be under pressure of congestion during peak hours.

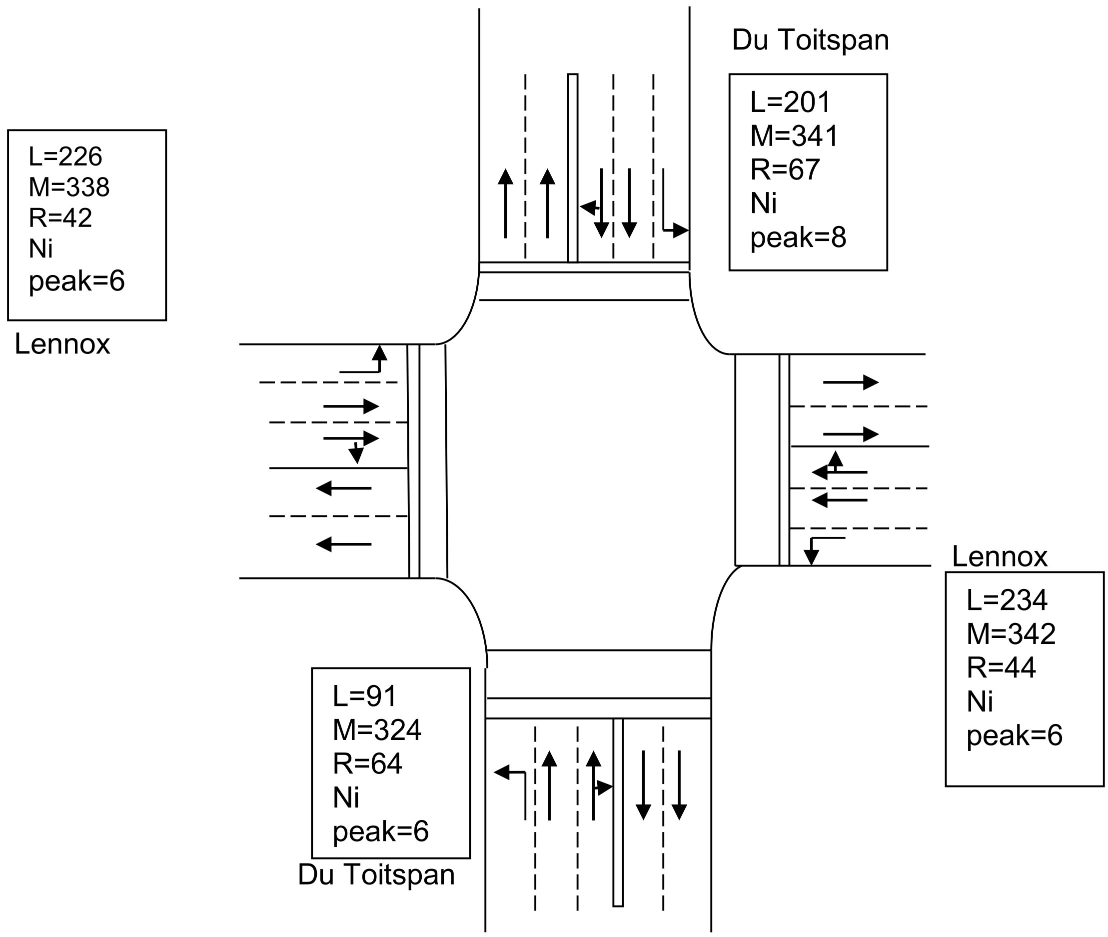

Figure 4.6: Schematic diagram of traffic flow in the junction joining Du Toitspan Road and Lennox Street

The traffic flow at the junction joining Transvaal Road and Old Main Road is presented in Figure 4.7. This junction is apparently located in the city centre (inside CBD). Transvaal Road is an arterial road carrying through traffic whereas the Old Main Road is a local street inside the CBD. Transvaal Road is a one way road. About 89.1% of the traffic on Transvaal Road is through traffic and about 5.2% to 5.6% of the traffic turns left and right respectively. The maximum queue length on this road at the junction varies from 12 to a significant 14. In contrast, Old Main Street does not carry as much traffic as Transvaal Road. No traffic turns from Old Main Street into Transvaal Road at the junction, although the turning traffic joins Transvaal Road at minor junctions located at a distance from this junction. The queue length on Old Main Road is also insignificant. On-street parking is located on Transvaal Road which interferers with through traffic on Transvaal Road, particularly during the entry and exit of the vehicles to and from the parking bay. A significant amount of pedestrian traffic is also observed on this road because of the availability of shopping centres along the Streets and around the area.

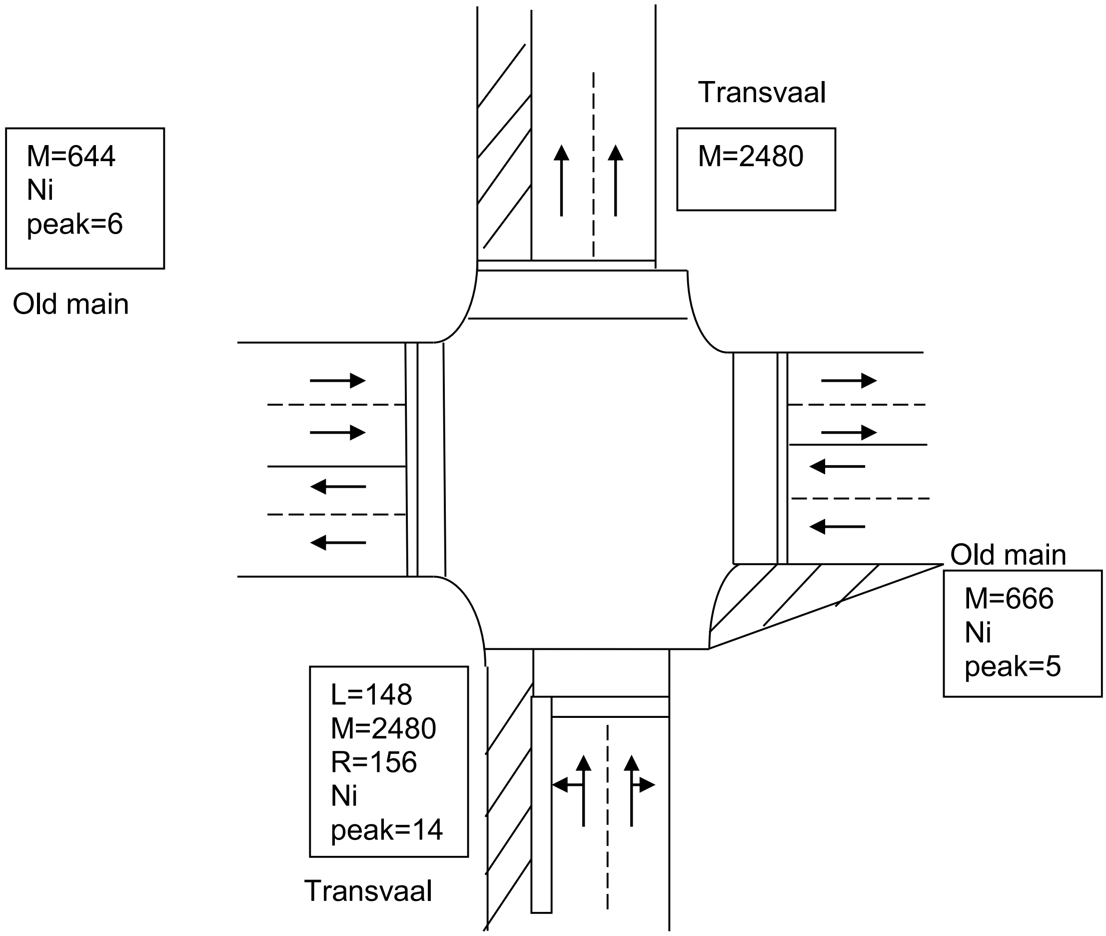

Figure 4.7: Schematic diagram of traffic flow in the junction joining Transvaal Road and Old Main Street

Figure 4.8 presents the peak hour traffic flow at the junction joining Bultfontein-, Pniel- and North Circular Road. This is a T- junction with three legs of roads as Bultfontein Road is closed down due to fear of caving in because of the presence of Big Hole nearby. The traffic on Pniel Road joins the two legs of North Circular Road at the junction. About 63.0% of the traffic on Pniel Road turns left and 37.0% turns right at the junction to join North Circular Road. On reaching the junction, about 40.0% of the traffic on North Circular Road turns left and 41.0% turns right to join Pniel Road. The traffic flow on North Circular Road is observed to be very low (ranging between 147 and 213 PCU) and the maximum queue lengths vary between 4 to 6, indicating that the junction is relatively congestion free.

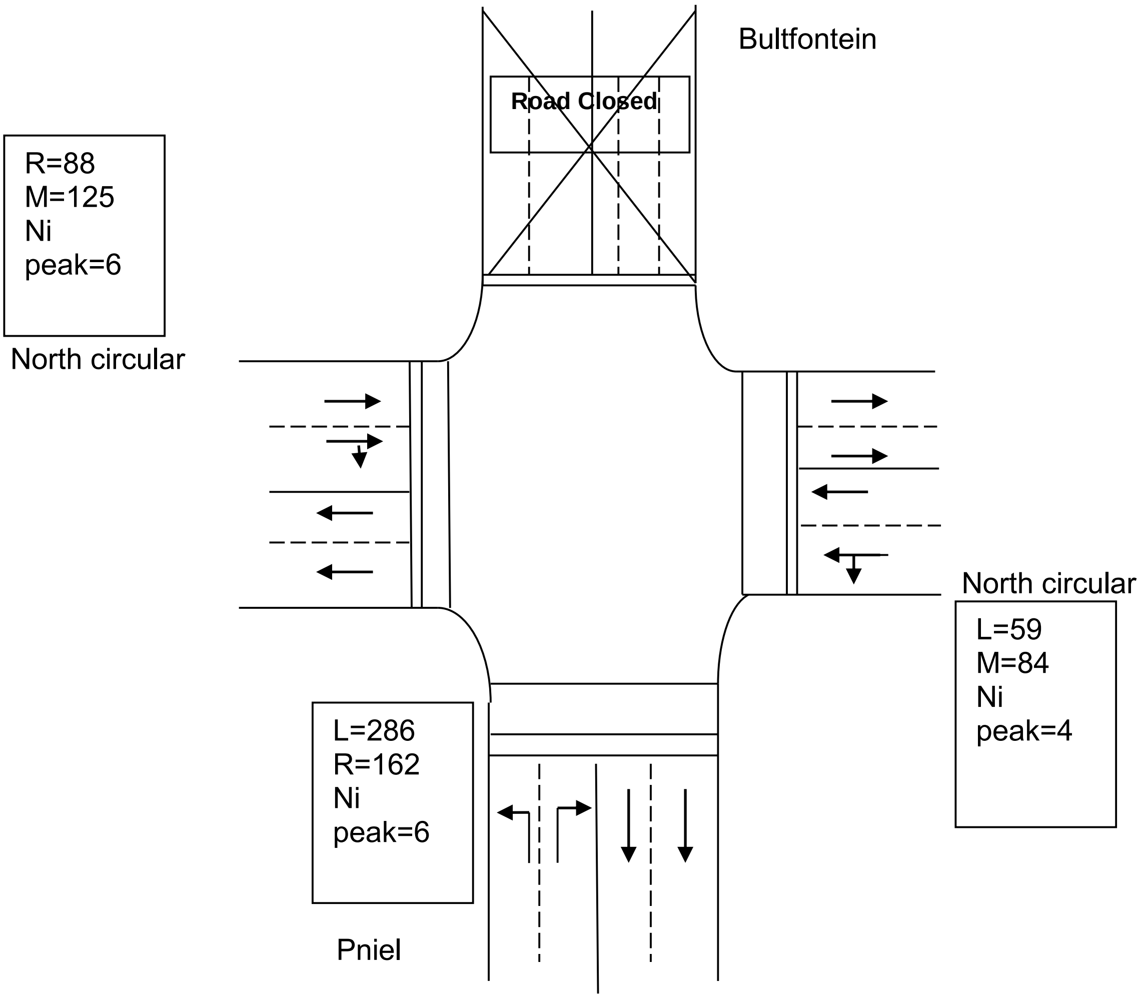

Figure 4.8: Schematic diagram of traffic flow in the junction joining North Circular Road and Bultfontein Road and Pniel road

4.3.3Traffic Speed

The average traffic speed during normal and peak hours is presented in Table 4.5. The average traffic speed on various roads during normal hours has been observed to vary between 42 km/h and 55 km/h. The average traffic speed on various roads during peak hours range from 24 km/h to 45 km/h. During normal hours, lower average speeds were experienced in Long Street (42 km/h), Transvaal Road (43 km/h), Bishop`s Road (44 km/h), and Cecil Sussman Road (45 km/h) whereas relatively higher average speeds were experienced in Schmidtsdrift Road (52 km/h), Main Street (51 km/h), Lyndhurst Road (55 km/h), North Circular Road (55 km/h) and South Circular Road (55 km/h). In none of the streets is the maximum allowed traffic speed of 60 km/h exceeded.

The average traffic speed during peak hours in Long Street (24 km/h), Transvaal Road (27 km/h), Bishop`s Road (30 km/h), Schmidtsdrift Road (27 km/h) and Cecil Sussman Road (32 km/h) is significantly low whereas the average peak hour speed on Main Street (40 km/h), Lyndhurst Street (38 km/h), North Circular Road (45 km/h) and South Circular Road (45 km/h) is relatively higher. The difference between the normal- and peak hour speed is found to range from 18.18% to 48.08%. Long Street, Barkley section 2 impacting Transvaal Road, Schmidtsdrift Road, and Transvaal Road influenced by Pniel Street, have registered higher differential speed between normal- and peak hours. It is apparent that the roads experiencing higher traffic during peak hours also experience higher differential speed between normal- and peak hours. The lower average speed in the majority of roads also indicates that these roads are under pressure due to high traffic volume.

Table 4.5: Average and peak hour speed on the roads of the study area

Roads	Direction	Average Speed during normal hours (in km/ h)	Average Speed peak hours (in km/ h)	Difference in speed between normal hours and peak hours In %
Long	N	42	24	42.86
	S	42	24	42.86
Barkley	N	48	36	25.00
	S	48	36	25.00
Bishop	N	44	30	31.82
	S	44	30	31.82
Carter	N	49	37	24.49
	S	49	37	24.49
Schmidtsdrift	N	52	27	48.08
	S	52	27	48.08
Barkley section 2 impacting Transvaal	N	48	27	43.75
	S	48	27	43.75
Memorial	N	52	34	34.62
	S	52	34	34.62
	N	43	27	37.21

Transvaal influenced by Pniel	S	43	27	37.21
Du Toitspan	N	51	37	27.45
	S	51	37	27.45
Main	N	53	40	24.53
	S	53	40	24.53
Lyndhurst (N)	N	55	38	30.91
	S	55	38	30.91
North Circular	N	55	45	18.18
	S	55	45	18.18
South Circular	N	55	45	18.18
	S	55	45	18.18
Cecil Sussman	N	45	32	28.89
	S	45	32	28.89

Figure 4.9 shows the hourly variation in average speed in a day on various roads in and around the CBD area of Kimberley. The average speed has been observed to vary between 24 km/h and a maximum of 60 km/h. The average speed during peak hours (varying between 24 km/h - 40 km/h) is also very low. The lowest speed experienced is in the morning hours between 6h30 to 8h00 after which the speed usually increases until 12h00. However, between 12h00 and 16h00 there is a fluctuation in speed ranging between 30 km/h to 45 km/h after which the speed drops again significantly during the second peak hour. Thus, during the off-peak hours the speed on various roads varies between 35 km/h and 55 km/h. During the early morning hours such as around 6h00- 6h30 and late afternoon hours from 18h00 and beyond, speeds of higher than 50 km/h are experienced.

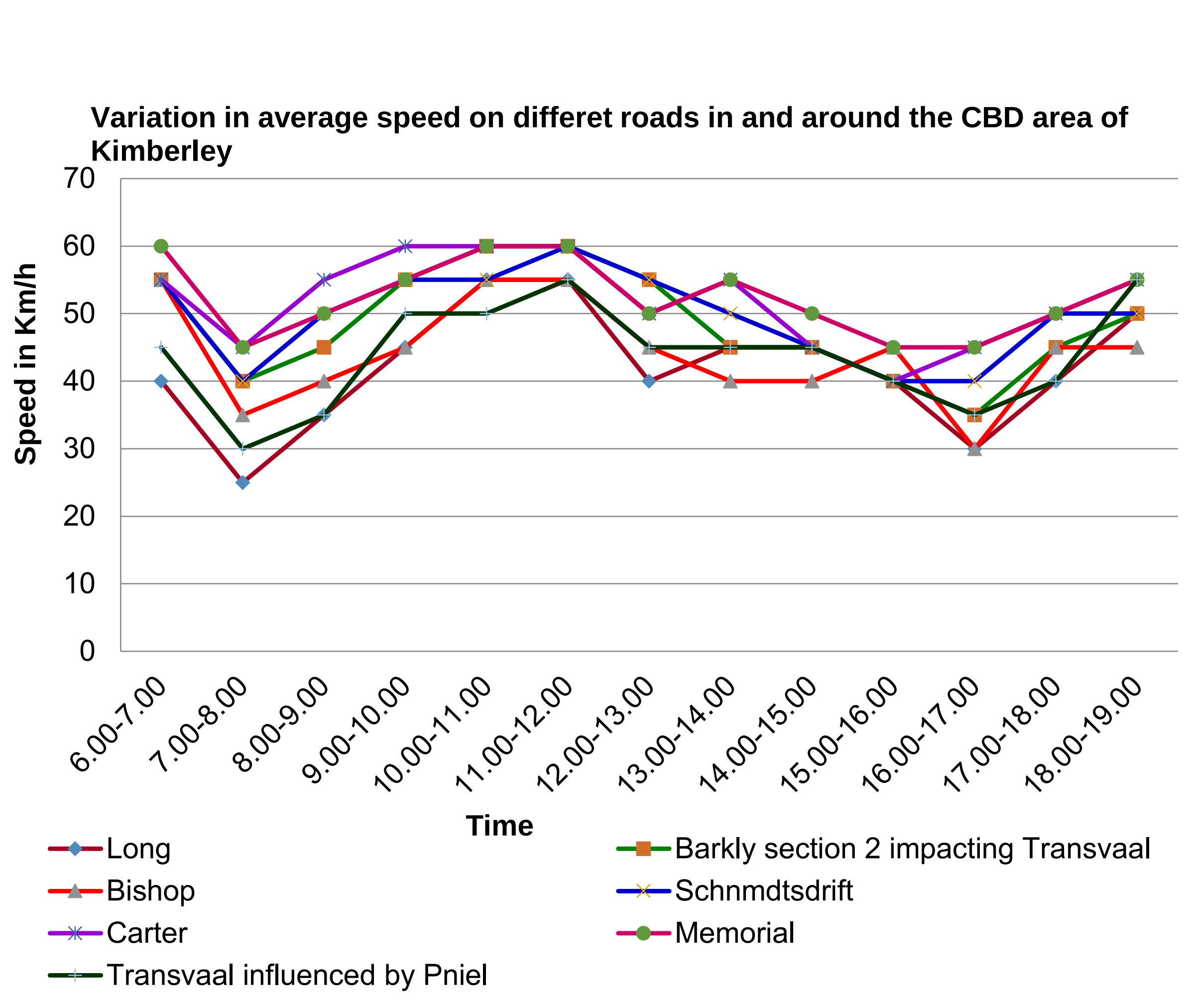

Figure 4.9: Variation in average speed on various roads in and around the Kimberley CBD area

4.3.4 Variation in traffic speed and number of speed changes between two adjacent important junctions

The variation in the traffic speed and the number of speed changes that occur between two important and adjacent junctions on various roads in and around the CBD area during peak hours are presented in the Table 4.6 and Figure 4.10. It can be observed in Figure 4.10 and Table 4.6 that fluctuation in speed is experienced in all the road sections between the two adjacent junctions. The absolute changes in speed range between 15 km/h to 22 km/h. Lower absolute changes in speed of 15 km/h were observed on roads such as Memorial Road, Long, Bishop-, Barkley-, Barkley section 2-, Main-, Du Toitspan- and Carter`s Road. The absolute speed change in Cecil Sussman Road is 18 km/h. On the other hand the absolute speed changes on Transvaal-, North Circular- and South Circular Road are relatively higher (22 km/h) followed by Lyndhurst- and Schmidtsdrift Road. The number of speed changes ranges between 4 and 6. More or less 6 speed changes were observed in each of the roads such as Long Street, Barkley section 2 impacting Transvaal Road, Schmidtsdrift Road, Memorial- and Carter Road. In comparison 5 speed changes were observed in Transvaal-, Lyndhurst-, Du Toitspan-, North Circular-, Main- and Cecil Sussman Road and 4 speed changes between two adjacent junctions in Barkley-, Bishop- and South Circular Road. Because the number of speed changes depends on the distance between the two junctions, the above observations do not conclusively indicate that the roads which carry a higher volume of traffic have lower absolute speeds and a higher number of speed changes. However, such as a relationship can be considered, as a lower absolute speed on roads is found to be associated with a higher number of speed changes.

Table 4.6: Variation in speed between two adjacent junctions in different roads during peak hours

Speed change	Long Street	Barkley section 2 impacting Transvaal	Barkley	Bishop	Schmidtsdrift	Carter	Memorial	Transvaal influenced by Pniel	Du Toitspan	Lyndhurst	Main	North Circular	South Circular	Cecil Sussman
1	30	35	35	45	30	45	40	45	45	35	50	52	30	34
2	35	30	40	40	40	50	35	35	35	40	40	27	38	40
3	30	25	40	25	45	35	30	23	30	45	35	25	38	46
4	25	20	30	20	35	25	35	23	30	45	35	25	47	46
5	20	25	30	30	25	15	25	28	20	35	30	30	47	34
6	30	30	20	35	20	25	20	18	15	30	20	20	42	20
7	15	20	15	15	0	30	15	23	20	25	25	30	52	16
Number of speed changes	6	6	4	4	6	6	6	5	5	5	5	5	4	5
Absolute speed change (Km/h)	15	15	15	22	20	15	15	22	15	20	15	22	22	18

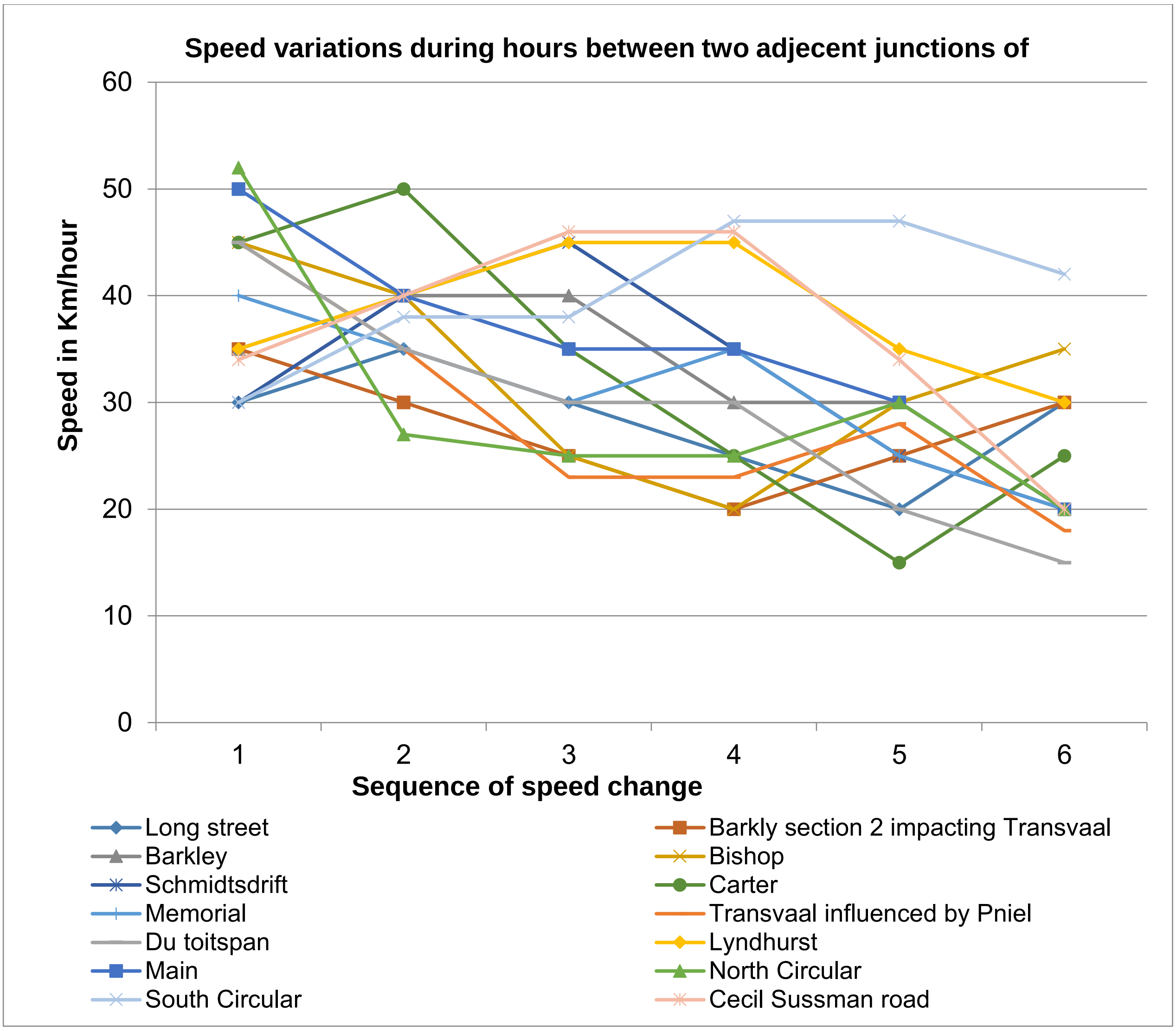

Figure 4.10: Variation in speed between two adjacent junctions on various roads in and around the Kimberley CBD area during peak hour

4.3.5 Parking facilities

On-street parking facilities are available in certain road sections of Long Street, Transvaal-, Carter-, Main- , Schmidtsdrift- and Du Toitspan Road. The parking facilities provided on these roads are predominantly a parallel parking system (Figure 4.11); however, in some sections inclined (at angle 30^0-60^0 with the road) parking facilities are also available. No on-street parking facilities are provided on the sides of the other roads. As observed from the physical and road geometric parameter survey, on street parking facilities available at different sections on Long street and Transvaal road close to CBD area are found to interfere with traffic flow, which cause traffic congestion, particularly during peak hours. In addition, open off-street facilities are provided at certain locations on the sides of Long Street, Cecil Sussman Road, Du Toitspan Road and North Circular Road, which could influence the traffic movement on these roads and are also found to be apparently interfering with the moving traffic during peak hours.

Figure 4.11: Parallel parking facilities on Transvaal Road passing through the CBD of Kimberley

4.3.6 Traffic control measures

Most of the junctions on all the roads are controlled by automated traffic signal systems. However, some of the minor junctions are controlled by stop signs. The signal cycle timings at important junctions are presented in Table 4.7. It is observed that most of the junctions surveyed have three-phase signal systems with facilities for signal times for right turn. The total cycle time in most of the junctions is 70 seconds during peak hours. However, the junction joining Bultfontein Road and Bishop Road has a cycle time of 140 seconds. The signal timings are found to be sufficient to clear the straight- and left turning traffic most of the times, but occasionally the signal timings provided for right turning traffic are found to be inadequate.

Adequate pavement markings and signage such as lane demarcation lines, pedestrian control lines, stop signs, no stop- and parking signs, movement direction, turn signs, etc., (Figure 4.12) confirm to standards recommended by the Road Traffic Signs Manual Volume 3, South Africa, (2012).

Table 4.7: Traffic signal timings at important junctions of the roads in and around the CBD area

Junction	Green time (Seconds)	Right turn time (Seconds)	Amber time (Seconds)	Red time (Seconds)	Phase (Seconds)	Actual Cycle time (seconds)	Required time (Signal timing cycle length in seconds)
J1(Long - Bultfontein)	30	3	3	34	2	70	57
J2 (Bishop, Lyndhurst – Bultfontein, Delham)	30	3	3	34	1	70	34
J3 (Transvaal - Cecil Sussman)	30	3	3	34	1	70	66
J4 (Du Toitspan - Lennox)	30	3	3	34	1	70	27
J5 (Transvaal – Old Main)	33	0	3	34	1	70	67
J6 (North Circular-Pniel)	40	0	3	27	1	70	24

Figure 4.12: Traffic control system on the roads in and around the CBD of Kimberley

4.4 TRAFFIC CONGESTION ANALYSIS

The analysis of traffic congestion in this study is based on the analyses of: the perception of people on the factors causing traffic congestion (Perception index); segment delay index (Ds); travel time delay index (TTI); Q- index; level of service of the roads; and queue length at the junctions.

4.4.1 Perception index of factors causing congestion

As discussed in the methodology section (cf section 1.9.1, perception index (PI) was computed based on road users' perception on various factors that could cause congestion on the roads. The PI of the various factors were calculated by using the average weighted index method (Eq. 1) based on the average weights (values ranging between 0 and 1.0) assigned to a particular factor by road users being surveyed. A PI value of ≥0.70 is considered as highly influential, whereas a PI value between 0.5 and 0.7 (0.5<PI<7.0) is considered as moderately influential. Any PI value less than 0.5 (PI< 0.5) is taken as less influential in causing congestion. The various broad parameters considered for these analyses include physical road factors, spatial/ land use and urban function factors, traffic factors, behavioural factors, environmental and emergency factors.

Table 4.8 presents the perception indices of the various factors under each broad parameter. According to the perception indices, road parking facilities (PI=0.76) and type of junctions (PI=0.74) are the major physical road related variables which cause congestion. The other physical road related factors being perceived to moderately influence occurrence of congestion on the roads of the CBD area of the study area, are inadequate number of lanes (PI=0.58), inadequate turning radius (PI=0.56) and insufficient lane width/ road width (capacity) (PI=0.55). . Median facilities (PI=0.48), pedestrian crossing facilities (PI=0.48), road conditions (PI= 0.42) and pavements/ footpaths (PI= 0.35) are not perceived to influence congestion significantly.

It is also observed that no spatial/ land use or urban function variables are perceived to highly influence the occurrence of congestion on the roads. The spatial/land use and urban function variables which are perceived to moderately influence the occurrence of congestion, are factors such as inadequate availability of space near junctions (PI= 0.68), availability of commercial function (PI= 0.54), availability of traffic nodes such as bus stops, taxi stops and availability of civic/administrative functions (PI= 0.52). On-road informal commercial activities (PI= 0.47), building offset (PI=0.38), encroachment of roads (PI= 0.33) and building size (PI= 0.32) are considered to be the least influential spatial/land use and urban function variables to cause congestion on the roads of the study area.

Under the traffic factors, traffic volume (PI = 0.78) and type and composition of vehicles – particularly plying of heavy vehicles (large trucks) (PI= 0.72), are perceived to be the two most important traffic related variables which highly influence occurrence congestion. Traffic speed

(PI= 0.52) is also found to be considered moderately influencing congestion. The influence of pedestrian volume (PI= 0.48) and of signalling, pavement markings, signage and control (PI= 0.44) is perceived to be low. Under signalling, pavement markings, signage and control, traffic calming measures such as speed breakers (PI= 0.52) are perceived to be a reason for occurrence of congestion, but traffic signs and pavement marking (PI= 0.36), stop signs (PI= 0.41) and traffic rule enforcement such as speed traps (PI= 0.48) are considered to have insignificant influence on traffic congestion.

It is also found that behavioural factors such as influence of alcohol and nausea (PI= 0.68), respect for driver behaviour (PI= 0.64), physical and mental condition of driver (PI= 0.62), traffic rules and regulations (PI= 0.62) and knowledge of traffic rules (PI= 0.56) are perceived to have some influence on the occurrence of congestion on the roads of CBD area of the study area.

Except for accidents (PI= 0.66), which are perceived to influence congestion moderately, all other environmental and emergency factors such as road blocks and unscheduled stops (PI= 0.44), heat (PI= 0.28), rain and storms (PI= 0.27) and slippery roads (PI= 0.19), are considered to be least influential factors for causing congestion on the roads of the study area.

It is thus found that indices on road parking facilities, type of junctions, traffic volume and type and composition of vehicles – particularly the plying of heavy vehicles (large trucks) – are perceived to be the major variables which significantly influence congestion on the roads in and around the CBD area of Kimberley. Unavailability of space near junctions; availability of commercial functions; availability of traffic nodes such as bus stops, taxi stops and civic/administrative functions; traffic speed; traffic calming measures such as speed breakers; influence of alcohol and nausea on driver; disrespect of traffic rules and regulations by road users; unruly driver behaviour; poor physical and mental condition of driver; lack of knowledge of traffic rules; and occurrence accidents are all considered to cause traffic congestion to a certain extent.

Variables such as lack of median facilities; unavailability of pedestrian crossing facilities; poor road conditions; lack of pavements/ footpaths; informal commercial activities; building offset; encroachment of roads; building size; pedestrian volume; traffic signs and pavement marking; stop signs; traffic rule enforcement such as speed traps, road blocks and unscheduled stops; and environmental factors such as heat , rain, storms and slippery roads; are perceived not to cause congestion on the roads of the study area.

According to the perceptions of the road users, diversion of vehicles from congested roads (PI= 0.76), modal split (segregation of heavy vehicles from normal cars) (PI= 0.73) and changing traffic pattern (0.67) are the major re-engineering interventions which could alleviate traffic congestion in the study area. It is also perceived that provision of off-street parking (PI= 0.58), removal of on-street parking (PI=0.56) and one-way streets could assist in the reduction of congestion. Furthermore, under the improvement of road infrastructure, road users perceive that the junctions should be improved (PI= 0.66). Road users are of opinion that the creation of traffic awareness and improving driver/user knowledge on traffic rules and regulations (PI=0.56) and improvement of public transportation (PI=0.52) are essential challenges that need to be looked at. They are also of opinion that measures such as availability of information through Information and Communication Technology (ICT), closure of roads (partial), segregation of vehicular and pedestrian traffic, pedestrian facilities in major areas, pedestrianisation of the whole CBD, improvement of the signalling system, and installation of cameras/ videography may not assist in reducing congestion.

Table 4.8: Perceptions of public and road users regarding the parameters influencing traffic congestion

Parameters	Index values	Rank	Parameters	Index values	Rank
Physical road factors			***Spatial/ Land use/ urban function factors***		
Capacity/Road width/ Lane width	0.55	5	Availability of commercial function	0.54	2
Number of lanes	0.58	3	Encroachment of roads	0.33	6
Footpaths/ pavements	0.35		Availability of civic/administrative functions	0.52	3
On-road parking facilities	0.76	1	Inadequate space available near the junctions	0.68	1
Median facilities	0.48	6	Building size	0.32	
Road condition	0.42	7	Building offset	0.38	5
Pedestrian crossing facilities	0.48	6	On-road informal commercial activities	0.47	4
Type of junctions	0.74	2	Availability of traffic nodes such as bust and taxi stops	0.54	
Turning radius at junctions	0.56	**4**			**2**

Traffic factors			***Behavioural factors***		
Traffic volume	0.78	1	Knowledge of traffic rules	0.56	4
Type and composition of vehicles	0.72	2	Respect of traffic rules and regulations	0.62	3
Traffic speed	0.54	3	Driver behaviour	0.64	2
Pedestrian volume	0.46	6	Driver's physical and mental condition	0.62	3
Signalling, pavement markings, signage control	0.44	7	Influence of alcohol and nausea	0.68	1
• Traffic signs and pavement marking	0.36	***9***	***Environmental and Emergency related factors***		
• Stop signs	0.41	8	Accidents	0.66	1
• Traffic calming measures such as speed breakers	0.52	4	Rain and storms	0.27	5
			Heat	0.28	3
• Traffic rule enforcement such as speed traps	0.48	5	Slippery roads	0.19	5
			Road blocks and unscheduled stops	0.44	2
Re-engineering measures for reduction of traffic congestion					
Availability of information through Information and Communication Technology (ICT)	0.43	10	Changing the traffic pattern	0.67	3
Segregation of heavy and light vehicles (Modal split)	0.73	2	Making one way streets	0.57	6
Diversion measures (Traffic assignment: choosing a different route)	0.76	1	Closure of roads (partial)	0.33	15
Use of public transportation systems	0.52	8	Segregation of vehicular and pedestrian traffic	0.36	14
Off-street parking provision	0.58	5	Improving the road infrastructure		
Removal of on-street parking system	0.56	7	• Improving junctions	0.66	4

Pedestrianisation of the whole CBD	0.32	16	• Increasing lane width	0.39	13
Pedestrian facilities in major areas	0.24	17	• Increasing number of lanes/road width	0.46	9
Improvement of signalling system	0.4	12	• Provision of pedestrian islands	0.43	10
Installing cameras/ videography	0.46	9	• Provision of footpaths/ pavements	0.42	11
Creation of traffic awareness and improving driver/user knowledge on traffic rules and regulations	0.56	7	Any other - please specify	-	

(Based on the statistical PI analysis from road user data collected, 2015)

4.4.2 Segment delay index (Ds)

Delay rate can be used to estimate the difference between system performance and the expectations for those system elements. Relative delay rate reflects the condition of flow that travelers relate to their travel experience. Total delay offers the possibility to estimate how any improvements within a transportation system could affect a particular corridor or the entire system. Total delay shows the effect of congestion in terms of the amount of travel time lost. However, segment delay provides the information on the travel time lost in a segment of a road section, thus is more relevant in parts of a road or road network. Thus, the segment delay analysis was conducted to determine the delays in important segments of roads in and around the CBD area of Kimberley. Table 4.9 presents the segment delay (total) particularly during peak hours on various roads of Kimberley city. It is observed that maximum delay occurs on Long Road (Ds= 92.06 to city and 87.26 from the city) followed by Transvaal Road impacted by Pniel Street (Ds= 79.69 to city and 79.03 from city). The moderate segment delay indices of Bishop Street (Ds= 34.71 to city and 33.74 from city) and Barkley section 2 impacting Transvaal Road (Ds= 30.81 to city and 30.09 from city) indicate that these roads are moderately congested. All other roads have Ds values ranging between 0.91 and 27.97 which indicate insignificant delay, and are thus observed to be relatively less congested.

Table 4.9: Segment delay index on various roads in and around the CBD of Kimberley

Roads	Direction	Actual travel time (TTac) (minutes per km)	Acceptable travel time TTap (minutes per km)	Vehicle volume in the peak period (Vp) per minute	Peak volume per hour	Segment (Ds)	Level of Congestion
Long	N	2.5	1.0	61.37	3682.5	92.06	HC
	S	2.5	1.0	58.17	3490.6	87.26	HC
Barkley	N	1.66	1.0	9.99	599.6	6.66	LC
	S	1.66	1.0	9.41	564.9	6.27	LC
Bishop	N	2.0	1.0	34.71	2082.7	34.71	MC
	S	2.0	1.0	33.74	2024.5	33.74	MC
Carter	N	1.62	1.0	22.84	1370.8	14.20	LC
	S	1.62	1.0	22.7883	1367.3	14.16	LC
Schmidtsdrift	N	2.22	1.0	22.89	1373.4	27.97	MC
	S	2.22	1.0	22.06	1324.1	26.97	MC
Barkley section 2 impacting Transvaal	N	2.22	1.0	25.21	1512.9	30.81	MC
	S	2.22	1.0	24.62	1477.3	30.09	MC
Memorial	N	1.76	1.0	14.33	860.1	10.96	LC
	S	1.76	1.0	13.20	792.3	10.09	LC
Transvaal influenced by Pniel	N	2.22	1.0	65.20	3912.3	79.69	HC
	S	2.22	1.0	64.66	3879.7	79.03	HC
Du Toitspan	N	1.62	1.0	11.28	676.9	7.01	LC
	S	1.62	1.0	10.71	642.6	6.65	LC
Main	N	1.5	1.0	5.09	305.5	2.54	LC
	S	1.5	1.0	4.94	296.6	2.47	LC
Lyndhurst (N)	N	1.57	1.0	6.36	381.9	3.68	LC
	S	1.57	1.0	5.94	356.4	3.43	LC
North Circular	N	1.33	1.0	4.07	244.6	1.35	LC
	S	1.33	1.0	2.73	164.3	0.91	LC

South Circular	N	1.33	1.0	4.14	248.8	1.38	LC
	S	1.33	1.0	3.77	226.4	1.25	LC
Cecil Sussman	N	1.87	1.0	12.24	734.4	10.71	LC
	S	1.87	1.0	11.71	702.6	10.24	LC

Note: HC= High congestion level, MC= Moderate congestion level, LC= Low congestion level

4.4.3 Travel time delay (TTI)

Travel time delay (TTI) is a time-based congestion measure. TTI provides guidance on identifying major concerns and enables policy makers to address the problems more efficiently and to evolve solutions that are more likely to have a greater impact. It expresses traffic congestion in terms of both space and time. In this investigation TTI has been analyzed on segments of the roads that impact the CBD area during the peak periods. Table 4.10 presents the TTI of the roads in and around the CBD area during the peak period. The high travel time index values observed on Long Road (TTI=2.5), Transvaal Road impacted by Pniel Street (TTI=2.22), Barkley Road section 2 impacting Transvaal Road (TTI=2.22), Schmidtsdrift Road (TTI=2.22) and Bishop Street (TTI= 2.0), indicate that the congestion level of these roads near the CBD area is relatively high during the peak hours. The moderate travel time index values observed on roads such as Cecil Sussman Road (TTI= 1.88), Memorial Road (TTI=1.76), Barkley Road (TTI=1.62) Carter Road (TTI=1.62) and Du Toitspan Street ((TTI=1.62), , indicate that the segments of these roads close to the CBD are moderately congested during peak periods. The lower TTI values of other roads such as Lyndhurst-, Main-, North Circular- and South Circular Road, indicate that the segments of these roads close to CBD area have a relatively lower level of congestion even during the peak periods.

Table 4.10: Travel time delay index on various roads in and around the CBD of Kimberley

Roads	Direction	Free Flow travel speed	Travel time under free flow speed per km (in mins)	Peak flow travel speed (in Km/h)	Travel time under peak flow travel speed (in mins)	Travel Time Index (TTI)	Level of congestion
Long	N	60	1	24	2.50	2.5	HC
	S	60	1	24	2.50	2.5	HC
Barkley	N	60	1	36	1.67	1.66	MC
	S	60	1	36	1.67	1.66	MC
Bishop	N	60	1	30	2.00	2.00	HC
	S	60	1	30	2.00	2.00	HC
Carter	N	60	1	37	1.62	1.62	MC
	S	60	1	37	1.62	1.62	MC
Schmidtsdrift	N	60	1	27	2.22	2.22	HC
	S	60	1	27	2.22	2.22	HC
Barkley section 2 impacting Transvaal	N	60	1	27	2.22	2.22	HC
	S	60	1	27	2.22	2.22	HC
Memorial	N	60	1	34	1.76	1.76	MC
	S	60	1	34	1.76	1.76	MC
Transvaal influenced by Pniel	N	60	1	27	2.22	2.22	HC
	S	60	1	27	2.22	2.22	HC
Du Toitspan	N	60	1	37	1.62	1.62	MC
	S	60	1	37	1.62	1.62	MC
Main	N	60	1	40	1.50	1.50	LC
	S	60	1	40	1.50	1.50	LC
	N	60	1	38	1.58	1.58	LC

Lyndhurst (N)	S	60	1	38	1.58	1.58	LC
North Circular	N	60	1	45	1.33	1.33	LC
	S	60	1	45	1.33	1.33	LC
South Circular	N	60	1	45	1.33	1.33	LC
	S	60	1	45	1.33	1.33	LC
Cecil Sussman	N	60	1	32	1.88	1.88	MC
	S	60	1	32	1.88	1.88	MC

(Note: LC= Low congestion level; MC= Moderate congestion level; HC = High congestion level)

4.4.4 Traffic Transmission index (Q index)

Traffic transmission index (Q index) measures congestion on the basis of speed. Thus congestion is considered as a function of the reduction in speed, which is the direct cause of loss of time that essentially leads to increased vehicle operating costs, fuel consumption, and emissions of air pollutants and greenhouse gases (GHGs). Because a speed based threshold accounts more for the impacts of congestion than would a threshold based on capacity, this analysis was conducted by using a range of speed and number and absolute quantum of change of speed in the study area to comprehend the level of congestion particularly during the peak hours. Peak hours were used for this analysis as the survey indicated that no significant speed changes were observed during the normal hours of day, whereas 4 to 6 speed changes with absolute changes of speed of 15 km/h to 22 km/h were observed on various roads of the study area (c.f Table 4.6) during peak hours.

The Traffic Transmission index (Q index) of the various roads is presented in Table 4.11. The Q index < 300 is considered as highly congested, 300<Q<450 is considered as moderately congested and Q>450 is considered as least congested. It can be observed from Table 4.10 that relatively higher congestion levels are experienced in Long Street (Q= 266.67), Transvaal Road impacted by Pniel Street (Q=245.45), Bishop`s Road (Q=227.27) and Barkley section 2 impacting Transvaal Road (Q= 300). Roads such as Schmidtsdrift Road (Q=337.50), Cecil Sussman Road (Q= 355.56), Memorial Road (Q= 377.78) and Lyndhurst Street (Q=380) are moderately congested. The least congested roads appear to be Barkley Road, Du Toitspan Road, Main Street, North Circular Road and South Circular Road.

Table 4.11: Traffic Transmission index (Q index) on various roads in and around the CBD of Kimberley

Roads	K	Average speed (S) (in *miles/hour)	Absolute of speed changes per mile (in *miles/hour)	Number of speed changes (Af)	Traffic Transmission index (Q index)	Level of congestion
Long	1000	14.59	9.12	6	266.67	HC
	1000	14.59	9.12	6	266.67	HC
Barkley	1000	21.88	9.12	4	600.00	LC
	1000	21.88	9.12	4	600.00	LC
Bishop	1000	18.24	13.37	6	227.27	HC
	1000	18.24	13.37	6	227.27	HC
Carter	1000	22.49	9.12	6	411.11	LC
	1000	22.49	9.12	6	411.11	LC
Schmidtsdrift	1000	16.41	12.16	4	337.50	MC
	1000	16.41	12.16	4	337.50	MC
Barkley section 2 impacting Transvaal	1000	16.41	9.12	6	300.00	HC
	1000	16.41	9.12	6	300.00	HC
Memorial	1000	20.67	9.12	6	377.78	MC
	1000	20.67	9.12	6	377.78	MC
Transvaal influenced by Pniel	1000	16.41	13.37	5	245.45	HC
	1000	16.41	13.37	5	245.45	HC
Du Toitspan	1000	22.49	9.12	5	493.33	LC
	1000	22.49	9.12	5	493.33	LC
Main	1000	24.32	9.12	5	533.33	LC
	1000	24.32	9.12	5	533.33	LC
Lyndhurst (N)	1000	23.10	12.16	5	380.00	MC
	1000	23.10	12.16	5	380.00	MC
North Circular	1000	27.36	12.16	5	450.00	LC
	1000	27.36	12.16	5	450.00	LC
	1000	27.36	13.37	4	511.36	LC

South Circular	1000	27.36	13.37	4	511.36	LC
Cecil Sussman	1000	19.45	10.94	5	355.56	MC
	1000	19.45	10.94	5	355.56	MC

*While calculating Kms/hour have been converted to miles/hour as per the requirement of the empirical model.

(Note: LC= Low congestion level MC= Moderate congestion level, HC = High congestion level)

4.4.5 Queue Length

Queue length of the vehicles at the junctions indicates whether the junction warrants a signal. It also offers a comparison between the actual queue length as observed from the survey and the theoretical queue length based on the arrival flow rate at the junctions. In this investigation an effort has been made to determine the queue length on the roads at various junctions and compared it with the actual queue length. While computing the queue length, the maximum flow rate on the lanes of the roads has been taken into consideration, as the signal timing is always dependent on the maximum flow rate. Table 4.12 presents the queue length on the roads at the junctions. It has been observed that all the junctions except the junction connecting North Circular- and Pniel Road (J6) have a theoretical queue length of more than 4 (number of vehicles consecutively aligned and stand in the same queue). However, the actual queue length of all the roads at all the junctions exceeds 4. Therefore, according to Road Traffic Sign Manual Volume 3 (Road Traffic Sign Manual Volume 3, South Africa, 2012) all the junctions necessitate automated signalling systems. It is also observed that the junctions joining Long Street and Bultfontein Road (J1); Bishop / Lyndhurst Street and Bultfontein Road / Delham Street (J2); Transvaal Road and Cecil Sussman Street (J3); and Transvaal Road and Old Main Street (J5); have significant queue lengths on the major roads. The queue lengths at junctions joining Du Toitspan Street and Lennox Street (J4); and North Circular Road and Pniel Street (J6); are observed to be insignificant, indicating lower levels of congestion at these junctions.

The comparative analysis of theoretical- and actual queue length also indicated that discrepancies between the two are marginal on the roads where significant traffic volumes are experienced. Although the comparative analysis of queue length does not directly clarify the level of congestion at the junctions, some of the junctions such as J1, J2, J3 and J5 are under stress of higher traffic flow rate and consequently higher congestion.

Table 4.12: Current scenario of queue length at different junctions on various roads in and around the CBD of Kimberley

Junction	Roads	Direction	Di = Average delay of vehicles in lane i in units of seconds/vehicle excluding acceleration and	Traffic volume per hour per road	No. of lanes at junctions	Qi = Arrival flow rate in lane i in units of vehicles/hour/lane	Ni=Di. Qi/3600	Actual Queue length measured
Long and Bultfon-tein (J1)	Long	N	90	3280	3	1326	33.15	32
		S	90	3199	3	1257	31.43	29
	Bultfontein	N	90	2409	3	1356	33.90	31
		S	90	2246	3	1248	31.20	28
Bishop -Lyndhurst-Bultfontein -Delham (J2)	Bishop	N	60	2082.7	3	750	12.50	17
	Lyndhurst	S	45	370	3	196	2.45	6
	Bultfontein	N	60	2065	3	1106	18.43	16
	Delham	S	45	1243	3	649	8.11	8
Transvaal - Cecil Sussman (J3)	Transvaal	N	73.33	3912.3	3	2007	40.88	33
		S	73.33	3879.7	3	1990	40.54	34
	Cecil Sussman	N	60	695	3	377	6.28	9
		S	60	664	3	360	6.00	6
Du Toitspan-Lennox (J4)	Du Toitspan	N	37.3	607	3	330	3.42	6
		S	37.3	640	3	347	3.60	8
	Lennox	N	45	620	3	342	4.28	6
		S	45	606	3	338	4.23	6
Transvaal – Old Main (J5)	Transvaal	N	60	2684	2	1240	20.67	17
		S	60	2480	2	1240	20.67	14

	Main	N	30	644	2	322	2.68	6
		S	30	666	2	333	2.78	5
North Circular Road-Pniel (J6)	North circular	N	20	231	2	125	0.69	6
		S	20	155	2	84	0.47	4
	Pniel	N	30	488	2	286	2.38	6

4.4.6 Level of Service (LOS)

Levels of service (LOS) or degrees of traffic congestion were measured by using the most relevant empirical models as discussed in the methodology section (c.f section 1.9.2.5). The Highway Capacity Manual, USA (HCM, 1985, 2000) provides fairly detailed norms for such measurements. Since, the traffic flow (type of vehicles an, volume) is almost similar in a CBD area, it can be more useful to measure congestion.

The LOS for different roads was measured by using a volume capacity ratio (V/C) in terms of Passenger Car Units (PCU) both for normal- and peak hours of the day. The reason for measuring the LOS in different roads during normal- and peak hours is to observe the traffic congestion scenario for normal- and peak hours of the day separately and to determine the possibility and the quantum of traffic to be diverted or re-routed from the heavily congested roads to the less congested roads at different periods of the day. While calculating the LOS, the following models (equations (Eq.1 and 2) were employed:

LOS (normal hours) = V/C………………… Eq. (1)

Where:

V=Average hourly volume of traffic = Annual Average Daily traffic / Total number of hours in the day experiencing traffic flow.

LOS (peak hours) = V_p/C………………… Eq. (2)

Where:

V_p= Average peak hourly volume of traffic = Annual Average total peak hour traffic / Total number of peak hours in the day.

C= Capacity of the roads

The capacity of roads is estimated by considering 1100 vehicles per hour per lane for arterial roads (Type II and III equivalent to U4-minor arterial roads and U5 roads in South African cities) (TRB, 1994, Appendix B-Traffic Level of Service Calculation Methods, B 6-7 (given in Annexure- VI); TRH26, COTO, 2012:22). The capacity was estimated based on a saturation flow rate of 1,900 vehicles per lane per hour (TRB, 1994, Appendix B-Traffic Level of Service Calculation Methods, B 6-7) and on the assumption that major roads would receive 60% of the green time and roads perpendicular to the major roads would receive 40% of the green time. Since the vehicles on the roads observed to constitute about 80% cars (with PCU 1) and about 20% other vehicles including heavy vehicles (trucks, trucks with double trolleys, large buses, mini- and midi buses, cars with trailers construction vehicles with average equivalent PCU of 2.5), the capacity of the roads/lanes is estimated to be 1430 PCU/ hour rounded to 1400 PCU/hour (the capacity of the roads/lanes = 1100*0.8*1.0+1100*0.2*2.5= 1430 PCU/ hour ≈1400 PCU/hour), and as the roads considered in the CBD area are one way and two lane systems, the total capacity of the roads is estimated to be 2800 (2*1400=2800) PCU/h.

The LOS in various roads of the CBD area of Kimberley City is presented in Table 4.13. The LOS of traffic movement both to – and from the city has been evaluated. It can be observed from Table 4.13 that during normal hours under the current scenario, Transvaal Road (influenced by Pniel Road) is highly congested having LOS level F (V/C (N) = 1.01, (V/C (S) =1.0) for traffic moving both towards and from the city. Both directions of Long Street are almost running to their capacity, having LOS level E (V/C (N) = 0.93 and V/C (S) = 0.91) and are a cause of concern. All other roads have LOS levels A (V/C = between 0 and 0.5) and as a result experience no congestion problems. Bishop`s Road, which carries a significant quantum of heavy vehicles is observed to be on the threshold (currently LOS A). Although it does not experience much congestion now, Bishop`s Road has the possibility to move to a higher level of congestion (LOS B) in future. Similarly, during peak hours both the ways of Long Street (Vp/C (N) = 1.24 and Vp/C (S) = 1.25) and Transvaal Road (Vp/C (N) = 1.40 and Vp/C (S) = 1.39) have LOS F (Vp/C > 1.0) and are highly congested. Bishop Street is experiencing LOS C (Vp/C (N) = 0.74 and Vp/C (S) = 0.72) during peak hours whereas all other roads have LOS A and are observed to be experiencing not much congestion, even during peak hours. The higher values of the V_p/C ratio – particularly on roads such as Carter`s Road, Barkley Street impacting Transvaal Road and Schmidtsdrift Road, show that there is a possibility of these roads moving to the next level of congestion in future. In view of the above findings, traffic congestion alleviation interventions are necessary in at least two roads, namely Long Street and Transvaal Road, although Bishop`s Road will also require careful attention in the near future.

Table 4.13: Current scenario of LOS on different roads in and around the CBD of Kimberley during normal and peak hours

Roads	Direction	No of lanes	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU Vp)	Capacity (C) of two lane arterial roads	V/C	LOS (Normal hours)	V_p/C	LOS (Peak hours)
Long	N	2	2611.9	3482.5	2800	0.93	E	1.24	F
	S	2	2542.90	3490.60	2800	0.91	E	1.25	F
Barkley	N	2	449.3	599.0	2800	0.16	A	0.21	A
	S	2	415.90	564.90	2800	0.15	A	0.20	A
Bishop	N	2	1531.50	2082.70	2800	0.55	A	0.74	C
	S	2	1503.40	2024.59	2800	0.54	A	0.72	C
Carter	N	2	988.10	1370.80	2800	0.35	A	0.49	A
	S	2	995.50	1367.30	2800	0.36	A	0.49	A
Schmidtsdrift	N	2	977.50	1373.40	2800	0.35	A	0.49	A
	S	2	967.60	1324.10	2800	0.35	A	0.47	A
Barkley section 2 impacting Transvaal	N	2	1084.70	1512.90	2800	0.39	A	0.54	A
	S	2	1052.80	1477.30	2800	0.38	A	0.53	A
Memorial	N	2	607.60	860.10	2800	0.22	A	0.31	A
	S	2	586.78	792.30	2800	0.21	A	0.28	A
Transvaal influenced by Pniel	N	2	2826.80	3912.30	2800	1.01	F	1.40	F
	S	2	2804.80	3879.70	2800	1.00	F	1.39	F
Du Toitspan	N	2	476.70	676.90	2800	0.17	A	0.24	A
	S	2	433.40	642.60	2800	0.15	A	0.23	A
Main	N	2	246.40	305.50	2800	0.09	A	0.11	A
	S	2	224.20	296.60	2800	0.08	A	0.11	A
Lyndhurst	N	2	288.20	381.90	2800	0.10	A	0.14	A
	S	2	268.80	356.40	2800	0.10	A	0.13	A

North Circular	N	2	182.30	244.60	2800	0.07	A	0.09	A
	S		132.50	164.30	2800	0.05	A	0.06	A
South Circular	N	2	176.70	248.80	2800	0.06	A	0.09	A
	S		168.40	226.40	2800	0.06	A	0.08	A
Cecil Sussman	N	2	527.80	734.40	2800	0.19	A	0.26	A
	S	2	498.60	702.60	2800	0.18	A	0.25	A

4.4.7 Summary of findings of the congestion analysis

Congestion analysis of the current scenario indicated that**:**

- Road parking facilities, type of junctions, traffic volume and type and composition of vehicles – particularly the plying of heavy vehicles (large trucks) – are the major variables which significantly influence congestion on the roads in and around the CBD area of Kimberley.
- Unavailability of space near junctions; availability of commercial function; availability of traffic nodes such as bus stops and taxi stops; and availability of civic/administrative functions are the urban development factors which influence the occurrence of congestion.
- On-road informal commercial activities; building offset; encroachment of roads; and building size are the least influential spatial/ land use and urban functions variables to cause congestion on the roads of the study area.
- Traffic speed and traffic calming measures such as speed breakers are the traffic related factors that cause traffic congestion.
- Signalling systems; traffic signs and pavement marking; stop signs; and traffic rule enforcement such as speed traps have insignificant influence on traffic congestion.
- The influence of alcohol and nausea on the driver; disrespect of traffic rules and regulations by road users; unruly driver behaviour; poor physical and mental condition of the driver; and lack of knowledge of traffic rules are the human and behavioural factors which influence congestion to a certain extent.
- Environmental and emergency factors such as road blocks and unscheduled stops, heat, rain, storms and slippery roads are least influential factors to cause congestion on the roads of the study area.
- Vehicular traffic collisions influence congestion to a certain extent.
- Median facilities, pedestrian crossing facilities, road conditions and pavements/ footpaths do not influence congestion significantly.

- According to the segment delay analysis, maximum delay occurs on Long Road followed by Transvaal Road impacted by Pniel. Moderate delay occurs on Bishop Street and Barkley section 2 impacting Transvaal Road and other roads do not experience much segment delay. Maximum congestion occurs on Long Road and Transvaal Street, followed by Bishop`s Road.
- The TTI analysis indicated that road sections close to the CBD of Long Street, Transvaal impacted by Pniel Road, Barkley section 2 impacting Transvaal Street, and Schmidtsdrift Road are under severe pressure, followed by Bishop`s Road.
- The Q indices show that Long Street, Transvaal Road impacted by Pniel Road, Bishop`s Road and Barkley section 2 impacting Transvaal Road have relatively high congestion levels. Roads such as Schmidtsdrift Road, Cecil Sussman Road, Memorial Road and Lyndhurst Street are moderately congested.
- The LOS of various roads during normal hours show that Transvaal Road (influenced by Pniel Road) is highly congested; whereas Long Street is almost running to its capacity and Bishop`s Road could become a cause of concern.
- The LOS of various roads during peak hours show that Transvaal Road (influenced by Pniel Road) is highly congested; whereas both ways of Long Street are highly congested, followed by Bishop`s Road. Carter`s Road, Barkley Street impacting Transvaal Road and Schmidtsdrift Road could become cause of concern. All other roads are least congested.
- Junctions connecting Long Street and Bultfontein Road (J1), Bishop-/Lyndhurst Street and Bultfontein Road/Delham Street (J2), Transvaal Road and Cecil Sussman Street (J3), and Transvaal Road and Old Main Street (J5) experience high queue length during peak hours and seem to be under pressure with regard to congestion.

4.5 FORECASTING OF TRAFFIC VOLUME, ANALYSIS OF SIMULATED FUTURE SCENARIO OF CONGESTION AND MEASURES FOR REDUCTION OF TRAFFIC CONGESTION

4.5.1 Forecasting of traffic volume on different roads in and around CBD area of Kimberley city

Forecasting of traffic volume on various roads is essential to develop remedial measures and policy interventions for alleviating traffic congestion challenges. Consequently forecasting of the traffic volume in terms of PCU (Kadiali, 2008) has been conducted by using a dynamic forecasting method and employing the algorithm as given in equation 8 (Eq. 8) as set out in the methodology section (c.f Chapter 1, section 1.9.2.3).

While forecasting the future traffic volume, the year 2015 is considered as the base year and the year 2025 is considered as the projected year. The prediction spans a period of 10 years. The volume of traffic at the base year is considered as the traffic volume at initial year (Vi) and the traffic volume at predicted years is taken as Vt. The average annual normal rate of increase in traffic volume (r1) was calculated based on the average rate of increase of traffic volume in last ten years. Similarly, the average annual rate of increase in traffic volume due to the establishment and operation of the Sol Plaatje University in Kimberley City (r2) was determined through discussion with experts, traffic officials and municipality officials. The average annual rate of decrease in traffic volume because of reduction in mining activities (r3) were calculated by considering the rate of increase and decrease in traffic volume in the city because of the changes in mining activities over the last 10 years (c.f Chapter 1, section 1.9.2.3). For this purpose discussion with experts, traffic officials and municipality officials were also held.

Table 4.14 presents the predicted average hourly traffic volume during normal- and peak hours on various roads in and around the CBD area of Kimberley City. It is observed that traffic volume on roads such as Long Street (>3100 PCU and >4100 during normal and peak hours respectively) and Transvaal Road (>3300 PCU and >4600 during normal- and peak hours respectively) is considerable. The traffic volume in Bishop`s Road (>1700 PCU and >2400), Barkley section 2 impacting Transvaal (>1200 PCU and >1700), Schmidtsdrift Road (>1100 PCU and >1500) and Carter Road (>1100 PCU and >1700) will also increase significantly.

Table 4.14: Predicted future traffic volume on roads in and around the Kimberley CBD by the year 2025.

Roads	Direction	No of lanes	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU Vp)
Long	N	2	3105	4142.24
	S	2	3023	4151.76
Barkley	N	2	534.41	712.48
	S	2	494.69	671.92
Bishop	N	2	1822.11	2477.76
	S	2	1788.21	2408.1
Carter	N	2	1187.07	1633.49

	S	2	1185.97	1626.33
Schmidtsdrift	N	2	1162.69	1633.58
	S	2	1174.7	1575.43
Barkley section 2 impacting Transvaal	N	2	1289	1799.51
	S	2	1252.25	1757.17
Memorial	N	2	722.71	1023.17
	S	2	697.22	942.4
Transvaal influenced by Pniel	N	2	3362.44	4653.46
	S	2	3336.15	4614.93
Du Toitspan	N	2	567.02	805.13
	S	2	515.51	764.22
Main	N	2	393.08	461.31
	S	2	266.91	352.79
Lyndhurst	N	2	342.6	454.25
	S	2	319.7	421.78
North Circular	N	2	216.64	290.94
	S		157.7	195.43
South Circular	N	2	210.17	295.55
	S		200.3	269.29
Cecil Sussman	N	2	627.79	873.55
	S	2	593.06	835.7

Table 4.15 presents the predicted queue length based on the predicted volume of vehicles at different junction in various roads of the study area. It is observed that the queue length on roads such as Long Street and Bultfontein Road at J1, Bishop`s Road and Bultfontein Road at J2, Transvaal Road impacted by Pniel Road at J3, and Transvaal Road at J5 will experience significant increase even during normal hours of traffic. The queue length at the respective junctions on these roads during peak hours will be much higher. For example, the queue length on Long Street will experience an increase of 60%. The queue length on Transvaal Road impacted by Pniel-, Bishop- and Bultfontein Road will increase from the current scenario by an average of 17.5%**.** It is also observed that the required signal timings at the junctions J1, J3 and J5 will exceed the currently provided cycle length signal timings of 70s second by 57.4%, 92.8% and 104.3%s respectively, which thus requires re-designing of signals at these junctions. It is therefore expected that in future junctions J1, J2, J3 and J5 will be under

pressure of congestion during both normal and peak hours, which will require interventions to reduce the congestion level at the junctions.

Table 4.15: Predicted queue length and required signal timings at different junctions on different roads in and around the Kimberley CBD

Junction	Roads	Direction	No of lanes at junctions	Predicted Qi = Arrival maximum flow rate in lane i in units of	Predicted Qi = Arrival maximum flow rate in lane i in units of	Predicted Ni=Queue length (Normal hours)	Predicted Ni=Queue length (Peak hours)	Predicted required length of signal timings (in seconds)
Long and Bultfontein (J1)	Long	N	3	1592.87	2124.97	39.82	53.12	110
		S	3	1550.8	2129.85	38.77	53.25	
	Bultfontein	N	3	1156	1593.3	28.90	39.83	
		S	3	1134	1466.4	28.35	36.66	
Bishop - Lyndhurst- Bultfontein - Delham (J2)	Bishop	N	3	967.54	881.25	16.13	14.69	43
	Lyndhurst	S	3	181.921	230.3	2.27	2.88	
	Bultfontein	N	3	967	1299.55	16.12	21.66	
	Delham	S	3	468	762.575	5.85	9.53	
Transvaal - Cecil Sussman (J3)	Transvaal	N	3	1724.93	2358.23	35.14	48.04	135
		S	3	1711.44	2338.25	34.86	47.63	
	Cecil Sussman	N	3	322.056	442.97	5.37	7.38	
		S	3	304.24	423	5.07	7.05	
Du Toitspan- Lennox (J4)	Du Toitspan	N	3	0	387.75	0.00	4.02	31
		S	3	278	407.72	2.88	4.22	
	Lennox	N	3	266	401.85	3.33	5.02	
		S	3	242	397.15	3.03	4.96	

Transvaal – Old Main Street (J5)	Transvaal	N	2	1032	1457	17.20	24.28	143
		S	2	1032	1457	17.20	24.28	
	Main	N	2	234	378.35	1.95	3.15	
		S	2	218	391.27	1.82	3.26	
North Circular - Pniel (J6)	North circular	N	2	111.13	146.8	0.62	0.82	25
		S	2	80.90	98.7	0.45	0.55	
	Pniel	N	2	248	336.05	2.07	2.80	

4.5.2 Simulated scenarios of congestion level

Simulated scenarios of level of congestion were developed in order to evolve policy interventions for reducing congestion on the roads in and around the CBD of Kimberley City. Of the various methods to assess the congestion level, Level of Service was selected to develop the simulated scenarios of congestion in future as this was found to be most suitable method of congestion analysis (HCM, 1985, 2000). Other methods such as Travel Time Index, Segment Delay Index and Q Index require traffic related data such as peak period travel time, actual travel time (in minutes), absolute of speed changes per mile and number of speed changes per mile which are not available for future years and are also not feasible to predict. On the other hand, data for assessment of LOS, which is based on the capacity and volume of vehicles, are available and can be predicted for the future.

Table 4.16 presents the simulated scenarios of assessment of congestion level. The simulated scenarios were developed by considering transportation planning and traffic congestion reduction interventions such as traffic assignment (traffic diversion from congested roads to relevant relatively free roads) and modal split (segregation of normal vehicles and heavy vehicles) for current traffic volume during peak periods as well as for predicted traffic volume for both normal- and peak hours. The simulated scenarios are discussed in the following sections.

Table 4.16: Simulated scenarios for assessment of congestion level

Simulated scenarios	Interventions	Change in Variables
Scenario 1 (Current scenario: Normal period)	Traffic assignment and percentage traffic diversion	Change in traffic assignment on roads through diversion of vehicles from congested roads to free roads.
Scenario 2 (Current scenario: Peak period)	Traffic assignment and percentage traffic diversion	Change in traffic assignment on roads through diversion of vehicles from congested roads to free roads in addition to provision of modal split up to the extent of share of heavy vehicles.
Scenario 3 (Current scenario: Peak period)	Combination of modal split and traffic assignment	Combination of modal split to a maximum level of actual number of the heavy vehicles on the congested roads and diversion of a minimum required percentage of normal cars
Scenario 4 (Projected scenarios: Normal period)	No interventions	If the current scenario of traffic flow continues
Scenario 5 (Projected scenarios: Normal period)	Traffic assignment and percentage traffic diversion	Change in traffic assignment on roads through diversion of vehicles from congested roads to free roads
Scenario 6 (Projected scenarios: Normal period)	Modal split	Segregation (modal split) of heavy vehicles and normal vehicles (cars) in congested roads and diverting them to relevant free roads to a maximum level of actual number of heavy vehicles on the congested roads
Scenario 7 (Projected scenario: Peak period)	Traffic assignment and percentage traffic diversion	Change in traffic assignment on roads through diversion of vehicles from congested roads to free roads
Scenario 8 (Projected scenario: Peak period)	Modal split and traffic assignment	Segregation (modal split) of heavy vehicles and normal vehicles (cars) in congested roads and diverting them to relevant free roads to a maximum level of actual number of heavy vehicles on the congested roads

4.5.2.1 Simulated scenario of congestion level (LOS) through traffic assignment and percentage traffic diversion: Scenario 1: Current scenario – normal hours

Table 4.17 presents the results of the simulated scenario1, which assesses change in speed on the roads during normal hours in the current scenario as well as the minimum amount of traffic volume that can be diverted from congested roads and assigned to relatively free roads. It is based on the principle of percentage traffic diversion which in turn is based on new (desired) travel time and old travel time. Based on acceptable desired travel time, the results indicated that about 26.0% of the traffic from Long Street, 28.80% of the traffic from Transvaal Road, 31.77% of the traffic from Bishop Road and 34.70% of the traffic from Cecil Sussman Street can be diverted. Consequently, the LOS level of Long Street and Transvaal Road will change from level E to level B and from level F to level C respectively. However, the LOS of Bishop`s Road and Cecil Sussman Street will remain the same at LOS A. It is also found that diverted vehicles from Long Street can be assigned to Du Toitspan- (13.0%), Lyndhurst- and Memorial Road (13.0%). Vehicles from Transvaal Road can be assigned to pass through Barkley section 2 (14.40%), Main Street (14.40%) and Lyndhurst Street (14.40%). Although the current scenarios of Bishop`s Road and Cecil Sussman Road do not warrant any diversion and traffic assignment to other roads, the traffic can be assigned to Main-, Du Toitspan- and Lyndhurst Street if necessary. So Main Street, Du Toitspan span and Lyndhurst carry additional traffic volume of 31.75%, 13.0% and 31.75% respectively. Despite carrying the additional traffic assignment through diversion of vehicles to these roads, the roads other than Long Street and Transvaal Street will experience LOSs of A, indicating least congestion. In addition, Long Street and Transvaal Road will experience an increase of 8 km/h and 7 km/h respectively from their current average speed (refer map 2 and map 3; annexure VIII and IX).

Table 4.17: LOS during normal hours under the current scenario after appropriate traffic assignment and diversion of traffic

Roads	Direction	Average speed increase from current actual speed (In	Travel time ratio = Time in new system/ Time in old system	Average hourly volume (V) (In PCU)	Minimum % vehicle requiring diversion 100-100/ (1+	Modified average hourly volume after traffic assignment (Vm)	Capacity (C) of two-lane arterial roads	Vm/C	LOS
Long Street	N	8 (42)	0.84	2611.9	26.00	1932.81	2800	0.69	B
	S	8 (42)	0.84	2542.90	26.00	1881.75	2800	0.67	B
Barkley Road	N	2 (48)	0.96	449.3	0.00	449.30	2800	0.16	A
	S	2 (48)	0.96	415.90	0.00	415.90	2800	0.15	A
Bishop`s Road	N	6 (44)	0.88	1531.50	31.77	1044.94	2800	0.37	A
	S	6 (44)	0.88	1503.40	31.71	1026.67	2800	0.37	A
Carter`s Road	N	1 (49)	0.98	988.10	0.00	988.10	2800	0.35	A
	S	1 (49)	0.98	995.50	0.00	995.50	2800	0.36	A
Schmidts drift Street	N	0 (52)	1.0	977.50	0.00	977.50	2800	0.35	A
	S	0 (52)	1.0	967.60	0.00	967.60	2800	0.35	A
Barkley section 2 impacting Transvaal Road	N	2 (48)	0.98	1084.70	-14.40	1240.90	2800	0.44	A
	S	2 (48)	0.98	1052.80	-14.40	1204.40	2800	0.43	A
Memorial Road	N	0 (52)	1.0	607.60	-13.00	686.59	2800	0.25	A
	S	0 (52)	1.0	586.78	-13.00	663.06	2800	0.24	A
Transvaal Road influence d by Pniel Road	N	7 (43)	0.86	2826.80	28.80	2012.68	2800	0.72	C
	S	7 (43)	0.86	2804.80	28.80	1997.02	2800	0.71	C
Du Toitspan Road	N	0 (51)	1.0	476.70	-13.00	538.67	2800	0.19	A
	S	0 (51)	1.0	433.40	-13.00	489.74	2800	0.17	A

Main Street	N	0 (53)	1.0	246.40	-31.75	324.63	2800	0.12	A
	S	0 (53)	1.0	224.20	-31.75	295.38	2800	0.11	A
Lyndhurst Street	N	0 (55)	1.0	288.20	-31.75	196.70	2800	0.07	A
	S	0 (55)	1.0	268.80	-31.75	354.14	2800	0.13	A
North Circular street	N	0 (55)	1.0	182.30	0.00	182.30	2800	0.07	A
	S	0 (55)	1.0	132.50	0.00	132.50	2800	0.05	A
South Circular Street	N	0 (55)	1.0	176.70	0.00	176.70	2800	0.06	A
	S	0 (55)	1.0	168.40	0.00	168.40	2800	0.06	A
Cecil Sussman Street	N	5 (45)	0.9	527.80	34.70	344.65	2800	0.12	A
	S	5 (45)	0.9	498.60	34.70	325.59	2800	0.12	A

4.5.2.2 Simulated scenario of congestion level (LOS) through traffic assignment and percentage traffic diversion: Scenario 2: Current scenario - peak hours

Table 4.18 presents the simulated scenarios of congestion level (LOS) through traffic assignment and percentage traffic diversion under the current scenario during peak hours. Based on the desired (new) travel time, it is found that a minimum of 20.77% of traffic from Long Street and 28.80% of traffic from Transvaal Street need to be diverted to reduce the level of congestion on these roads from LOS F to LOS E. About 15.11% of traffic may be diverted from Bishop Street to reduce the current congestion level of LOS C to LOS B. Although the other roads do not warrant any diversion, 12.73% of traffic from Barkley-, 9.0% of traffic from Barkley section 2-, 14.10% of traffic from Carter-, and 20.77% of traffic from Cecil Sussman Road can be diverted. These vehicles can be assigned to Memorial Road (12.23%), Du Toitspan Road (20. 77%), Lyndhurst Street and Main Street (25.80%) without increasing the congestion level in these roads. Consequently, the two most congested roads (Long Street and Transvaal Road) will experience an increase in speed of 8 km/h and 5 km/h respectively. The speed on Bishop`s Road and Cecil Sussman Road will increase by 10 km/h and 8 km/ h respectively. It is thus apparent that Long Street and Transvaal Road need significant traffic diversion whereas Bishop`s Road needs traffic diversion to a certain extent in order to reduce congestion and improve speed during peak hours. The traffic diverted from these roads can be assigned to Memorial Road, Du Toitspan-, Lyndhurst- and Main Street without enhancing the congestion level during peak periods.

Table 4.18: LOS at peak hours under the current scenario after appropriate traffic assignment and diversion of traffic

Roads	Direction	Average speed increase from current to actual speed (In km/ h)	Travel time ratio = Time in new system/ Time in old system	Minimum % vehicles requiring diversion 100-100/ (1+ t_R^6)	Peak hourly volume (In PCU V_p)	Modified peak hour volume after traffic assignment (Vpm)	Capacity (C) of two lane arterial roads in PCU	Vpm/C	LOS Peak hour
Long Street	N	8 (24)	0.8	20.77	3482.5	2759.18	2800	0.99	E
	S	8 (24)	0.8	20.77	3490.6	2765.60	2800	0.99	E
Barkley Road	N	14 (36)	0.72	12.23	599	525.75	2800	0.19	A
	S	14 (36)	0.72	12.23	564.9	495.82	2800	0.18	A
Bishop`s Road	N	10 (30)	0.75	15.11	2082.7	1768.03	2800	0.63	B
	S	10 (30)	0.75	15.11	2024.59	1718.70	2800	0.61	B
Carter`s Road	N	13 (37)	0.74	14.10	1370.8	1177.45	2800	0.42	A
	S	13 (37)	0.74	14.10	1367.3	1174.45	2800	0.42	A
Schmidtsdrift Road	N	13 (27)	0.68	0.00	1373.4	1373.40	2800	0.49	A
	S	13 (27)	0.68	0.00	1324.1	1324.10	2800	0.47	A
Barkley section 2 impacting Transvaal Road	N	13 (27)	0.68	9.00	1512.9	1376.74	2800	0.49	A
	S	13 (27)	0.68	9.00	1477.3	1344.34	2800	0.48	A
Memorial Road	N	16 (34)	0.68	-12.23	860.1	965.29	2800	0.34	A
	S	16 (34)	0.68	-12.23	792.3	889.20	2800	0.32	A
Transvaal Road influenced by Pniel Road	N	5 (27)	0.86	28.80	3912.3	2785.56	2800	0.99	E
	S	5 (27)	0.86	28.80	3879.7	2762.35	2800	0.99	E
Du Toitspan Road	N	13 (37)	0.74	-20.77	676.9	817.49	2800	0.29	A
	S	13 (37)	0.74	-20.77	642.6	776.07	2800	0.28	A
Main Street	N	10 (40)	0.8	-25.80	305.5	384.32	2800	0.14	A
	S	10 (40)	0.8	-25.80	296.6	373.12	2800	0.13	A

Lyndhurst Street	N	12 (38)	0.95	-25.80	381.9	480.43	2800	0.17	A
	S	12 (38)	0.95	-25.80	356.4	448.35	2800	0.16	A
North Circular Street	N	5 (45)	0.9	0.00	244.6	244.60	2800	0.09	A
	S	5 (45)	0.9	0.00	164.3	164.30	2800	0.06	A
South Circular Street	N	5 (45)	0.9	0.00	248.8	248.80	2800	0.09	A
	S	5 (45)	0.9	0.00	226.4	226.40	2800	0.08	A
Cecil Sussman Street	N	8 (32)	0.8	20.77	734.4	581.87	2800	0.21	A
	S	8 (32)	0.8	20.77	702.6	556.67	2800	0.20	A

4.5.2.3 Simulated scenario of congestion level (LOS) under the combination of modal split and traffic assignment (Scenario 3: current scenario -peak hours)

The current scenario of LOS during peak hours on various roads of the study area under the combination of modal split and traffic assignment is presented in Table 4.19. Maximum segregation of heavy vehicles on the various roads, along with diversion of a certain percentage of cars has been done here to explore the congestion levels. It has been established that total modal split (segregation of vehicles up to the maximum proportion of heavy vehicles (12%-15%) as the case may be does not reduce the congestion level during peak period in two of the most congested roads, namely Long Street and Transvaal Road. Consequently, an attempt was made to combine the modal split with traffic diversion of normal vehicles. The simulated result indicated that under the combination of total modal split and the diversion of a minimum of 8% normal traffic (cars) from Long Street and 14% of normal traffic (cars) from Transvaal Road, congestion on these roads will be reduced from LOS F levels to LOS E levels. Other roads, however, do not need any modal split or diversion of vehicles under the current scenario. The heavy vehicles and cars diverted from Long Street and Transvaal Road can be assigned to Du Toitspan Road, Main Road and Lyndhurst Street without affecting the congestion level of these roads.

Table 4.19: LOS at peak hours under the current scenario under the combination of modal split and traffic assignment

Roads	Direction	Average hourly volume (In PCU V)	Peak hourly volume (In PCU Vp)	% heavy vehicles in equivalent PCU	% heavy vehicles diverted (% modal split in major roads)	% cars diverted (PCU)	Peak hour volume after modal split (Vpm)	Capacity of two lane arterial roads (C)	(Vpm/C)	LOS
Long Street	N	2611.9	3482.5	12.00	-12.00	-8.00	2786	2800	0.99	**E**
	S	2542.9	3490.6	12.00	-12.00	-8.00	2792.5	2800	0.99	**E**
Barkley Road	N	449.3	599	3.00	0.00	0.00	599	2800	0.21	A
	S	415.9	564.9	3.00	0.00	0.00	564.9	2800	0.20	A
Bishop Road	N	1531.5	2082.7	4.00	0.00	0.00	2082.7	2800	0.74	C
	S	1503.4	2024.59	4.00	0.00	0.00	2024.6	2800	0.72	C
Carter Road	N	988.1	1370.8	4.00	0.00	0.00	1370.8	2800	0.49	A
	S	995.5	1367.3	4.00	0.00	0.00	1367.3	2800	0.49	A
Schmidtsdrift Road	N	977.5	1373.4	2.00	0.00	0.00	1373.4	2800	0.49	A
	S	967.6	1324.1	2.00	0.00	0.00	1324.1	2800	0.47	A
Barkley section 2 impacting Transvaal Road	N	1084.7	1512.9	6.00	0.00	0.00	1512.9	2800	0.54	A
	S	1052.8	1477.3	6.00	0.00	0.00	1477.3	2800	0.53	A
Memorial Road	N	607.6	860.1	6.00	0.00	0.00	860.1	2800	0.31	A
	S	586.78	792.3	6.00	0.00	0.00	792.3	2800	0.28	A
Transvaal Road influenced by Pniel Road	N	2826.8	3912.3	15.00	-15.00	-14.00	2777.7	2800	0.99	E
	S	2804.8	3879.7	15.00	-15.00	-14.00	2754.6	2800	0.98	E
Du Toitspan Road	N	476.7	676.9	2.00	13.50	11.50	846.13	2800	0.30	A
	S	433.4	642.6	2.00	13.50	11.50	803.25	2800	0.29	A

Main Street	N	246.4	305.5	1.00	13.50	11.50	381.88	2800	0.14	A
	S	224.2	296.6	1.00	13.50	11.50	370.75	2800	0.13	A
Lyndhurst Street	N	288.2	381.9	2.00	13.50	11.50	477.38	2800	0.17	A
	S	268.8	356.4	2.00	13.50	11.50	445.5	2800	0.16	A
North Circular Street	N	182.3	244.6	2.00	0.00	0.00	244.6	2800	0.09	A
	S	132.5	164.3	2.00	0.00	0.00	164.3	2800	0.06	A
South Circular Street	N	176.7	248.8	2.00	0.00	0.00	248.8	2800	0.09	A
	S	168.4	226.4	2.00	0.00	0.00	226.4	2800	0.08	A
Cecil Sussman Street	N	527.8	734.4	6.00	0.00	0.00	734.4	2800	0.26	A
	S	498.6	702.6	6.00	0.00	0.00	702.6	2800	0.25	A

(Note: 100% diversion of heavy vehicles from major roads + partial diversion of cars during the peak hours**)**

4.5.2.4 Simulated scenario of congestion level (LOS) during normal hours and peak hours under the projected future traffic scenario without any interventions

Table 4.20 presents the LOS on different roads in the study area during normal– and peak hours with the predicted traffic volumes in the projected year 2025. The results indicated that should the current pattern of traffic flow continue on the various roads of study area, Long Street and Transvaal Road will experience a very high level of congestion F (LOS F) and Bishop Street will reach a level of congestion C (LOS C) during normal hours. However, all other roads will remain at the same level of LOS A, without undergoing much change in the congestion level during normal hours. The higher volume and capacity ratio of Long Street (LOS F) and Transvaal Road (LOS F) during peak period, suggest that these roads will become more congested during peak periods. Similarly, Bishop`s Road will also reach a LOS level of D during peak hours. However, the higher volume and capacity ratio (0.86 - 0.88) on this road suggests that it will be at the threshold of LOS E, which is a cause of concern. Barkley section 2 will experience a LOS level of B. Although roads such as Carter- and Schmidtsdrift Road will have a LOS level of A, and they will be at the threshold of LOS B and as a result will remain susceptible for higher congestion levels in future.

Table 4.20: LOS during normal hours and peak hours under the projected future traffic scenario without any interventions (Scenario 4-: usual traffic flow - no policy interventions)

Roads	Direction	No of lanes	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU Vp)	Capacity (C) of two lane arterial roads	Vt/C	LOS (Normal hours)	Vt_p/C	LOS (Peak hours)
Long Street	N	2	3105	4142.24	2800	1.11	F	1.48	F
	S	2	3023	4151.76	2800	1.08	F	1.48	F
Barkley Road	N	2	534.41	712.48	2800	0.19	A	0.25	A
	S	2	494.69	671.92	2800	0.18	A	0.24	A
Bishop Road	N	2	1822.11	2477.76	2800	0.65	C	0.88	D
	S	2	1788.21	2408.1	2800	0.64	C	0.86	D
Carter Road	N	2	1187.07	1633.49	2800	0.42	A	0.58	A
	S	2	1185.97	1626.33	2800	0.42	A	0.58	A
Schmidtsdrift Road	N	2	1162.69	1633.58	2800	0.42	A	0.58	A
	S	2	1174.7	1575.43	2800	0.42	A	0.56	A
Barkley section 2 impacting Transvaal Road	N	2	1289	1799.51	2800	0.46	A	0.64	B
	S	2	1252.25	1757.17	2800	0.45	A	0.63	B
Memorial Road	N	2	722.71	1023.17	2800	0.26	A	0.37	A
	S	2	697.22	942.4	2800	0.25	A	0.34	A
Transvaal Road influenced by Pniel Road	N	2	3362.44	4653.46	2800	1.20	F	1.66	F
	S	2	3336.15	4614.93	2800	1.19	F	1.65	F
Du Toitspan Road	N	2	567.02	805.13	2800	0.20	A	0.29	A
	S	2	515.51	764.22	2800	0.18	A	0.27	A

Main Street	N	2	393.08	363.31	2800	0.14	A	0.13	A
	S	2	266.91	352.79	2800	0.10	A	0.13	A
Lyndhurst Street	N	2	342.6	454.25	2800	0.12	A	0.16	A
	S	2	319.7	421.78	2800	0.11	A	0.15	A
North Circular Street	N	2	216.64	290.94	2800	0.08	A	0.10	A
	S		157.7	195.43	2800	0.06	A	0.07	A
South Circular Street	N	2	210.17	295.55	2800	0.08	A	0.11	A
	S		200.3	269.29	2800	0.07	A	0.10	A
Cecil Sussman Street	N	2	627.79	873.55	2800	0.22	A	0.31	A
	S	2	593.06	835.7	2800	0.21	A	0.30	A

4.5.2.5 Simulated scenario of congestion level (LOS) during normal hours under the projected future traffic scenario after diversion of traffic and appropriate traffic assignment. Scenario 5: - Projected scenario – normal period with traffic assignment

Table 4.21 presents the simulated scenarios of congestion level (LOS) during normal hours under the projected future traffic scenario after diversion of traffic and appropriate traffic assignment. It is observed that about 26.0% of traffic from Long Street and 28.80% of traffic from Transvaal Road will need to be diverted, consequently reducing the congestion levels of the two roads from level F to level D. About 31.77% of the traffic from Bishop`s Road and 34.70% of the traffic from Cecil Sussman Street may be diverted, which will decrease their LOS levels to level A. The diverted traffic from these roads may be assigned to Barkley impacting Pniel Street (14.40%), Memorial Road (13.00%), Du Toitspan Street (13.00%), Lyndhurst Street (31.75%) and Main Street (31.75%) without increasing the congestion level on these roads. This will result in an increase in speed of 8 km/h in Long Street, 7 km/h in Transvaal Road, 6 km/h in Bishop`s Road and 5 km/h in Cecil Sussman Street.

Table 4.21: LOS during normal hours under the projected future traffic scenario after diversion of traffic and appropriate traffic assignment. (Scenario 5: Projected scenario – normal hours with traffic assignment)

Roads	Direction	Average speed increase from current actual speed (In km/h)	Travel time ratio = Time in New system/ Time in old system	Average normal hourly volume (Vapt) (In PCU	Minimum % vehicles requiring diversion 100-100/ (1+	Modified average normal hourly volume after traffic assignment (Vpnt)	Capacity (C) of two lane arterial roads	Vpat/C	LOS
Long Street	N	8 (42)	0.84	3105	26.00	2297.70	2800	0.82	D
	S	8 (42)	0.84	3023	26.00	2237.02	2800	0.80	D
Barkley Road	N	2 (48)	0.96	534.41	0.00	534.41	2800	0.19	A
	S	2 (48)	0.96	494.69	0.00	494.69	2800	0.18	A
Bishop`s Road	N	6 (44)	0.88	1822.11	31.77	1243.23	2800	0.44	A
	S	6 (44)	0.88	1788.21	31.71	1221.17	2800	0.44	A
Carter`s Road	N	1 (49)	0.98	1187.07	0.00	1187.07	2800	0.42	A
	S	1 (49)	0.98	1185.97	0.00	1185.97	2800	0.42	A
Schmidtsdrift Road	N	0 (52)	1.0	1162.69	0.00	1162.69	2800	0.42	A
	S	0 (52)	1.0	1174.7	0.00	1174.70	2800	0.42	A
Barkley section 2 impacting Transvaal Road	N	2 (48)	0.98	1289	-14.40	1474.62	2800	0.53	A
	S	2 (48)	0.98	1252.25	-14.40	1432.57	2800	0.51	A
Memorial Road	N	0 (52)	1.0	722.71	-13.00	816.66	2800	0.29	A
	S	0 (52)	1.0	697.22	-13.00	787.86	2800	0.28	A
Transvaal Road influenced by Pniel Road	N	7 (43)	0.86	3362.44	28.80	2394.06	2800	0.86	D
	S	7 (43)	0.86	3336.15	28.80	2375.34	2800	0.85	D
	N	0 (51)	1.0	567.02	-13.00	640.73	2800	0.23	A

Du Toitspan Road	S	0 (51)	1.0	515.51	-13.00	582.53	2800	0.21	A
Main Street	N	0 (53)	1.0	393.08	-31.75	517.88	2800	0.18	A
	S	0 (53)	1.0	266.91	-31.75	351.65	2800	0.13	A
Lyndhurst Street	N	0 (55)	1.0	342.6	-31.75	233.82	2800	0.08	A
	S	0 (55)	1.0	319.7	-31.75	421.20	2800	0.15	A
North Circular Street	N	0 (55)	1.0	216.64	0.00	216.64	2800	0.08	A
	S	0 (55)	1.0	157.7	0.00	157.70	2800	0.06	A
South Circular Street	N	0 (55)	1.0	210.17	0.00	210.17	2800	0.08	A
	S	0 (55)	1.0	200.3	0.00	200.30	2800	0.07	A
Cecil Sussman Street	N	5 (45)	0.9	627.79	34.70	627.79	2800	0.22	A
	S	5 (45)	0.9	593.06	34.70	593.06	2800	0.21	A

4.5.2.6 Simulated scenario of congestion level (LOS) during normal hours under the projected future traffic scenario after appropriate modal split. Scenario 6: Projected scenario - normal hours with modal split

Table 4.22 presents the LOS during normal hours under the projected future traffic scenario after appropriate modal split. It is found that modal split is only essential in Long Street and Transvaal Road. Should all the heavy vehicles be segregated and diverted, Long Street will experience congestion of LOS E. However, the LOS of Transvaal road will remain at F, which indicates that Transvaal Road will remain congested and that further diversion of vehicles from this road will be required to reduce the congestion level. The congestion on all other roads, except Bishop`s Road, will be LOS A, even after the equal assignment of heavy vehicles to Du Toitspan Road, Lyndhurst Street and Main Street, Bishop`s Road will experience congestion of LOS B, which is still acceptable and does not warrant any modal split.

Table 4.22: LOS during normal hours under the projected future traffic scenario after appropriate modal split (Scenario 6: Projected scenario - normal hours with modal split)

Roads	Direction	Average normal hourly volume (V) in PCU	% heavy vehicles in equivalent PCU	% heavy vehicles diverted (modal split in major roads)	Modified average normal hourly volume after modal split (Vpm)	Capacity	V/C	LOS
Long Street	N	3105	12.0	-12.0	2732.4	2800	0.98	E
	S	3023	12.0	-12.0	2660.24	2800	0.95	E
Barkley Road	N	534.41	3.0	0	534.41	2800	0.19	A
	S	494.69	3.0	0	494.69	2800	0.18	A
Bishop`s Road	N	1822.11	4.0	0	1822.11	2800	0.65	B
	S	1788.21	4.0	0	1788.21	2800	0.64	B
Carter`s Road	N	1187.07	4.0	0	1187.07	2800	0.42	A
	S	1185.97	4.0	0	1185.97	2800	0.42	A
Schmidts-drift Road	N	1162.69	2.0	0	1162.69	2800	0.42	A
	S	1174.7	2.0	0	1174.7	2800	0.42	A
Barkley section 2 impacting Transvaal Road	N	1289	6.0	0	1289	2800	0.46	A
	S	1252.25	6.0	0	1252.25	2800	0.45	A
Memorial Road	N	722.71	6.0	0	722.71	2800	0.26	A
	S	697.22	6.0	0	697.22	2800	0.25	A
Transvaal Road influenced by Pniel Road	N	3362.44	15.0	-15.0	2858.074	2800	1.02	F
	S	3336.15	15.0	-15.0	2835.728	2800	1.01	F
Du Toitspan Road	N	567.02	2.0	13.5	643.56	2800	0.23	
	S	515.51	2.0	13.5	585.10	2800	0.21	A

Main Street	N	393.08	1.0	13.5	446.14	2800	0.16	A
	S	266.91	1.0	13.5	302.94	2800	0.11	A
Lyndhurst Street	N	342.6	2.0	13.5	388.85	2800	0.14	A
	S	319.7	2.0	13.5	362.85	2800	0.13	A
North Circular Street	N	216.64	2.0	0	216.64	2800	0.08	A
	S	157.7	2.0	0	157.7	2800	0.06	A
South Circular Street	N	210.17	2.0	0	210.17	2800	0.08	A
	S	200.3	2.0	0	200.3	2800	0.07	A
Cecil Sussman Street	N	627.79	6.0	0	627.79	2800	0.22	A
	S	593.06	6.0	0	593.06	2800	0.21	A

4.5.2.7 Simulated scenario of congestion level (LOS) during peak hours under the projected future traffic scenario after appropriate traffic assignment. Scenario 7: - Projected scenario – peak hours with traffic assignment

Table 4.23 shows the simulated scenarios of congestion level (LOS) through traffic assignment and percentage traffic diversion under a predicted peak hour scenario. Based on the desired (new) travel time, it has been established that a minimum of 33.71% of traffic from Long Street and 40.05% of traffic from Transvaal Road needs to be diverted to reduce the level of congestion on these roads from LOS F to LOS E. About 17.79% of the traffic in Bishop`s Road could be diverted to reduce the congestion level from LOS D to LOS C. None of the other road warrants any diversion. With the inclusion of the diverted traffic from Long Street, Transvaal Road and Bishop`s Road, the LOS level of all the other roads except Barkley section 2 will remain at LOS A. The level of congestion on two legs of Barkley section 2 Street will increase to LOS B (from the city) and LOS C (to the city). Thus, during peak hours in the projected year, two of the roads, namely Long Street and Transvaal Road, will be under severe pressure of congestion and will require a significant proportion of their traffic to be assigned to other roads.

Table 4.23: LOS during peak hours under the projected future traffic scenario after appropriate traffic assignment Scenario 7: Projected scenario – peak hours with traffic assignment

Roads	Direction	Average speed increase from current actual speed (in km/ h)	Travel time ratio = Time in New system/ Time in old system	Peak hourly volume (V) (in PCU	Minimum % vehicles requiring diversion 100-100/ (1+ t_R^6)	Modified peak hourly volume after traffic assignment (Vm)	Capacity (C) of two lane arterial roads	Vm/C	LOS
Long Street	N	3 (24)	0.89	4142.24	33.19	2767.431	2800	0.99	E
	S	3 (22)	0.89	4151.76	33.19	2773.791	2800	0.99	E
Barkley Road	N	14 (36)	0.72	712.48	0	712.48	2800	0.25	A
	S	14(36)	0.72	671.92	0	671.92	2800	0.24	A
Bishop Road	N	10 (30)	0.75	2477.76	17.79	2477.76	2800	0.88	C
	S	10 (30)	0.75	2408.1	17.79	2408.1	2800	0.86	C
Carter Road	N	13 (37)	0.74	1633.49	0	1633.49	2800	0.58	A
	S	13 (37)	0.74	1626.33	0	1626.33	2800	0.58	A
Schmidtsdrift Road	N	13 (27)	0.68	1633.58	0	1633.58	2800	0.58	A
	S	13 (27)	0.68	1575.43	0	1575.43	2800	0.56	A
Barkley section 2 impacting Transvaal Road	N	13 (27)	0.68	1799.51	-25.00	1828.302	2800	0.65	C
	S	13 (27)	0.68	1757.17	-25.00	2048.86	2800	0.73	B
Memorial Road	N	16 (34)	0.68	1023.17	-25.00	1193.01	2800	0.43	A
	S	16 (34)	0.68	942.4	-25.00	1098.83	2800	0.39	A
Transvaal influenced by Pniel Road	N	3 (27)	0.935	4653.46	40.05	2789.74	2800	0.99	E
	S	5 (22)	0.89	4614.93	40.05	2766.65	2800	0.99	E
Du Toitspan Road	N	13 (37)	0.74	805.13	-28.43	938.78	2800	0.34	A
	S	13 (37)	0.74	764.22	-28.43	891.08	2800	0.32	A

Main Street	N	10 (40)	0.8	363.31	-28.43	423.61	2800	0.15	A
	S	10 (40)	0.8	352.79	-28.43	411.35	2800	0.15	A
Lyndhurst Street	N	2 (38)	0.95	454.25	-28.43	529.65	2800	0.19	A
	S	2 (38)	0.95	421.78		491.79	2800	0.18	A
North Circular Street	N	5 (45)	0.9	290.94	0	290.94	2800	0.10	A
	S	5 (45)	0.9	195.43	0	195.43	2800	0.07	A
South Circular Street	N	5 (45)	0.9	295.55	0	295.55	2800	0.11	A
	S	5 (45)	0.9	269.29	0	269.29	2800	0.10	A
Cecil Sussman Street	N	8 (32)	0.8	873.55	0	873.55	2800	0.31	A
	S	8 (32)	0.8	835.7	0	835.7	2800	0.30	A

Note: The number in the bracket indicate the current average speed of vehicles on the roads.

4.5.2.8 Simulated scenarios of congestion level (LOS) during peak hours under the projected future traffic scenario with a combination of modal split, diversion of traffic and appropriate traffic assignment. Scenario 8: Peak hour modal split with traffic diversion and assignment

LOS on various roads of the study area during peak hours in the predicted scenario under modal split and a combination of traffic diversion and assignment is presented in Table 4.24. In this scenario a maximum capacity segregation of heavy vehicles on different roads has been made along with the diversion of a minimum required percentage of cars to explore the congestion levels. However, total modal split (segregation of vehicles up to the maximum number of heavy vehicles) has been found not to reduce the congestion level during peak period in two of the most congested roads, namely Long Street and Transvaal Road. As a result, an attempt was made to combine the modal split with traffic diversion of normal vehicles. The simulated result indicated that under the combination of total modal split and diversion of a minimum of 21.0% normal traffic (cars) from Long Street and 25.0% normal traffic (cars) from Transvaal Road, congestion will be reduced from LOS F to LOS E. Although Bishop Road and Barkley section 2 Street do not warrant any segregation, the high volume and capacity ratio (Bishop Road- 0.85; Barkley section 2 Street- 0.67) signify that they may come under pressure of congestion in the long run. Modal split up to the maximum number of heavy vehicles on these roads indicated that the congestion level in Bishop Road will not be affected and will remain at LOS level D. The congestion level of Barkley section 2 Street will reduce from LOS level C to LOS level B. Despite the assignment of heavy vehicles and diversion of normal vehicles in the projected scenario, none of the other roads will require any modal split or diversion of vehicles. The heavy vehicles and cars diverted from Long Street, Transvaal Road, Bishop Road and Barkley section 2 Street can be assigned to Du Toitspan-, Lyndhurst-, Main Street and Memorial Road without affecting the congestion level of these roads.

Table 4.24: LOS during peak hours under the projected future traffic scenario after appropriate traffic assignment. Scenario 8: Projected scenario – peak hours with modal split (diversion of heavy vehicles) and additional diversion of normal cars

Roads	Average hourly volume (In PCU V)	Peak hourly volume (Vp) (In PCU	% of heavy vehicles in equivalent PCU	% of heavy vehicles diverted (modal split in major roads)	% of cars diverted (PCU)	Peak hour volume after modal split (Vpm)	Capacity of two lane arterial roads (C)	(Vpm/C)	LOS
Long (N)	3105	4142.24	12.00	-12.00	21.00	2775.3	2800	0.99	E
Long (S)	3023	4151.76	12.00	-12.00	21.00	2781.7	2800	0.99	E
Barkley (N)	534.41	712.48	3.00	0.00	0.00	712.48	2800	0.25	A
Barkley (S)	494.69	671.92	3.00	0.00	0.00	671.92	2800	0.24	A
Bishop (N)	1822.11	2477.76	4.00	-4.00	0.00	2378.6	2800	0.85	D
Bishop (S)	1788.21	2408.1	4.00	-4.00	0.00	2311.7	2800	0.82	D
Carter (N)	1187.07	1633.49	4.00	0.00	0.00	1633.5	2800	0.58	A
Carter (S)	1185.97	1626.33	4.00	0.00	0.00	1626.3	2800	0.58	A
Schmidtsdrift(N)	1162.69	1633.58	2.00	0.00	0.00	1633.6	2800	0.58	A
Schmidtsdrift(S)	1174.7	1575.43	2.00	0.00	0.00	1575.4	2800	0.56	A
Barkley section 2 impacting	1289	1799.51	6.00	-6.00	0.00	1894.1	2800	0.67	B

Transvaal (N)									
Barkley section 2 impacting Transvaal (S)	1252.25	1757.17	6.00	-6.00	0.00	1894.1	2800	0.67	B
Memorial (N)	722.71	1023.17	6.00	-13.50	-12.00	1146	2800	0.41	A
Memorial (S)	697.22	942.4	6.00	-13.50	-12.00	1055.5	2800	0.38	A
Transvaal influenced by Pniel (N)	3269.44	4653.46	15.00	15.00	25.00	2792.1	2800	1.00	E
Transvaal influenced by Pniel S)	3236.15	4614.93	15.00	15.00	25.00	2769	2800	0.99	E
Du Toitspan (N)	567.02	805.13	2.00	-13.50	-23.00	1111.1	2800	0.40	A
Du Toitspan (S)	515.51	764.22	2.00	-13.50	-23.00	1054.6	2800	0.38	A
Main (N)	393.08	363.31	1.00	-13.50	-23.00	501.37	2800	0.18	A
Main (S)	266.91	352.79	1.00	-13.50	-23.00	486.85	2800	0.17	A
Lyndhurst (N)	342.6	454.25	2.00	-13.50	-23.00	626.87	2800	0.22	A
Lyndhurst (S)	319.7	421.78	2.00	-13.50	-23.00	582.06	2800	0.21	A
North Circular (N)	216.64	290.94	2.00	0.00	0.00	290.94	2800	0.10	A
North Circular (S)	157.7	195.43	2.00	0.00	0.00	195.43	2800	0.07	A
South Circular (N)	210.17	295.55	2.00	0.00	0.00	295.55	2800	0.11	A
South Circular (S)	200.3	269.29	2.00	0.00	0.00	269.29	2800	0.10	A

Cecil Sussman (N)	627.79	873.55	6.00	0.00	0.00	873.55	2800	0.31	A
Cecil Sussman (S)	593.06	835.7	6.00	0.00	0.00	835.7	2800	0.30	A

4.6 TESTING OF HYPOTHESES

The hypotheses were tested to establish the relationship between the two policy intervention scenarios of adequate traffic assignment through traffic diversion from congested roads to relatively free roads and of segregation of vehicles (modal split). Hypotheses testing of relationship between traffic volume after policy interventions and level of congestion (V/C ratio) was conducted by using t- test and p (one-tailed and two-tailed) values (significance test) for a confidence level of 95% ($\alpha \leq 0.05$). Table 4.25 presents the results of t-test and p vales. The table indicates that under the different policy interventions of traffic diversion and assignment on the one hand and modal split on the other hand, the p values (both one-tailed and two-tailed) are significantly low (<0.05) for $\alpha \leq 0.05$. It thus establishes that (a) segregation of traffic (modal split) will appreciably reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of the CBD and (b) optimal traffic assignment (diversion to alternative roads) will significantly reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of the CBD.

Table 4.25: Hypotheses testing between different policy interventions scenarios and congestion level

Policy intervention scenarios for alleviation of congestion	T value	df	p*	p**
Traffic diversion and assignment: Normal hours - current scenario	7.007	27	0.00000008	0.00000016
Traffic assignment and percentage traffic diversion: Peak hours - current scenario	6.72	27	0.00000016	0.00000033
Combination of modal split and traffic assignment: Peak hours - current scenario	7.10	27	0.00000006	0.00000012

Traffic assignment and percentage traffic diversion: Projected scenarios - normal hours	7.30	27	0.00000004	0.00000007
Modal split: Projected scenarios - normal hours	6.47	27	0.00000031	0.00000062
Traffic assignment and percentage traffic diversion: Projected scenario - peak hours	7.78	27	0.00000001	0.00000002
Modal split and traffic assignment: Projected scenario - peak hours	8.08	27	0.00000001	0.00000002

Note: *One- tailed, **Two- tailed

4.7 CONCLUSION

In this chapter analysis of various variables influencing traffic congestion was conducted. These variables include appraisal of the physical and geometric characteristics of roads; traffic scenario analyses with regard to traffic volume, modal split, speed; and people's perception regarding the variables influencing traffic congestion. Assessment of the current traffic congestion level and forecasting of future traffic volume has been conducted. Analysis of simulated traffic congestion under different traffic congestion reduction interventions and hypotheses testing have been conducted. Observations on the extent of traffic congestion on various roads in and around the CBD area of Kimberley city and projections on the traffic volume for the year 2015 were made. The extent to which congestion can be reduced and speed on the roads can be increased without any large scale modifications on the physical characteristics of the roads was also examined under different scenarios of policy interventions and re-engineering measures such as traffic assignment and modal split. The testing of hypotheses established that segregation of traffic (modal split) will appreciably reduce traffic congestion on the roads of the CBD in terms of improved LOS, and that optimal traffic assignment (diversion on alternate roads) will significantly reduce traffic congestion in terms of improved LOS and consequently improved travel time and reduced delay on the roads in and around the CBD area of Kimberley. The findings of the results will be discussed in chapter 5 along with findings from literature reviews and study area analyses in order to develop and recommend appropriate policy interventions to alleviate congestion in the CBD area of Kimberley City.

5. CHAPTER 5: FINDINGS, RECOMMEDATIONS, AND CONCLUSION

5.1 INTRODUCTION

In order to evolve a set of policy interventions and guidelines to alleviate the congestion challenges on the roads in and around the CBD area of the study area through re-engineering of traffic without any major changes to the physical road infrastructure and disturbing the land use and urban function, it warranted an investigation that evaluates the existing socio-economic-, road-, and traffic congestion scenarios of the city. For the purposes of this investigation, existing literature was reviewed, the profile of the study area was analysed, and surveys were conducted to collect different kinds of data related to the physical and geometric characteristics of the roads, traffic characteristics, and the people's perception regarding factors causing congestion in the study area. These were followed up by congestion analyses employing different models under varying scenarios for the current situation and for the projected year 2025. Simulated scenarios were developed under various re-engineering policy interventions of traffic assignment to examine the reduction in congestion level and the diversion of traffic from congested roads to relatively free and accommodating road in the study area. Hypotheses were tested to establish the relation between reduction of traffic congestion and appropriate traffic assignment and modals split of the vehicles on the roads of the study area.

In this chapter the inferences and findings drawn from the results of the various analyses (literature reviews, study area analyses, different types of congestion analyses and simulated scenarios) are discussed and used to evolve policy guidelines and plausible recommendations for reduction of congestion and improvement of accessibility to public parks in the residential CBD area of Kimberley City.

5.2 INFERENCES FROM LITERATURE REVIEW

The following inferences can be made from literature review:

- The process of mode choices, purpose of trip, and route choices contribute to the flow of traffic on the roads of urban areas.

- Traffic congestion occurs when traffic is delayed due to the presence of an excess in number of vehicles on the same portion of the roadway at a particular time, resulting into slower than the normal or "free flow" speeds.
- Inadequate road capacity, inappropriately designed roads according to the required road characteristics for accommodating the traffic generated, and inappropriate urban functions in or around those roads, can cause traffic congestion and vehicular collisions.
- The extreme dependence on automobiles also causes traffic congestion on roads of the urban areas.
- Traffic congestion can be defined as a high vehicle concentration moving at a low flow speed the number of vehicles on the road being close to – or exceeding the maximum capacity of the road, causing an imbalance between travel demand and supply of the transport system.
- Congestion is categorised into a recurrent-, non-recurrent-, congestion- and pre-congestion state.
- Recurrent congestion occurs when there are too many vehicles at the same time, consequently reducing traffic speed and increasing commuting time.
- Recurrent congestion may relate to rapid growth in population, urbanization and growth in car ownership and use thereof.
- Recurrent congestion occurs typically during peak hours, although it can also occur during off-peak hours.
- Non-recurrent congestion is associated with random conditions or special and unique conditions, including traffic incidents.
- There are generally seven causes of traffic congestion, which can be grouped into three broad categories, namely traffic influencing events (traffic incidents, work zones and weather), traffic demand (fluctuations in normal traffic) and physical road features (physical and geometric characteristics of the road, poor traffic control devices and physical bottlenecks (capacity) of the road).
- The limited space, higher concentration of activities, and automobile dependence in the central area of cities are responsible for occurrence higher congestion in the CBD area of the cities.
- The impacts of congestion could be – but are not limited to – competitive or aggressive driving, harder or tiring driving, limited freedom of action increasing the risk of traffic accidents, intensified pollution, increased fuel consumption and a major source of driver stress.

- The various indicators of congestion are the difference in speed during free flow and actual speed, mean journey times, variability of journey times, throughput (total number of vehicles per time interval that pass a point on the carriageway), queue lengths, and speed differential between lanes and delay per hour/day.
- Empirical models being developed and used for measuring congestion include Segment delay index, Travel time index, Queue length, Lane mile duration index, LOS, and models suggested by the Highway Agency (1997), and Dft (2003, 2005). These models although have limitations have applicability in different contexts.
- Measures to reduce traffic congestion include meticulous traffic design, application of ITS, efficient vehicle routing, punctuality of routes and diversion of vehicles, congestion pricing, park-and-ride lots, high-occupancy-vehicle lanes, high-occupancy-toll lanes, employer commute option programs, telecommuting, alternative work schedules, and traffic calming measures.
- The need for cost effective policies without considerable increase in infrastructure has been emphasized, as the creation of infrastructure can only provide a partial solution.

5.3 INFERENCES FROM ANALYSIS OF THE STUDY AREA

The following inferences can be drawn from analysis of the study area:

- The spatial pattern of Kimberley constitutes five important components, namely suburbs and townships; the urban edge; movement: transport corridors and routes; open space systems, heritage and sensitivity; and a hierarchy of activity nodes, which are interlinked and interconnected.
- Population growth is 1.18% per year, which is higher than the national average. The population density is 1439.23 persons/ sq. km, which is higher than the population density of the province and the national average.
- About 68.0% of the population belong to the active age groups of 15- 65 years (of which about 36.0% falls within 15-36 years), which indicates a large employable population that needs movement facilities in the city.
- The tertiary sector (82.60%) dominates the economy in the city, followed by the primary sector (9.50%) and secondary sector (7.90%). Community services and the finance and transport sector constitute the major part of the tertiary sector. Although mining is the most important activity in the city, not many people are employed in that sector in the current scenario.
- The city contributes about one third of the GDP to the Northern Province economy and about 0.7% to the National GDP.

- The growth in GDP in the city follows a classical V shape from 2008 onwards. After experiencing ups and downs during the middle part of the last decade (from 2004 to 2008) and reaching the nadir (-2.1%) in the year 2009, it shows a gradual recovery from the year 2009 onwards, which implies that there may be need for increased traffic flow.
- About 11.0% of the residents belong to the higher income group, 46.0% to the middle- and 43.0% to the lower income group. This indicates that about 57.0% of the residents can afford to use private automobiles for their transportation needs.
- Residents spend about 12.81% of their income on transportation.
- Although tourism is not a prime activity in the city, sit is a growing industry with tourist arrival increasing at an annual rate of 1.8% since 2004.
- The city has a designated CBD, which performs multifarious activities that includes commerce, trade, finance, and administration.
- Two major national roads, the N8 and N12 intersect in the city close to the CBD. Regional roads, such as the R 31, R 64 and R 357 also pass through the city, connecting the city with other parts of the country. The city is thus strategically located with regards to road transportation.
- Although the major roads seem to radiate from the city centre, the road network system in the city has a grid iron pattern.
- According to COTO (2012), are the internal roads classified as U4 local collector roads. The arterial roads are national, regional or U3 arterials.
- A portion of the Bultfontein Road near the Big Hole has been closed down because of the risk of instability and caving in of the road. This has forced the majority of heavy vehicles carrying mined products from the mining areas in and around the city, other cargo vehicles travelling to various destinations outside the city and vehicles coming from Johannesburg, to pass through the other arterial roads in the CBD area (refer Figure 3.16). As a result, traffic pressure and congestion are created on the roads in and around the CBD.
- About 23.7% of the vehicles registered in Northern Cape Province to occupants of Kimberley. The numbers of vehicles are increasing at an annual rate of 2.79% in the city. About 58.0% of vehicles in Kimberley City are passenger cars and 2.0% are heavy vehicles. About 6.0% of the heavy vehicles of the province also ply on the roads of the city.
- The public transportation service in Kimberley City constitutes public taxis operating on different routes which connect various suburbs and nodal points in the city. The taxis offer transportation services both inside the city for short distance travellers and

for long distance travellers. Long distance buses joining the major cities of the country and province, also pass through the city.

- Traffic flow at major junctions is managed by automated traffic signalling systems and minor junctions are controlled by stop signs and yields. There are no automated traffic control systems at very small junctions.
- All the pavements of roads in the city are properly marked according to rules and regulations provided by the South African National Road Agency Limited (SANRAL) G2 manual and Road Traffic Sign Manual Volume 3, South Africa, (2012).
- The roads of the city are provided with proper signage systems such as speed control, directional flow, yielding, stopping, etc.
- Speed traps such as fixed cameras or stationed radars, are situated at random points within the city.
- There are both on-street and off-street parking systems in the city. On- street parking proves to be a problem when the road width is insufficient particularly during peak hours.
- The Sol Plaatje University is located close to city centre and is expected to be in full operation soon. The university is expected to contribute a significant amount of vehicular, pedestrian and bicycle traffic to the roads in and around the CBD area of the city in the near future.

5.4 INFERENCES FROM SURVEYS, SPATIAL ANALYSES, APPLICATION OF THE MODEL AND THE SIGNIFICANCE TESTS IN THE STUDY AREA

The inferences drawn from the various surveys conducted in the study area, such as the physical and geometric characteristics of the roads, the traffic scenario analysis, people's perception regarding the variables influencing traffic congestion, the current traffic congestion analysis, the forecasting of future traffic, and the simulated traffic congestion analyses and application of re-engineering methods to reduce traffic congestion are presented below:

- The roads are either national-, regional-, arterial- (U3) or collector (U4) roads.
- The major roads, that include Long Street-, Bishop`s Road-, Barkley Road-, Memorial Road-, Main Street-, Lyndhurst Street-, North Circular- and South Circular Road, have inadequate lane widths and consequent road widths, which is a cause of concern with regard to traffic congestion (refer map 1; annexure VII).

- Physically built median structures are not available on a majority of the roads. The roadways are divided by road marking (lines) and this may cause challenges in traffic movement in the CBD area because of the interference of oncoming traffic.
- Kerbs are available on the roadsides of almost all roads, except Barkley Road which does not have any pavement facilities.
- All roads, except the Barkley Road, have adequate pavements for pedestrians. Some of the pedestrian pavements are permanently paved, whereas pavements on the sides of a significant number of roads are either partially paved or unpaved.
- Pedestrian pavements do not seem to interfere with the traffic movement and do not influence the congestion on the roads.
- The surface condition of all the roads is either acceptable or good and no challenges such as potholes or broken sections were observed.
- It has been established that adequate sight distances are provided on all the roads.
- The roads have gentle curves.
- The gradient of the roads are within acceptable limits.
- Congestion on the roads in and around the CBD area of Kimberley is significantly influenced by parking facilities, type of junctions, traffic volume and type and composition of vehicles – particularly the plying of heavy vehicles (large trucks).
- Urban development factors such as unavailability of space near junctions; availability of commercial function; and availability of traffic nodes such as bus- and taxi stops; and availability of civic/administrative functions, influence the occurrence of congestion in and around the CBD area of the city.
- On-road informal commercial activities, building offset, encroachment of roads, and building size do not cause congestion on the roads of the study area.
- Traffic related factors such as speed, and traffic calming measures such as speed breakers are observed to cause traffic congestion.
- Traffic control systems such as signalling systems, traffic signs and pavement marking, stop signs, and traffic rule enforcement such as speed traps have insignificant influence on traffic congestion.
- Driver- and human behaviour related aspects such as influence of alcohol and nausea on driver, disrespect of traffic rules and regulations by road users, unruly driver behaviour, poor physical and mental condition of driver, and lack of knowledge of traffic rules influence congestion to a certain extent.
- Environmental and emergency factors such as road blocks and unscheduled stops, heat, rain, storms and slippery roads are some of the least influential factors to cause congestion on the roads of the study area.

- Vehicular traffic collisions are also found to influence congestion to a certain extent.
- Median facilities, pedestrian crossing facilities, road conditions and pavements/ footpaths do not have much influence on occurrence of congestion.
- There are two peak hours in the city with regard to traffic movement. The duration of day between 6h30 to 8h30 is the first peak hour and 16h00 to 17h30 is the second peak hour.
- The average hourly traffic volumes on different roads during normal hours vary between a minimum of 132.50 PCU/h on North Circular Road (away from the CBD) to a maximum of 2826.60 PCU/hour on Transvaal Road influenced by Pniel (towards the CBD).
- The average traffic volume both towards- and away from the CBD on Long Street, Transvaal Road, Bishop Road and Barkley Street section 2 are significant during normal hours.
- The average traffic volume during normal hours on other roads such as Barkley-, Memorial-, Main- , Carter-, Schmidtsdrift-, Du Toitspan-, Lyndhurst-, North Circular-, South Circular- and Cecil Sussman Street are not significant.
- The average traffic volume during peak hours on various roads of the study area range between a minimum of 164.30 PCU/h to 3912.30 PCU/h.
- The maximum peak hour traffic being observed is on Transvaal Road, Long Street, Barkley section 2 Street, Bishop`s Road, Carter`s Road and Schmidtsdrift Road.
- The heaviest traffic being observed during the peak hours is on Long Street and Transvaal Road influenced by Pniel.
- Long Street (12.00%) and Transvaal Road (15.00%) have been observed to carry a significant amount of heavy vehicles.
- The percentage heavy vehicle on other roads varies between 2.0% to 6.0%.
- The average traffic speed during normal hours on the various roads varies between 42 km/ h to 55 km/ h.
- The average traffic speed during peak hours on the various roads ranges from 24 km/h to 45 km/h.
- The number of speed changes ranges between 4 and 6.
- An average of 6 speed changes is experienced on Long Street, Barkley section 2 impacting Transvaal Road, Schmidtsdrift Road, Memorial Road and Carter`s Road whereas 5 speed changes on Transvaal-, Lyndhurst-, Du Toitspan-, North Circular-, Main- and Cecil Sussman Road, and 4 speed changes between two adjacent junctions on Barkley-, Bishop- and South Circular Road. .

- Lower absolute speed on roads is found to be associated with a higher number of speed changes.
- Both on street and off street parking facilities are available.
- The parking facilities provided on these roads are predominantly a parallel parking system.
- Parking facilities in some of the roads are found to be apparently interfering with the moving traffic during the peak hours.
- On-street parking facilities are available in certain sections of Long Street, Transvaal Road (Phakamile Mabija Road), Carter`s Road, Main Street, Schmidtsdrift Road and Du Toitspan Street.
- The on- parking facilities of Transvaal Road (Phakamile Mabija Road) and Long Street, available on the road sections farther from the CBD area, do not interfere with the traffic movement, however the sections passing through or close to CBD area are a cause of concern with respect to traffic congestion particularly during the peak hours.
- According to the segment delay analysis, maximum delay occurs on Long Street, followed by Transvaal Road impacted by Pniel. Moderate delay occurs on Bishop Street and Barkley section 2 impacting Transvaal Road. Other roads do not experience much segment delay. As a result, maximum congestion occurs on Long Street and Transvaal Road followed by Bishop`s Road.
- As per TTI analysis, road sections close to the CBD on Long Street, Transvaal impacted by Pniel road, Barkley section 2 impacting Transvaal Road, and Schmidtsdrift Road are under severe pressure of congestion, followed by moderate pressure on Bishop`s Road.
- Analysis of Q indices indicated that relatively higher congestion levels are experienced on Long Street, Transvaal Road impacted by Pniel Road, Bishop Road and Barkley section 2 impacting Transvaal Road. Moderate congestion is experienced on Schmidtsdrift Road, Cecil Sussman Road, Memorial Road and Lyndhurst Street. .
- Analysis of LOS under normal hours indicated that Transvaal Road (influenced by Pniel Road) is highly congested, Long Street is almost running to its capacity and Bishop`s Road could become a cause of concern.
- During peak hours, Transvaal Road (influenced by Pniel Road) and Long Street are highly congested, followed by Bishop`s Road. Carter`s Road, Barkley Road impacting Transvaal and Schmidtsdrift Road could become a cause of concern. Little congestion occurs on all the other roads. .
- High queue length during peak hours is experienced at the junctions connecting Long Street and Bultfontein Road (J1), Bishop-/Lyndhurst Street and Bultfontein

Road/Delham Street (J2), Transvaal Road and Cecil Sussman Street (J3), and Transvaal Road and Old Main Street (J5) and they seem to be under pressure with regard to congestion.

- Traffic volume on Long Street (>3100 PCU and >4100 during normal and peak hours respectively) and Transvaal Road (>3300 PCU and >4600) during normal and peak hours respectively) is expected to I have increased considerably in the projected year 2025.
- The traffic volume on Bishop Street (>1700 PCU and >2400), Barkley section 2 impacting Transvaal (>1200 PCU and >1700), Schmidtsdrift Road (>1100 PCU and >1500), and Carter`s Road (>1100 PCU and >1700) is also expected to increase significantly.
- Significant increase in queue length – even during normal hours of traffic – will be experienced on Long Street and Bultfontein Road at J1, Bishop`s Road and Bultfontein Road at J2, at Transvaal Road impacted by Pniel Street at J3, and Transvaal Road at J5.
- The queue length during peak hours at the respective junctions on these roads will be much higher and may range from 17.5% to 60.0%.
- The required signal timings during peak hours at junctions J1, J3 and J5 will exceed the current signal timings (70 seconds cycle length) by 57.4%, 92.8% and 104.3%s respectively and thus requires re-design of signals at these junctions.
- A simulated scenario of congestion level (LOS) through traffic assignment and percentage traffic diversion during normal hours in the current scenario indicated that:
    - About 26% of traffic from Long Street, 28.80% from Transvaal Road, 31.77% Bishop`s Road and 34.70% Cecil Sussman Street can be diverted. As a result, the LOS level of Long Street will change from level E to level B and that of Transvaal Road from level F to level C. The LOS of Bishop`s Road and Cecil Sussman Street will remain the same at level A.
    - Vehicles diverted from Long Street can be assigned to Du Toitspan-, Lyndhurst-, and Memorial Road. Similarly vehicles from Transvaal Road can be assigned to pass through Barkley section 2, Main Street and Lyndhurst Street.
    - No diversion and traffic assignment to other roads is warranted for Bishop`s Road and Cecil Sussman Road, although traffic can be assigned to Main- , Du Toitspan- and Lyndhurst Street if necessary without significantly affecting the LOS of these roads.

  - Long Street and Transvaal Road (Phakamile Mabija Road) will experience increase in speed of 8 km/h and 7 km/h respectively from their current average speed because of traffic diversion.
- A simulated scenario of congestion level (LOS) through traffic assignment and percentage traffic diversion during peak hours in the current scenario indicated that:
  - A minimum of 20.77% traffic from Long Street and 28.80% from Transvaal Road needs to be diverted to reduce the congestion on these roads from LOS F to LOS E.
  - About 15.11% traffic may be diverted from Bishop`s Road to reduce the congestion from LOS C to LOS B.
  - None of the other roads warrant any diversion, but 12.73% traffic from Barkley Street, 9.0% from Barkley section 2, 14.10% from Carter`s Road and 20.77% from Cecil Sussman Road can be diverted.
  - These diverted vehicles can be assigned to Memorial Road (12.23%), Du Toitspan Road (20.77%), Lyndhurst and Main Street (25.80%) without increasing the congestion level on these roads.
  - The two most congested roads, Long Street and Transvaal Road (Phakamile Mabija Road), will experience increase in speed by 8 km/h and 5 km/h respectively.
  - The speed on Bishop`s Road and Cecil Sussman Road will increase by 10 km/h and 8 km/ h respectively.
- A simulated scenario of congestion level (LOS) under the combination of modal split and traffic assignment during peak hours in the current scenario indicated that:
  - Under the combination of total modal split (segregation of all the heavy vehicles from the traffic) in addition to diversion of a minimum of 8.0% normal traffic (cars) from Long Street and 14.0% normal traffic (cars) from Transvaal Road will reduce congestion on these roads from LOS F to LOS E.
  - The other roads do not need any modal split or diversion of vehicles in the current scenario.
  - The heavy vehicles and cars diverted from Long Street and Transvaal Road can be assigned to Du Toitspan Road, Main Road and Lyndhurst Street without affecting the congestion level of these roads.
- A simulated scenario of congestion level (LOS) during normal- and peak hours under a projected future traffic scenario without any in interventions indicate that:

- Should the current pattern of traffic flow during normal hours continue on the various roads of study area Long Street and Transvaal Road will experience a very high level of congestion (LOS F) and Bishop`s Road will reach LOS C.
- Congestion during normal hours on all the other roads will remain at LOS A.
- Long Street (LOS F) and Transvaal Road (LOS F) will get further congested during peak hours as suggested by the higher volume and capacity ratio.
- Bishop`s Road will reach LOS D, although its higher volume and capacity ratio (0.86 - 0.88) suggests that it will be at the threshold of LOS E, which is a cause of concern.
- Barkley section 2 will experience congestion of LOS B.
- Although the congestion on Carter`s Road and Schmidtsdrift Road will be LOS A, it will be at the threshold of LOS B and will thus remain susceptible to a higher level of congestion.

- A Simulated scenario of congestion level (LOS) during normal hours under a projected future traffic scenario after appropriate traffic assignment and diversion during normal hours indicated that:
  - There is need for diverting about 26.0% of the traffic from Long Street and 28.80% from Transvaal Road, to decrease the congestion from LOS F to LOS D.
  - About 31.77% of the traffic from Bishop Street, and 34.70% from Cecil Sussman Street may be diverted, which will result in a decrease in congestion to LOS A.
  - The diverted traffic may be assigned to Barkley impacting Pniel Street (14.40%), Memorial Road (13.00%), Du Toitspan Street (13.00%), Lyndhurst Street (31.75%) and Main Street (31.75%) without increasing the congestion level in these roads.
  - This will result in an increase in speed by 8km/h in Long Street, 7km/h in Transvaal Road, 6 km/h in Bishop`s Road and 5 km/ h in Cecil Sussman. A Simulated scenario of congestion level (LOS) during normal hours under the projected future traffic scenario after appropriate modal split shows that:
- Modal split (segregation of heavy vehicles from normal light vehicles) is not essential in all the roads, except Long Street and Transvaal road (Phakamile Mabija Road).
- Should all the heavy vehicles be segregated and diverted, Long Street will experience level E congestion and Transvaal Road (Phakamile Mabija Road) will remain at level F, which indicates that Transvaal Road (Phakamile Mabija Road) will remain congested and further diversion of vehicles from this road will be required to reduce the congestion level.

- Except for Bishop`s Road, the congestion on all other roads will be at level A – even with equal assignment of heavy vehicles to Du Toitspan Road, Lyndhurst Street and Main Street.
- Bishop Road will experience a LOS B, which is still acceptable and does not warrant any modal split.
- A simulated scenario of congestion level (LOS) during peak hours under the projected future traffic scenario after appropriate traffic assignment during the peak period, indicated that:
  - A minimum of 33.71% of the traffic from Long Street and 40.05% from Transvaal Road needs to be diverted to reduce the level of congestion on these roads from LOS F to LOS E.
  - About 17.79% of the traffic may be diverted from Bishop`s Road to reduce the congestion level from LOS D to LOS C.
  - None of the other roads warrants any traffic diversion.
  - With the addition of the diverted traffic from Long Street, Transvaal Road and Bishop`s Road, congestion on all the other roads except Barkley section 2 will remain at LOS A.
  - The level of congestion on two legs of Barkley section 2 Street will increase to LOS B (from the city) and LOS C (to the city).
  - It is thus indicated that during peak hours in the projected year, two of the roads, namely Long Street and Transvaal Road, will be under severe pressure of congestion, which will require the assignment of a significant proportion of their traffic to other roads.
- A Simulated scenario of congestion level (LOS) under the projected future traffic scenario with a combination of modal split and diversion of traffic and appropriate traffic assignment during peak hours, revealed that:
  - Total modal split (segregation of vehicles up to the maximum number of heavy vehicles) does not reduce the congestion level during peak period in two of the most congested roads such as Long Street and Transvaal Road.
  - Under the combination of total modal split in addition to diversion of a minimum of 21.0% normal traffic (cars) from Long Street and 25.0% normal traffic (cars) from Transvaal Road, congestion will be reduced from LOS F to LOS E.
  - Although Bishop`s Road and Barkley section 2 Street do not warrant any segregation, the high volume and capacity ratio indicate that they may come under pressure of congestion in the long run.

- Modal split up to the maximum number of heavy vehicles on these roads, indicated that the congestion level in Bishop`s Road will not be affected and remain at LOS D, The congestion level of Barkley section 2 will reduce from LOS C TO LOS B.
- Despite the assignment of heavy vehicles and diversion of normal vehicles, none of the other roads will require any modal split or diversion of vehicles in the projected scenario.
- The heavy vehicles and cars diverted from Long Street, Transvaal Road, Bishop`s Road, and Barkley section 2 Street can be assigned to Du Toitspan Street, Lyndhurst Street, Main Road and Memorial Road without affecting the congestion level of these roads.

- Testing of the hypotheses established that reduction in congestion level on the roads in and around the CBD area of Kimberley City can be achieved by appropriate traffic diversion from the congested roads and appropriate traffic assignment to relatively less congested roads. Similarly, modal split (segregation of vehicles) along with the diversion of normal cars and appropriate assignment of these vehicles to relatively less congested roads would also reduce congestion levels appreciably, allowing smooth traffic operation on the roads in and around the CBD area of the city.

5.5 RE-ENGINEERING CONCEPT FOR REDUCTION OF CONGESTION

The concept of re-engineering is adopted to reduce the congestion level on the roads in and around the CBD area of the city and facilitate smooth traffic movement. Re-engineering of the transportation system indicates how – without designing and creating a new transportation infrastructure or making major alterations to the existing system – the existing road- and traffic infrastructure can be utilised to a maximum extent to alleviate the traffic congestion challenges in and around the CBD area of study area. In order to evolve policy interventions and develop a set of policy guidelines, the following broad re-engineering strategies have been adopted:

- Appropriate traffic diversion from the congested roads to relevant less congested roads during normal hours of traffic.
- Appropriate traffic diversion from congested roads to relevant relatively less congested roads during peak hours.
- Segregation of heavy vehicles during normal hours.
- Segregation of heavy vehicles and diversion of an appropriate proportion of normal cars during peak hours.
- Appropriate use of less congested roads for carrying diverted traffic.

- Prevention of the use of on-street parking facilities during peak hours.
- Modification of the signalling cycle time at major junctions during the peak hours in the projected year 2025.

5.6 ALTERNATIVE POLICIES

Based on the above re-engineering concept and the analysis of various simulated scenarios of traffic congestion, a number of alternative policy scenarios were devised and are presented below.

- Policy 1 - Diversion of vehicles from congested roads to free roads and traffic assignment to free roads during normal hours.

  About 26.0% of traffic from Long Street, 28.80% from Transvaal Road, 31.77% from Bishop Street and 34.70% from Cecil Sussman Street can be diverted. Diverted vehicles from Long Street and Transvaal Road can be assigned to pass through Barkley section 2 (14.40%), Du Toitspan Street (31.75%), Main Street (31.75%) and Lyndhurst Street (31.75%).
- Policy 2 - Diversion of vehicles from congested roads to free roads and traffic assignment to free roads during peak hours:

  A minimum of 20.77% of the traffic from Long Street and 28.80% from Transvaal Street should be diverted. About 15.11% of traffic from Bishop Street, 12.73% from Barkley Road, 9.0% from Barkley section 2, 14.10% from Carter Road, and 20.77% from Cecil Sussman Road can be diverted. The diverted vehicles can be assigned to Memorial Road (12.23%), Du Toitspan Street (20.77%), Lyndhurst Street (20.77%) and Main Street (25.80%).
- Policy 3 - Combination of modal split and diversion of traffic from congested roads and traffic assignment to relatively free roads during peak hours:

  All the heavy vehicles from Long Street (12.00%) and Transvaal Road (15.00%), in addition to a minimum of 8% normal traffic (cars) from Long Street and 14% normal traffic (cars) from Transvaal Road can be diverted during peak hours. The heavy vehicles and cars diverted from Long Street and Transvaal Road can be assigned to Du Toitspan- , Lyndhurst- and Main Street without affecting the congestion level of these roads.
- Policy 4 - Diversion of traffic from congested roads and appropriate traffic assignment to less congested roads during normal hours in the projected years.

  About 26.0% of traffic from Long Street and 28.80% from Transvaal Road can be diverted. About 31.77% of traffic from Bishop Street, and 34.70% from Cecil Sussman

Street may also be diverted. The diverted traffic from these roads may be assigned to Barkley impacting Pniel Road (14.40%), Memorial Road (13.00%), Du Toitspan Street (13.00%), Lyndhurst Street (31.75%) and Main Street (31.75%) without increasing the congestion level on these roads.

- Policy 5 - Appropriate modal split during normal hours in the projected years:
  In the projected years all the heavy vehicles should be diverted from Long Street and Transvaal Road during normal hours and could be equally assigned to Du Toitspan-, Lyndhurst- and Main Street.
- Policy 6 – Diversion of traffic from congested roads and appropriate assignment to less congested roads during peak hours in the projected years:
  A minimum of 33.71% of the traffic from Long Street and 40.05% from Transvaal Road should be diverted. About 17.79% of the traffic may be diverted from Bishop Street. No diversion from any of the other roads is necessary. About 25.0% of the diverted traffic may be assigned to Memorial Road and Barkley Road impacted by Pniel Street and 28.43% may be equally assigned to Du Toitspan- , Lyndhurst- and Main Street.
- Policy 7 – A total modal split with traffic diversion from heavily congested roads and appropriate assignment to less congested roads:
  A total modal split (segregation of 12% heavy vehicles) in addition to the diversion of a minimum of 21.0% normal traffic (cars) from Long Street, and segregation of all the heavy vehicles (15%) and a minimum diversion of 25.0% of normal traffic (cars) from Transvaal Road should be done during peak hours in the projected period. The diverted traffic should be assigned to Memorial Road (13.5 % heavy traffic and 12.0% normal cars); Barkley section 2 Street (6% heavy vehicles); and Du Toitspan-, Lyndhurst- and Main Street (13.50% heavy vehicles and 23% of normal cars) during peak hours.

5.6.1 Recommended policies

The comparative analysis of the above mentioned policies suggest that normal hours do not need any intervention in the current situation. However, under the normal scenario, policy 2 – where a minimum of 20.77% of traffic from Long Street and 28.80% from Transvaal Road should be diverted – will be most relevant in the peak period. In addition about 15.11% of the traffic from Bishop Road, 12.73% from Barkley Road, 9.0% from Barkley section 2, 14.10% from Carter`s Road and 20.77% from Cecil Sussman road can be diverted. All the vehicles diverted can be assigned in proportions of 12.23%to Memorial Road, 20.77% to Du Toitspan Road, 20.77% to Lyndhurst Street, and 25.80% to Main Street. Similarly, during peak periods in the projected years, policy 6, i.e., a minimum diversion of 33.71% of the traffic from Long

Street and 40.05% from Transvaal Road should be executed. About 17.79% of the traffic from Bishop Road may be diverted. Consequently, about 25.0% of the diverted traffic may be assigned to Memorial Road and Barkley Road impacted by Pniel Road and 28.43% may be equally assigned to Du Toitspan, Lyndhurst, and Main Street. In future (the projected year), necessary provision should be made not to allow all the heavy vehicles to ply on Transvaal Road (Phakamile Mabija Road) and Long Street during peak hours and these vehicles may be assigned to roads such as Main, Du Toitspan and Lyndhurst Street.

5.7 PLAUSIBLE PLANNING GUIDELINES AND RECOMMENDATIONS

Based on the detailed survey analysis of various spatial-, land use-, traffic- and road related factors, and in addition to the policy alternatives mentioned above, the various plausible policy guidelines to reduce the traffic congestion on the roads of the CBD area of Kimberley City are as follows:

- On-street parking facilities should be avoided in the central area of Kimberley City during all hours of the day particularly on the two most congested roads such as Long Street and Transvaal Road.
- On-street parking on less congested roads and on the congested roads outside the CBD area should be avoided during peak hours.
- No heavy vehicles should be allowed on the roads passing through the CBD area during the peak hours of day specifically on Long Street and Transvaal Road.
- Medians should be provided on the roads where the roadways (directional flow) are separated by pavement markings or divider lines.
- All the roads with partial or no pedestrian pavement facilities should be provided with full pedestrian pavement facilities.
- Adequate space at the junctions may be created by making marginal modification to the junctions.
- Adequate turning radius should be provided, particularly at junctions close to the CBD area.
- On-road informal commercial activities – if any – should be avoided particularly along Long Street, Transvaal Road and Cecil Sussman Street.
- The traffic nodes such as bus- and taxi stops, may be improved by marginal modifications following urban design and traffic design principles; however, consideration may be made to relocate them to appropriate locations outside the CBD area in future.

- The use of road blocks and unscheduled stops should be avoided particularly during peak hours.
- Enforcement of traffic rules is necessary to improve driver behaviour.
- Pedestrian crossings should be strengthened.

5.8 CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

Traffic congestion has been found to be a recurring and pressing challenge in cities all over the world. In South African cities this challenge has also been mounting over the years and Kimberley is no exception to this phenomenon. The city is increasingly experiencing traffic congestion challenges over the years, particularly in some of the important roads in and around the CBD area, which warranted this investigation. Thus, a case study was conducted to comprehend the traffic congestion scenario in and around the CBD area of Kimberley City with the aim to evolve plausible re-engineering interventions to alleviate the traffic congestion challenges experienced in the city. For the purpose of the study, a critical literature review was conducted to understand the various parameters influencing traffic congestion; the causes of traffic congestion; relevant empirical models useful for assessment of traffic congestion levels; and to find out the different approaches and interventions used for improving the scenario. The literature review provided a thorough background relating to the study. Then, a survey research methodology was used for the collection of data, followed by statistical analyses and application of empirical models to analyse the traffic congestion scenarios in the study area. Simulated scenarios based on different re-engineering interventions were evolved, which assisted in engendering policies and strategic interventions that can reduce traffic congestion and improve the smooth traffic flow in and around the CBD area of the city.

Findings suggest that the major factors causing traffic congestion in and around the CBD area of the city are traffic volume with regards to type and composition of vehicles (particularly the plying of heavy vehicles such as large trucks), on-road parking facilities and type of junctions; traffic speed with regards to inadequate number of lanes, inadequate turning radius, insufficient lane width/road width (capacity) and inadequate availability of space near junctions; availability of commercial functions with regard to traffic nodes such as bus- and taxi stops and civic/administrative functions close to the roads. The results of the application of empirical models such as Segment delay (Ds), TTI, Q index, LOS and Queue length indicated that two of the major roads, namely Long Street and Transvaal Road impacted by Pniel road, are experiencing high levels of congestion both during normal- and peak hours. Similarly, some of the other roads such as Bishop`s Road, Carter`s Road, Barkley Road impacting Transvaal and Schmidtsdrift Road, are cause of concern during peak hours. Future scenario analyses indicated that all of these roads will become severely congested. Analyses of the current scenario also indicated that junctions connecting Long Street and Bultfontein Road (J1), Bishop-/ Lyndhurst Street and Bultfontein Road/Delham Street (J2), Transvaal Road (Phakamile Mabija Road) and Cecil Sussman Street (J3), and Transvaal Road (Phakamile Mabija Road) and Old Main Street (J5) experience high queue lengths during peak hours and seem to be under pressure with regard to congestion.

However, re-engineering interventions such as appropriate traffic diversion from the congested roads to relevant less congested roads during normal hours of traffic; appropriate traffic diversion from congested roads to relevant relatively less congested roads during peak hours; segregation of heavy vehicles and diversion of an appropriate proportion of normal cars during the peak hours; optimal use of less congested roads for carrying diverted traffic; prevention of the use of on-street parking facilities during peak hours and modification of the signalling cycle time at major junctions during peak hours, would assist in reducing congestion on the roads in and around the CBD area of the city in the projected year 2025. However, policy 2 will be most relevant in the peak period under normal scenario. For example, a policy that a minimum of 20.77% of the traffic from Long Street, 28.80% from Transvaal Road, 15.11% from Bishop`s Road, 12.73% from Barkley Road, 9.0% from Barkley Road section 2, 14.10% from Carter`s Road, and 20.77% from Cecil Sussman Road can be diverted and assigned in proportions to Memorial Road (12.23%), Du Toitspan Street (20.77%), Lyndhurst Street (20.77%), and Main Street (25.80%), would appreciably reduce the traffic congestion in the congested roads without increasing the traffic congestion level on the relatively free roads. Similarly, during peak periods in projected years, a policy of diverting a minimum of 33.71% of the traffic from Long Street, 40.05% from Transvaal road (Phakamile Mabija Road) and possibly 17.79% from Bishop`s Road and assigning the diverted traffic to Memorial road (25.0%), Barkley Road impacted by Pniel Road (25.0%) and 28.43% equally to Du Toitspan, Lyndhurst and Main Street, will reduce traffic congestion on the roads under pressure of traffic without significantly increasing the traffic congestion levels on the relatively free roads. Simulated scenarios of the percentage traffic diversion based on travel time ratio and change in speed, show that with a reasonable level of diversion of traffic from congested roads to less congested roads can increase speed and reduce travel time on the roads of the CBD area of the city and vice versa, allowing roads to be more efficiently utilised.

The two hypotheses being tested established that segregation of traffic (modal split) will appreciably reduce- and optimal traffic assignment (diversion to alternate roads) will

significantly reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of the CBD.
The novelty of this investigation lies with the use of concept of re-engineering of traffic system and spatial urban infrastructure in the context of central business districts (CBD) of cites in South Africa. Similar studies with regards to re-engineering of traffic management system and associated spatial urban infrastructure are found to be scarce, particularly in South African context. The study was conducted by using most relevant analytical models to assess how the traffic congestion scenario in the CBD areas can be improved by re-engineering the existing road transportation infrastructure and traffic system without appreciable changes and creation additional infrastructure and facilities. Although, the investigation used several existing models to analyse the traffic congestion scenario in the CBD area, their relevancy was first ascertained for the context by understanding their limitations and advantages through rigorous literature review and applications from case studies so. The study established the various models that can be utilised in analysing traffic congestion scenario in and around CBD area of cities to good effect, as well as the re-engineering measures that can suitably able to alleviate traffic congestion in the central areas of the cities of South Africa. Overall, the research contributes to the body of existing knowledge of analysis of traffic congestion and re-engineering of traffic system and transportation system in cities particularly in the context of central areas of South African cities.

The investigation has a few limitations. The analyses were carried out on certain roads and junctions by primarily using traffic data collected through surveys. Some of the other roads and junctions also need to be investigated. In addition, a larger data set could provide further insight in the problem of traffic congestion in the CBD area. The scope of the study was also limited to the roads in and around the CBD area of Kimberley City and therefore the results cannot be generalised for other cities of South Africa. Besides, study was confined to assess the traffic congestion scenario and to explore re-engineering solutions. The development of a detailed traffic management plan was excluded of the scope of this research. Besides, the environmental implication of the reengineering measures has not been included in the scope of the study.

This study also offers several opportunities for further research. Some of the possibilities for further research include the development of a traffic congestion assessment model to comprehend the traffic congestion scenario and evolve policy intervention scenarios; and to explore the use of ICT, ITS and real time scenario analyses to evolve strategies to reduce traffic congestion in the CBD area of South Africa. Another scope of further research is the development of a detailed traffic management plan and exploring its feasibility under different simulated scenarios.

Despite the limitations, this study established that some of the roads in the CBD area of Kimberley City are severely congested during both normal- and peak hours. However, re-engineering policy interventions such as traffic diversion from highly congested roads to less congested/ underutilized roads will ease the problem of traffic congestion as well as improve travel time and speed, which could result in optimal utilisation of all the roads in the CBD area of the city.

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ANNEXURES

Annexure - I

Re-engineering of traffic systems in the Central Business District (CBD) of a South African city: The case of the Kimberley City

Questionnaire for road transportation and traffic survey

This survey is part of a M. Tech study which involves the assessment of road and traffic system in Kimberley city, South Africa. It is aimed at to find out the influence of relevant land use, urban functions, road transportation system, and traffic system on the traffic congestion in Kimberley city and understand the perceptions of road users and people on how to alleviate the challenge of traffic congestion in the city.

The results of this survey will be used to explore the control parameters that influence traffic congestion, to evaluate the levels of congestion and evolve suitable policy interventions to reduce traffic congestion. This will be solely used for academic research purposes.

Questionnaire

Schedule No:

1. Demographic profile

1.1 Name:
1.2 Address: 1.3.Location:
1.4 Age 1.5. Gender:
1.6 Number of members in the family:
1.7 Age of family members:

Age	1-6	6-15	16-25	25-45	46-60	>60
Number						

2. Socio-Economic profile

2.1 Occupation: Govt. Service/ self-employed/ Industry/ mining/ Professional/ student/ service activities (traders)/Farming/ unemployed/ any other

2.2 Income: Primary income (self) Secondary income (Household):

2.3 Education: Primary/ Secondary/ Bachelors/ Masters/ Ph.d/ Professional (level of education)/ None

3. Road Travel related

3.1 Purpose of travel: Job/ education purposes /entertainment/ shopping/ health care/ civic activities/ any other (you can provide more than one choices)

3.2 Vehicle ownership: Owned a vehicle/ rented a vehicle/ no vehicle ownership

3.2.1 Type of vehicle owned: Car/ MUV/SUV/Minibuses/ Bus/ Pickup trucks/ Heavy vehicles/any other

3.2.2 Number of vehicles owned:

3.3 Use of modes for travel: Private cars/ Public transportation (Bus)/ Public transportation (taxi)/ Public transportation (shared taxis)/ Trams/ Motor Bikes/ By foot/ Bicycle/ any other

3.4 Travel pattern

3.4.1 Average number of trips per day (personal)

3.4.2 Average number of trips by family members (total)

3.4.3 Average travel distance per day

3.4.4 Average travel distance by family (total)

3.5 Origin Destination

3.5.1 Outside of city to outside sixty/ inside to out/ inside to inside/ outside to inside

3.6 Frequently travelled major roads in and around CBD

3.7 Frequently travel days: weekday/ weekends/ both

3.8 Frequently travel period of the day: weekdays: (Please provide the time of the day both start and return)

3.9 Frequently travel period of the day: weekends: (Please provide the time of the day both start and return)

3.10 Major challenges frequently faced during the travel: Congestion/ Delay/ Long queue at junctions/ Long queue on roads/ Long waiting time at junctions/ Slow speed/ Accident/ Pollution/ Parking/ Breakdown/psychological/ Physical stress/ any other

3.11 Average time spend per day in travelling

3.12 Average time spend per trip

4. Traffic Congestion scenarios

4.1 On what days congestion occurs: weekdays/ weekends

4.2 On what period of the day congestion occurs

Level of congestion	6.00-8.00	8.00-10.00	10.00-12.00	12.00-14.00	14.00-16.00	16.00-18.00	18.00-20.00	20.00-22.00	22.00-24.00	Any other specific period
No congestion										
Appreciable										
Close to maximum										
Maximum										

4.3 Major causes of congestion (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1,0***
Physical road factors										
Spatial/ Land use urban function factors										
Traffic factors										
Emergency related factors										
Behavioural factor										

4.4 Physical road factors responsible for congestion (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1.0***
Capacity/Road width/ Lane width										
Inadequate/ lack of Footpaths/ pavements										
Lack of Pedestrian crossing facilities										
Inadequate Entry/ exit radius at junctions										
On road Parking facilities										
Median facilities										

Road condition										
Type of junctions										
Four way right angled										
Three way T										
L Junctions										
Y Junctions										
Roundabout										
Small circles										

4.5 Spatial/ Land use urban function factors (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***
Availability of commercial function									
Availability of civic/administrative functions like schools/ colleges/ hospitals/ offices/ entertainment areas/sports centres									
Inadequate space available near the junctions									
Building size									
Building Offset									
On road informal commercial activities									
Availability of traffic nodes like bust stops, taxi stops									
Inadequate service road facilities to activity areas									

4.6 Traffic factors (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1.0***
Traffic Volume										
Type of vehicles										
Heavy Vehicles										
Cars										
Motor bikes										
Traffic speed										
Pedestrian volume										
Signalling and control										
Type of signalling (Automatic)										
Stop signs										

Yields										
Lack of or inadequate Traffic signs and pavement marking										
Traffic calming measures like speed breakers										
Traffic rule enforcement like speed traps										

4.7 Emergency related factors (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1.0***
Accidents										
Rain and storms										
Heat										
Floods										
Any other (Please specify)										

4.8 Behavioural factors (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1.0***
Lack of Knowledge of traffic rules										
Lack of Respect to traffic rule and regulations										
Inappropriate Driver behaviour										
Driver physical and mental condition Floods										
Influence of alcohol and nausea										
Any other (Please specify)										

4.9 Reengineering measures to reduce traffic congestion (Rate in a scale of 0 to 1)

Parameters	***0.1***	***0.2***	***0.3***	***0.4***	***0.5***	***0.6***	***0.7***	***0.8***	***0.9***	***1.0***
Availability of information through ICT										
Segregation of heavy and light vehicles (Modal split)										
Percent diversion measures (Traffic assignment) Choosing a different route										

Using public transportation system										
Off street parking provision										
Pederstrianisation of the whole CBD										
Pedestrian facilities in major areas										
Improvement of signalling system										
Improving the road infrastructure										
Junctions										
lane width										
Number of lanes/road width										
Provision of pedestrian islands										
Provision of footpaths/ pavements										
Installing Cameras/ videography										
Creation of traffic awareness and improving driver/user knowledge on traffic rules and regulations										
Changing the traffic pattern										
One way streets										
Closure of roads (partial)										
Segregation of vehicular and pedestrian traffic										
Any other please specify										

4.10. Any other opinion/suggestions to improve traffic congestion scenario

Signature:

Ms M Keetse

Annexure -II

Re-engineering of traffic systems in the Central Business District (CBD) of a South African city: The case of the Kimberley City

Template for physical and road geometric parameter survey

This survey is part of a M. Tech study which involves the assessment of road and traffic system in Kimberley city, South Africa. It is aimed at to find out the influence of relevant land use, urban functions, road transportation system, and traffic system on the traffic congestion in Kimberley city and understand the perceptions of road users and people on how to alleviate the challenge of traffic congestion in the city.

The results of this survey will be used to explore the control parameters that influence traffic congestion, to evaluate the levels of congestion and evolve suitable policy interventions to reduce traffic congestion. This will be solely used for academic research purposes.

Physical characteristics of the roads in the CBD area of Kimberly city

Name of the roads	Road type (like N/R/ Arterial/ local streets, etc.)	Road width	Number of lanes	Lane width	Availability of pedestrian/ bicycle lane	Pavements/ footpaths /shoulders width	Kerbs	Median width	Sight distance	Radius of Curvature	Type of Road surface	Condition of road surface	Availability of Traffic control system	On street parking type Right angle/ inclined/ parallel
Long (N)														
Long (S)														
Barkly (N)														
Barkly (S)														
Bishop (N)														
Bishop (S)														

Carter (N)														
Carter (S)														
Schmidtsdrift (N)														
Schmidtsdrift (S)														
Barkly section 2 (impacting Transvaal) (N)														
Barkly section 2 (impacting Transvaal) (S)														
Memorial (N)														
Memorial (S)														
Transvaal (influenced by Pniel) (N)														
Transvaal (influenced by Pniel) (S)														

Du Toitspan (N)														
Du Toitspan (S)														
Main street (N)														
Main street (S)														
Lyndhurst road (N)														
Lyndhurst road (S)														
North circular road (N)														
North circular road (S)														
South Circular road(N)														
South Circular road (S)														
Cecil Sussman road (N)														

Cecil Sussman road(S)														

N= North (Towards inside of the city)

S = South (Towards outside of the city)

Annexure III

Data collection proforma for traffic volume survey on road sections

Road Classification……………………….

Date and day of the week:

Direction of traffic: N (To city)/ S (Away from city): From……………..To………………..

Name of the road ………………..road section …………………………………. Close to land mark if any:

Hour of count	**Types of vehicles**						
	Cars	Buses	Trucks	Motor-cycles	Bicycle	Other (Specify)	Remarks ,including weather conditions
6h00- 6h30							
6h30- 7h00							
7h00- 7h30							
7h30- 8h00							
8h00- 8h30							
8h30- 9h00							
9h00- 9h30							
9h30- 10h00							
10h00- 10h30							
10h30- 11h30							
11h30- 12h00							
12h00- 12h30							
12h30- 13h00							
13h00- 13h30							
13h30- 14h00							
14h00- 14h30							
14h30- 15h00							
15h00- 15h30							
16h00- 16h30							
16h30- 17h00							

17h00- 17h30							
17h30- 18h00							
18h00- 18h30							
18h30- 19h00							
19h00- 19h30							
19h30- 20h00							

Name of enumerator:

Signature:

Date:

Name of supervisor:

Signature:

Date:

Annexure IV

Data collection proforma for traffic volume survey at intersections

Date and day of the week:

Direction of traffic: N (To city)/ S (Away from city): From……………..To………………..

Name of the road ………………..road section …………………………………… Close to land mark if any:

Traffic entering intersection from

Name of approach road:

Travelling (Compass direction):

Time of the day:

Direction of Flow	**Types of vehicle**						
	Cars	Buses	Trucks	Motor-cycles	Bi-cycles	Others(Specify)	Remarks, including weather conditions
Vehicles turning left							
Vehicles proceeding straight ahead							
Vehicles turning right							

Annexure: V

Speed survey schedule

Name of the surveyor:

Date:

Location:

Name of the Road:

Road section identity:

Type of road:

Road condition:

Duration of the day (Time)	Dista-nce in (m)	Type of vehicles																			
		Car				Bus				Heavy vehicles				Motor bikes				Others			
		Tim e in	Time out	Diff (s)	Spe ed	Time in	Time out	Diff (s)	Spe ed	Time in	Time out	Diff (s)	Sp eed	Time in	Time out	Diff (s)	Spee d	Tim e in	Time out	Diff (s)	Spee d
6h00-6h30																					
6h30-7h00																					
7h00-7h30																					

7h30- 8h00																					
8h00- 8h30																					
8h30- 9h00																					
9h00- 9h30																					
9h30- 10h00																					
10h00- 10h30																					
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15h00- 15h30																					
16h00- 16h30																					
16h30- 17h00																					
17h00- 17h30																					
17h30- 18h00																					
18h00- 18h30																					
18h30- 19h00																					
19h00- 19h30																					
19h30- 20h00																					

Annexure –VI

Level of service (LOS) criteria

Table B-4

Level of Service Criteria for Arterials

Arterial Class	I	II	III
Range of Free-Flow Speeds (mph)	45 to 35	35 to 30	35 to 25
Typical Free-Flow Speed (mph)	40 mph	33 mph	27 mph

Level of Service	Average Travel Speed (mph)		
A	≥ 35	≥ 30	≥ 25
B	≥ 28	≥ 24	≥ 19
C	≥ 22	≥ 18	≥ 13
D	≥ 17	≥ 14	≥ 9
E	≥ 13	≥ 10	≥ 7
F	< 13	< 10	< 7

mph miles per hour
≤ less than or equal to
≥ greater than or equal to

Source: Transportation Research Board, *Highway Capacity Manual, Special Report 209* (Washington, D.C., 1994), pp. 11-4.

B-7

Table B-5

CMP Level of Service Criteria for Arterials[a] Based on Volume-to-Capacity Ratios

Level of Service	Description	V/C[b]
A	Free-flow conditions with unimpeded maneuverability. Stopped delay at signalized intersection is minimal.	0.00 to 0.60
B	Reasonably unimpeded operations with slightly restricted maneuverability. Stopped delays are not bothersome.	0.61 to 0.70
C	Stable operations with somewhat more restrictions in making mid-block lane changes than LOS B. Motorists will experience appreciable tension while driving.	0.71 to 0.80
D	Approaching unstable operations where small increases in volume produce substantial increases in delay and decreases in speed.	0.81 to 0.90
E	Operations with significant intersection approach delays and low average speeds.	0.91 to 1.00
F	Operations with extremely low speeds caused by intersection congestion, high delay, and adverse signal progression.	Greater Than 1.00

[a] For arterials that are multilane divided or undivided with some parking, a signalized intersection density of four to eight per mile, and moderate roadside development.
[b] Volume-to-capacity ratio.

≥ greater than or equal to.
< less than.

Source: Transportation Research Board, *Highway Capacity Manual, Special Report 209* (Washington, D.C., 1994).

B-8

Signalized Intersections

The TRB *Circular 212* Planning method is the selected level of service calculation method for the designated intersections in the San Mateo County's CMP Roadway System. A signalized intersection's level of service, according to the method described in TRB *Circular 212,* is based on dividing the sum of the critical volumes by the intersection's capacity. This calculation yields the volume-to-capacity ratio (V/C). The critical movements are the combinations of through movements plus right-turn movements if there is no exclusive right-turn lane, and opposing left-turn movements that represent the highest per-lane volumes. Descriptions of levels of service for signalized intersections, together with their corresponding V/Cs, are presented in Table B-6.

Table B-6

Intersection Level of Service Definitions

Level of Service	Interpretation	V/C Ratio
A	Uncongested operations; all queues clear in a single signal cycle.	Less Than 0.60
B	Very light congestion; an occasional approach phase is fully utilized.	0.60 to 0.69
C	Light congestion; occasional backups on critical approaches.	0.70 to 0.79
D	Significant congestion on critical approaches, but intersection functional. Cars required to wait through more than one cycle during short peaks. No long-standing queues formed.	0.80 to 0.89
E	Severe congestion with some long-standing queues on critical approaches. Blockage of intersection may occur if traffic signal does not provide for protected turning movements. Traffic queue may block nearby intersection(s) upstream of critical approach(es).	0.90 to 0.99
F	Total breakdown, stop-and-go operation.	1.00 and Greater

B-9