IMPROVING THE PERFORMANCE OF HIGH OCCUPANCY VEHICLE INFRASTRUCTURE TO ALLEVIATE CITY CONGESTION

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ABSTRACT

The rate of rural-urban migration has increased demand on the infrastructural facilities in cities and towns and resulted in traffic congestion. Transportation enables the movement of people and facilitates trade thereby boosting the economy, social and political relations in South Africa. There is however, a higher vehicle ownership in South Africa which makes traffic congestion one of the major problems South African cities are facing. Traffic congestion results in long journey times and a rise in road accidents which impacts negatively on economic growth. Traffic congestion also has impacts on the environment as cars then produce a large volume of carbon emissions which cause respiratory problems and global warming. Various mitigation measures have been proposed to reduce traffic congestion which among others include improving parking facilities, increasing lanes, introduction of congestion fees, park and ride facilities, high occupancy vehicle infrastructure and ridesharing. It is even so, crucial to combine the engineering factors with the economic when devising a traffic mitigation plan for a particular city. An investigation was conducted to explore high occupancy vehicles (HOV) infrastructure, and how it can be better promoted and introduced to drivers and vehicle owners. Bloemfontein which is a medium-sized city experiencing rapid growth and located in the Free State of South Africa was used as a case study.

Data was collected through traffic surveys and interviews administered to drivers to. The interviews and traffic surveys were meant to determine vehicle occupancy, the nature of traffic flow as well as areas experiencing the most congestion. 150 interviews were distributed electronically and physically to drivers residing in Bloemfontein using the systematic stratified random sampling process. The intersections where the traffic surveys were conducted were selected based on the responses from the interviews which indicated where the most congestion is experienced during morning and afternoon commutes. This were intersections of roads entering the central business district (CBD) from various suburbs and locations in Bloemfontein. Traffic counts were done on weekdays in the morning and evening during peak times as reflected in the interview responses.

Findings from the study showed that congestion is caused by private vehicles especially those having commuters traveling alone. Most of these commuters travel to work in the CBD resulting in arterial routes to the CBD being the most congested roads. The study also indicated that even though private vehicle owners commute alone most of them use motor cars which can carry up to 5 people. Most commuters took 6 to 14 trips per week and the peak travel times were found to be between 06:30 and 08:30 in the morning and 15:30 and 17:30 in the afternoons. Respondents showed that they are eager for introduction of HOV infrastructure with 85% of commuters indicating that they may be open to ridesharing which may significantly reduce peak hour traffic.

The simulated scenarios revealed that traffic congestion decreases as vehicle occupancy increases. In turn vehicle occupancy may increase with incentives such as provision of high occupancy vehicle infrastructure which gives ridesharing commuters an opportunity to use the priority lanes. The most reduction is seen when most vehicles are full to capacity. This may be somewhat possible when HOV infrastructure is introduced in the busiest streets going to the CBD and private vehicles having more than one occupant are permitted to use HOV lanes.

Key words: congestion; mitigation; high occupancy vehicle infrastructure; ridesharing; African cities

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own independent work and that this dissertation, or any part thereof, has not previously been submitted by anyone or by me to another institution in order to obtain a degree.

Signature   Date: 15 August 2022

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Acquired Immunodeficiency Syndrome……………………………………………………..AIDS
Annual Average Daily Traffic……………………………………………………………AADT
Average Daily Equivalent…………………………………………………………………ADE
Avenue………………………………………………………………………………………Ave
Bus Rapid Transit………………………………………………………………………… BRT
Carbon Dioxide…………………………………………………………………………….CO_2
Central Business District………………………………………………………………… CBD
Drive………………………………………………………………………………………..Dr.
General Purpose…………………………………………………………………………..GP
Geographic Information System………………………………………………………...GIS
Greenhouse Gas………………………………………………………………………… GHG
Gross Domestic Product………………………………………………………………… GDP
High Occupancy Vehicle………………………………………………………………… HOV
Human Immunodeficiency Virus…………………………………………………………HIV
Information and Communications Technology…………………………………………ICT
Integrated Development Plan…………………………………………………………….IDP
Intelligent Transportation System…………………………………………………………ITS
Interstate Bus Line………………………………………………………………………..IBL
Mangaung Metropolitan Municipality……………………………………………………..MMM
Mobility-on Demand……………………………………………………………………….MoD
National Household Travel Survey………………………………………………………NHTS
Non-motorized transportation…………………………………………………………… NMT
Peer-to-peer………………………………………………………………………………...P2P
Road………………………………………………………………………………………..Rd
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Street………………………………………………………………………………………..St
Transnet Freight Rail……………………………………………………………………….TFR
Transport Networking Companies…………………………………………………………TNCs

CHAPTER 1. INTRODUCTION AND RESEARCH DESIGN

1.1 INTRODUCTION

Traffic congestion happens when the number of vehicles on the road is greater than the available road capacity at a given time (Munuhwa, Govere, Mojewa, & Lusenge, 2020; Struyf, Sys, Van de Voorde, Vanelslander, 2020). Afrin and Yodo (2020) state that traffic congestion may be caused by recurring and non-recurring events. The rush hour traffic is the recurring congestion and non-recurring congestion is congestion caused by planned events (e.g., special events, road construction) and unplanned events (e.g., Accidents, weather) (Fernando, 2019). Recurrent congestion tends to be predictable and repetitive as it is generated by periodic traffic flow, and many studies have proven its predictable nature using time related series (Ma, Zhou, Xu & Xu, 2020). Fernando (2019) further states that recurring congestion occurs in time intervals associated with peak hours where the demand for traffic exceeds the available road capacity. Due to the predictable nature of recurring congestion, it is much easier to control than non-recurrent congestion.

Numerous factors contribute to traffic congestion including inadequate infrastructure and urbanization. Bashingi, Mostafa and Das (2019) state that although traffic congestion is experienced in both developed and developing world countries. The urbanization of developing world cities resulted in an influx of unmanageable urban planning and development problems such as the rapid increase in vehicles as well as the inefficiency of vehicles contributing to congestion (Bashingi, et al, 2019). Congestion in developing countries is also associated with limited road infrastructure and lack of traffic management resources. Poor traffic management leads to inconvenience as it is characterized by an increase in travel time (Bashingi, et al, 2019).

Bashingi, et al (2019) states that growing car ownership and congestion are a threat to transportation sustainability in urban areas globally. Often public transportation systems are considered unreliable, unsafe and inconvenient, resulting in people who have access to private vehicles being less interested in the use of public transportation (Bashingi, et al, 2019). Private vehicles are also used for flexibility, personal space and convenience. These increase in private vehicles especially by people in the middle class has contributed to increased levels of traffic congestion in South African cities. Increased private vehicle use leaves only captive travelers for the public transportation system. Captive travelers include the elderly, the young, those unable to drive due to disabilities or lack of driver’s licenses and financially disadvantages users who do not afford private vehicle ownership (Bashingi, et al, 2019).

Most developing countries do not have infrastructure in place to cater for non-motorized transportation (NMT). Vanderschuren (2015) mentions that in addition to infrastructure, lack of facilities poses a danger to the safety of those using NMT's on the road. This poses challenges to people who may have a desire to use non-motorized transportation such as bicycles and they therefore resort to using motorized transportation. The lack of accessibility for NMT's and rapid growth of motorized transportation therefore leads to an increase in traffic congestion (Bashingi, et al, 2019). Dinh (2019) adds that this intensive use of cars leads to traffic congestion.

The increased use of private vehicles and urbanization leads to increased congestion and air pollution (Mohamedmeki and Al-Mumaiz, 2020). This also affects the economy, commuters and contributes to the lack of transportation system sustainability as well as environmental issues (Bashingi et al., 2019; Ranjan, Bhandari, Zhao, Kim and Khan, 2020; Khan, Khan, Sarker, Huda, Zaman, Nurullah, Rahman, 2018). Bashingi et al. (2019) adds that urban poor population are prone to suffer the negative consequences of congestion the most due to their confinement to public transportation systems, therefore lower classes are more vulnerable to congestion. Traffic congestion constrains mobility and reduces accessibility and is therefore a problem in developed and developing countries (Mondschein and Taylor, 2017).

The rise in traffic congestion in cities not only impacts the productivity costing billions but is also responsible for more than 40% of all carbon emissions results in global warming and air pollution (Fernando, 2019; Afrin and Yodo,2020). This pollution of the environment directly impacts the productivity, reliability, and well-being of residents and visitors. When the number of vehicles (density) increases on the road, the speed decreases, and the time of displacement is prolonged. This results in an additional emission of air pollution as well as noise pollution. Noise pollution deprives people of quality sleep and causes stress whereas the effects of some gases may affect the respiratory health of people.

Road congestion causes extra time to move from point of origin to point of destination. This reduction of speed may lead to a decrease in social contact between people especially when the time of travel is not tolerable. This additional time also influences the delivery times of goods as well as travel time. In addition, traffic congestion reduces the labor hours as well as accessibility to economic activities (Fernando, 2019).

Fiedler, Čap and Čertický (2017) affirm that the usage of private vehicles in the majority of densely populated metropolitan areas is unsustainable. Private vehicles take up large amounts of space when parked at a destination and require high-capacity highways (Fiedler et al, 2017). This therefore results in more capital required to be invested in infrastructural development which most developing countries cannot afford.

Reduced vehicles on the roads would mean less congestion, reduced travel time, less pollution and improved mobility. Scholars have proposed a number of solutions to try and solve the traffic congestion problem. These among others include the following:

- Introduction of congestion charges as ways of reducing vehicles on the roads and promoting public transportation usage (Bashingi, et al, 2019; Wang, Wang, Xie & Zhou 2018; Eliasson, 2021).
- Encouraging modal shift from private vehicles to walking, cycling and public transportation by improving the quality of public transportation (Bashingi, et al, 2019; Raje, Tight and Pope, 2018; Amatuni, Ottelin, Steubing and Mogllon, 2020; Abdulrazzaq, Abdulkareem, Yazid, Borhan & Mahdi, 2020).
- ICT enabled public transportation makes transportation more sustainable and leads to increased use of public transportation (Zhankazie, et al, 2018; Agarwal and Alam, 2018; Bashingi, et al, 2019). Information disseminated through technology may include traffic conditions, road accidents and optimal routes (Ackaah, 2019).
- Mobility-on Demand (MoD) systems can help reduce the parking space requirements by increasing the utilization of vehicles in the system (Fiedler, et al, 2017).
- Large scale rides-sharing (Aydin, Gokasar & Kalan, 2020; Alisoltani, Leclercq & Zargayouna, 2021; Tafreshian, Masoud & Yin, 2020; Fiedler, et al, 2017).
- Expansion and construction of new roads (Fernando, 2019)

Despite the fact that various academics have proposed various solutions to traffic congestion, it is worth noting that a solution is problem specific. A lot of factors have to be taken into consideration prior to implementing a solution which would include the social, economic and ecological aspects of the area in question as well as the stakeholders. A solution for cities of developing countries like South Africa therefore has to be formulated based on the specific causes of congestion.

1.2 PROBLEM STATEMENT

South Africa is one of the still developing countries in the African continent and has had a stagnant economy for some years. A low-cost sustainable solution to traffic congestion is therefore ideal for South Africa to avoid putting a strain on the little available funds. This study shall focus on investigating how ridesharing may be used as a way to reduce traffic congestion. Julagasigorn, Banomyong, Grant and Varadejsatitwong, 2021 suggest that the use of ridesharing may be encouraged in various ways which may include the internet, high occupancy vehicle (HOV) infrastructure as well as the introduction of tolls for single occupant vehicles using bus lanes.

Traffic congestion is a major problem in most South African cities (Feikie, Das and Mostafa, 2018; Netshisaulu, 2021; Das and Keetse, 2016). Congestion on the roads of cities of South Africa is mainly because of urbanisation and increasing vehicle ownership (Feikie, et al, 2018; Mlambo, 2018). Feikie, et al (2018) states that traffic congestion and delay are the major road transportation challenges in Bloemfontein due to the large use of private vehicles as illustrated below (see Figure 1-1).

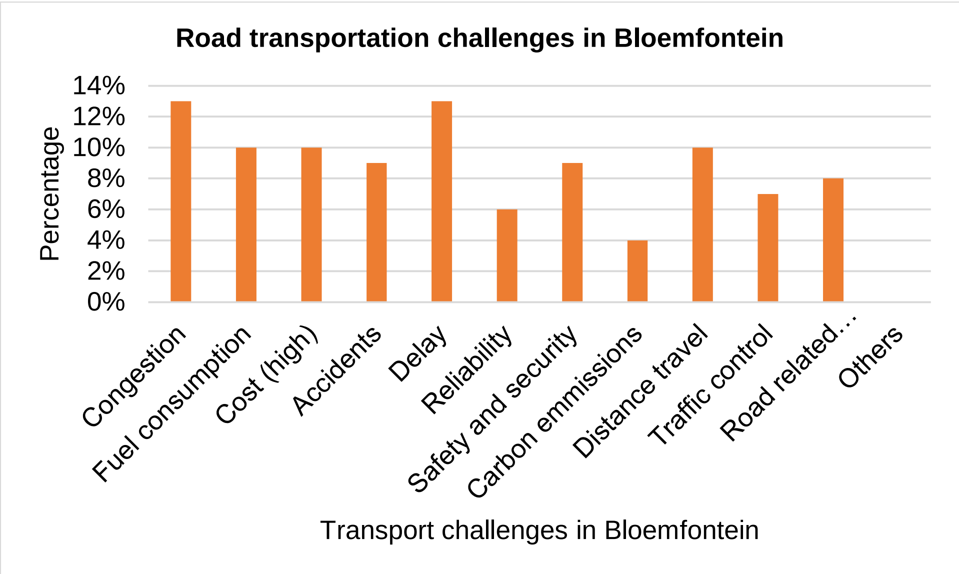


Figure 1-1: *Road transportation challenges in Bloemfontein*
(Feikie, et al., 2018)

Increased car ownership has proven to be one of the major causes of city congestion and therefore affects the mobility, accessibility, health and liveability of the city (Luke, 2018; Su, Liu & Li, 2020). An increase in vehicle ownership especially with the middle to high income class groups, has seen the number of vehicles growing exponentially on the roads, causing congestion (Loubser and Bester, 2009). Fernando (2019) states that the transport infrastructure of many cities has not been able to keep up with the pace of growth in the motorization rate or to counteract the intensification of urban traffic.

The rise in traffic congestion in cities is also responsible for more than 40% of all carbon dioxide (CO_2) emissions which results in global warming (Fernando, 2019). If travel patterns are not controlled, they may have a substantial impact on land resources, water quality, air quality and biodiversity. According to the Green Transport Strategy 2016-2021, emissions from the transport sector in South Africa account for 13% of the country's total greenhouse gas (GHG) emissions, of which 86% is from the combustion of liquid fossil fuels. Road transport alone is said to have contributed 91.2% of total transport GHG emissions in 2010 (Olojede, 2021). This is shown below (see Figure 1-2).

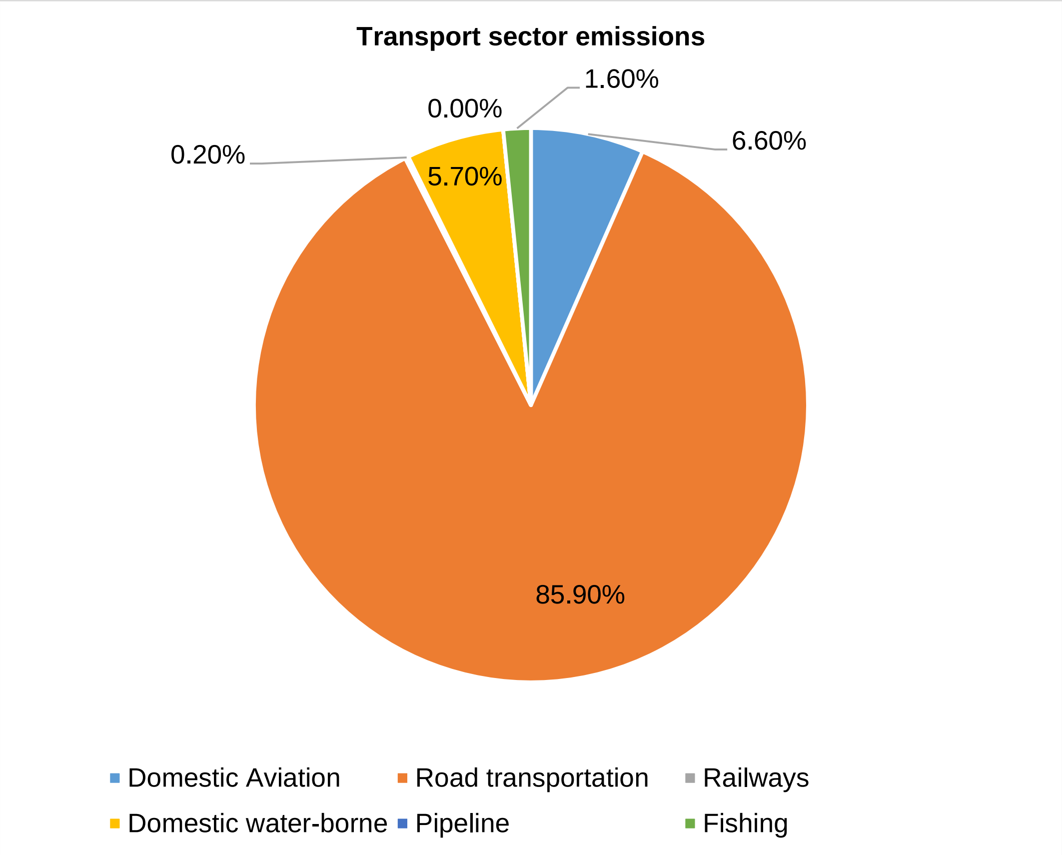


Figure 1-2: *Transport sector emissions according to 2000-2010 National Greenhouse Gas Inventory*
(Green Transport Strategy 2016-2021)

South African cities would experience significantly less traffic congestion as a result of fewer private vehicles on the road, hence it is necessary to look at ways to promote ridesharing. The concept of ridesharing is part of a broader concept known as 'sharing economy" (Vanderschuren & Baufeldt, 2018). Vanderschuren and Baufeldt (2018) indicate that successful ride-share schemes could reduce congestion, fuel consumption, emissions during peak travel periods, reduce parking costs for travellers and employers, and provide a reliable alternate mode to private car ownership.

Ridesharing may be implemented using numerous tools and techniques which may include digital techniques (e.g. online platforms and apps) and non-digital ridesharing techniques (i.e. based on personal and professional networks) (Pigalle and Aguiléra, 2023). Studies have been done on various measures to implement in order to protect riders and drivers using digital methods to connect. Tang, Duan and Zhao (2019) add that the functionality of ridesharing is dependent on the driver and riders communicating, negotiating and agreeing on what could be beneficial and functional for all the parties involved.

1.3 PURPOSE OF THE STUDY

1.3.1 Research Aims of the Study

By using Bloemfontein as a case study, this research investigates ridesharing and HOV infrastructure as feasible ways to reduce traffic congestion in middle-sized cities. This will be accomplished by performing traffic counts, looking at networking tools for car owners, and determining vehicle occupancy during peak travel hours and how vehicle occupancy may affect traffic flow if there was HOV infrastructure.

1.3.2 Objectives of the Study

The research objectives set for the purpose of achieving the aim above (1.3.1) are as follows:

- Identify the major causes of congestion in middle sized cities using Bloemfontein as a case study.

- Investigate the tools and techniques that may be used to connect private vehicle users.

- Identify how HOV infrastructure may be incorporated into the already existing infrastructure in South African cities to motivate ridesharing.

- Determine the impact of ridesharing on the volume of traffic.

- Establish whether private vehicles owners will adopt ridesharing or not and factors that may influence their choice.

1.4 SCOPE OF THE STUDY

The scope of the investigation is limited to developing a strategy and planning guidelines to reduce congestion by improving mobility and transportation infrastructure in arterial roads of Bloemfontein, South Africa. This was done by evaluating the major causes of traffic congestion in the city as well as areas mostly affected. Research was done by using sample surveys to determine the most congested areas of the city, peak commute times as well as vehicle occupancy during peak times. Bloemfontein was selected as the study area because it is the economic hub of the Mangaung Metropolitan Municipality (MMM) and is the city experiencing the most urbanisation in the Free State. The researcher believes that traffic congestion in Bloemfontein may be greatly reduced and future congestion avoided if this study bears positive findings and recommendations made from those findings are followed. Commuting times will be shortened, carbon emissions lowered, and vehicle owners will also save money.

1.5 RESEARCH DESIGN

1.5.1 Methodology of the Study

The investigation follows a detailed systematic methodology (see Figure 1-3). The various steps identified in the methodology include:

- Identification of the problem
- Setting of objectives and research design
- Collection of data from literature
- Identification and justification of the selected study area (Bloemfontein)
- Data collection – Interviews
    - Traffic surveys
- Analysis of the data collected and simulations
- Drawing of inferences
- Policy analysis
- Development of policies and planning guidelines
- Recommendations

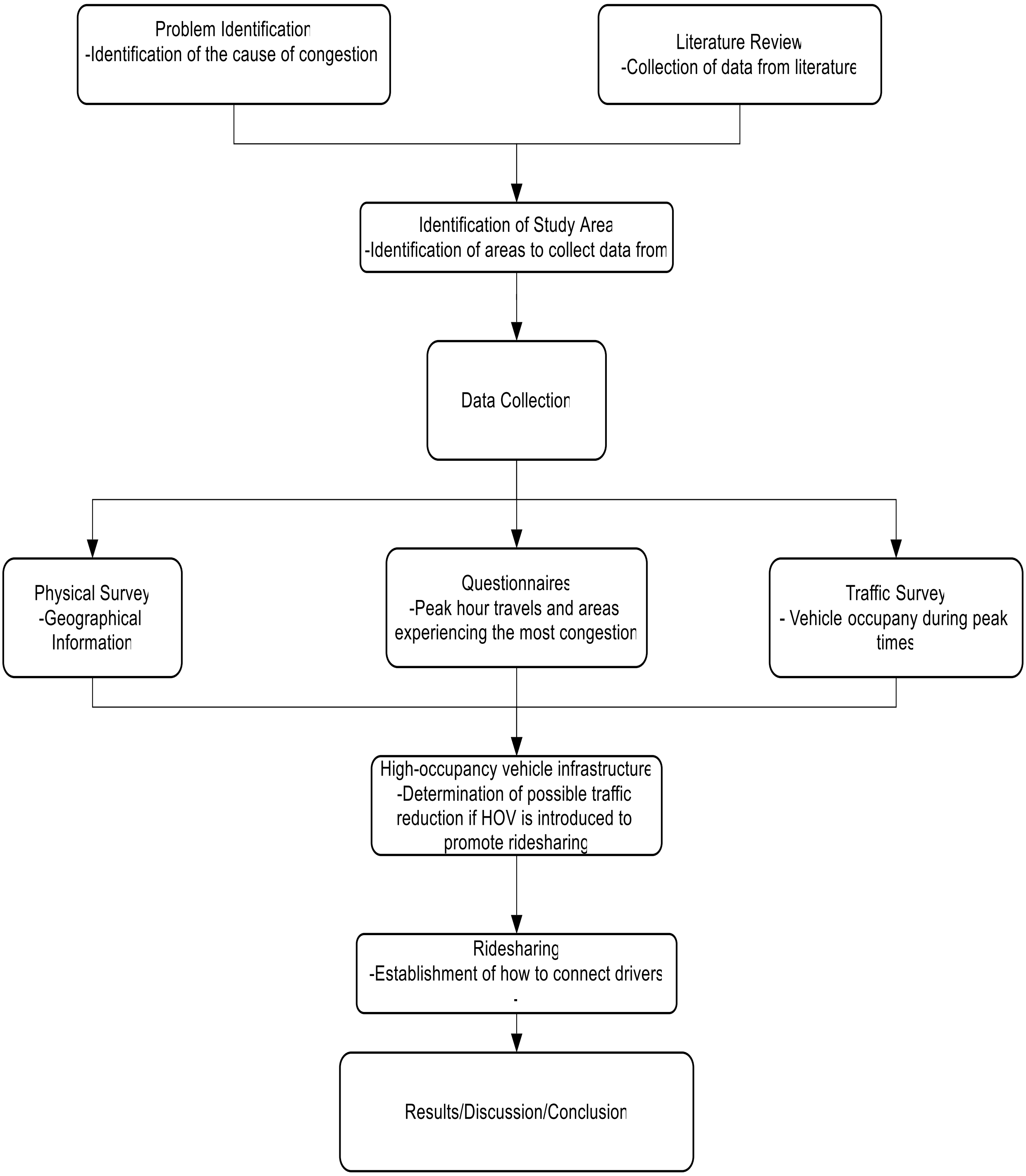


Figure 1-3: *Methodology flow chart*

1.5.2 Study Area

Bloemfontein was selected as the study area since it is the Free State province's capital and is experiencing increasing traffic congestion. Bloemfontein, the administrative centre of the MMM and the seat of South Africa's judiciary, is a medium-sized city. Due to the aforementioned factors, the city is becoming increasingly urbanized as residents of Thaba Nchu, Botshabelo, and other nearby places move there in quest of employment, business prospects, and educational chances. This has led to a lot of pressure being put on the existing infrastructure which was initially not intended to cater for such a large number of people as well as increased traffic. The city covers an area of 236.2 km^2 and hosts a population of approximately 588 000 people. Figure 1-4 below shows the population growth of the city since 1950.

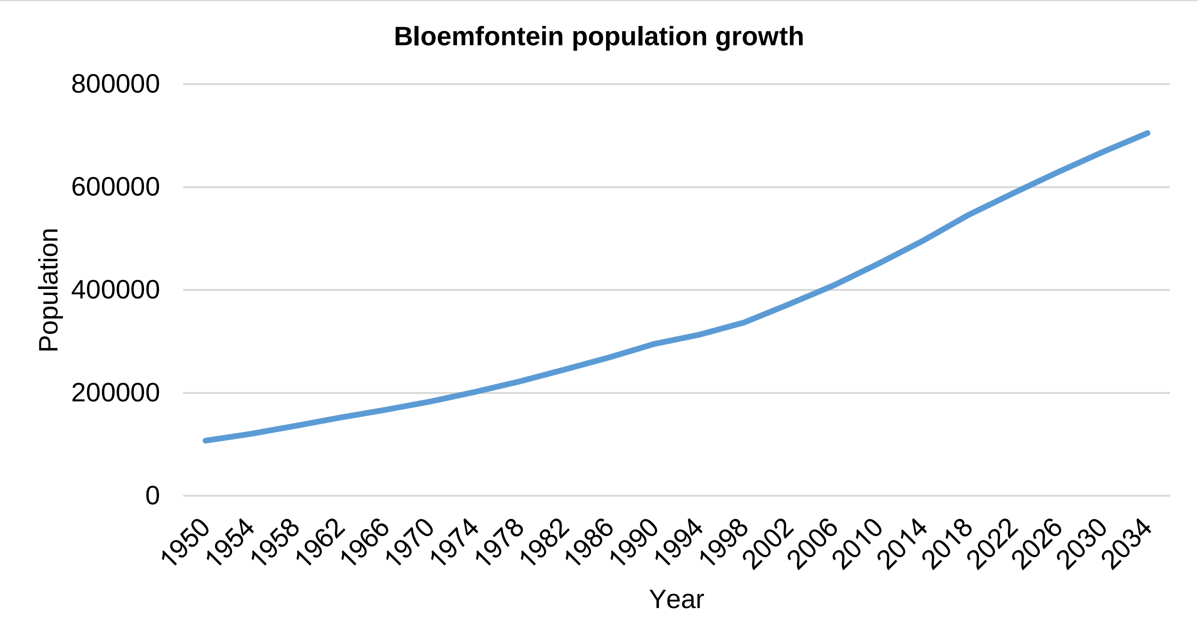


Figure 1-4: *Bloemfontein population growth*
(Population Stat, 2017-2022)

In addition to Bloemfontein experiencing continuous population growth, the city has two national roads passing through it being the N1 and N8 which add to the daily traffic flow. Most economic activities are located in the central business district (CBD) resulting in people commuting daily from the suburbs to this area resulting in it being congested. Figure 1-5 below shows the location of the CBD in relation to Bloemfontein suburbs. Unlike most cities, Bloemfontein has no provision for passenger rail transportation which makes commutes to be done solely by road transportation and hence it was chosen as the study area for finding mitigation measures to congestion in middle sized cities. Like most medium cities across the globe, Bloemfontein is not able to keep up with the fast-paced urbanisation (Zhu, Liu, Liu, Zhang, Chen and Meng, 2021).

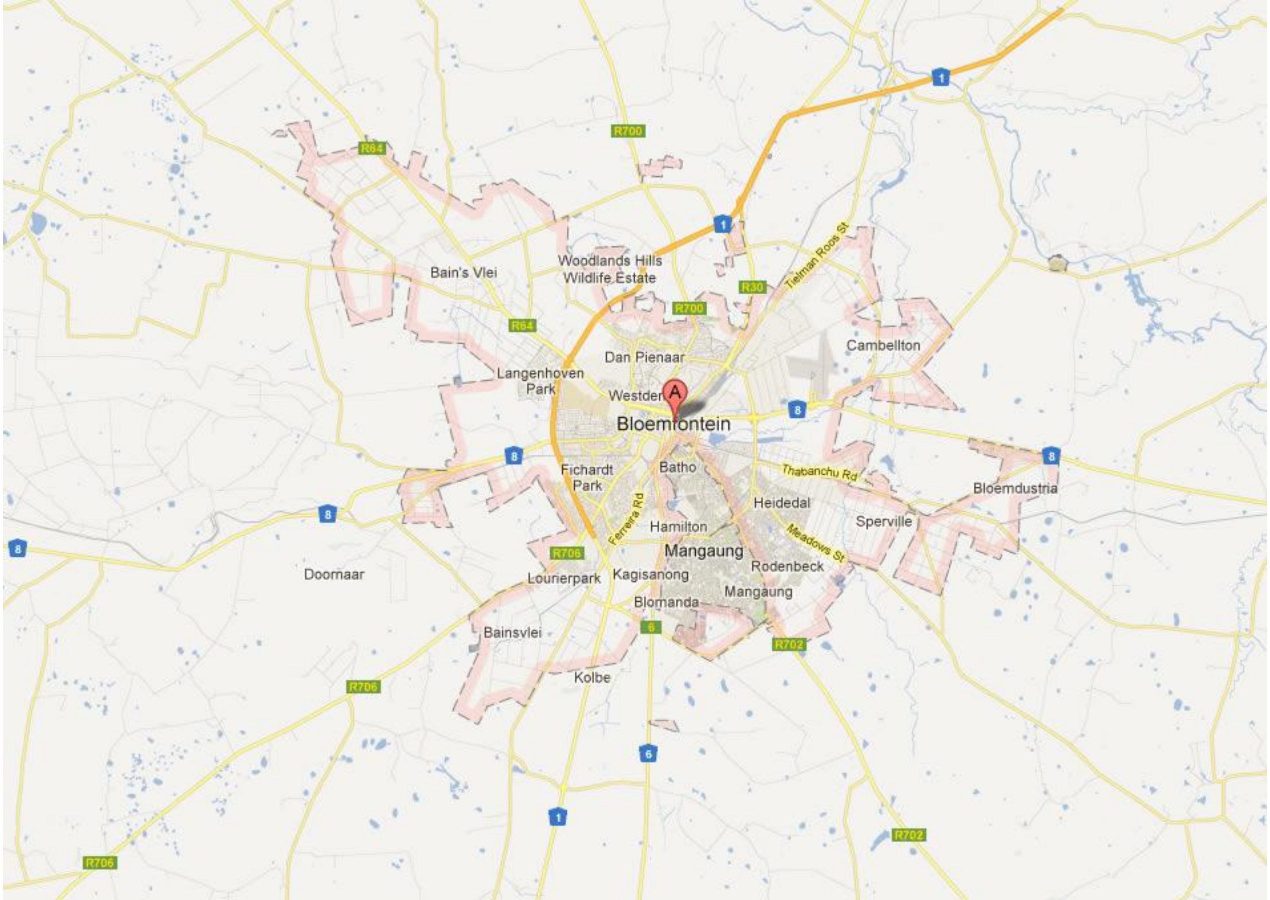


Figure 1-5: *Map of Bloemfontein*
(GuideOfTheWorld.net 2006-2022)

1.5.3 Data Collection

In this inquiry, both primary and secondary data have been gathered and used.

Primary Data

Primary data was collected through administering of interviews to drivers and traffic surveys (traffic volume survey) to obtain first-hand information. Data collection from primary sources was crucial in obtaining accurate data from commuters as well as determining the socio-economic conditions and traffic conditions of private vehicle owners. In addition to this, the planning guidelines and development of policies for the reduction of congestion in middle sized cities required a deep understanding of travel patterns as well as parameters impacting vehicular flow in the study area. The interviews administered comprised of the following four major sections.

Section 1 – Demographics and types of vehicles used by the respondents. This included the gender, age as well as the type of vehicle used by each respondent and its carrying capacity.

Section 2 – This section determined the peak commute times, number of trips commuters take per week, travel times, time taken for each trip, average distance travelled per trip, reasons for travel as well as the origins and destinations of the trips taken.

Section 3 - Determining the commuter's response to the introduction of HOV infrastructure in Bloemfontein, areas with the most congestion and roads that may be recommended for the introduction of HOV infrastructure.

Section 4 – The openness of commuters to ridesharing. The maximum number of people each private vehicle may carry was determined after which drivers and vehicle owners were interviewed to determine their willingness to rideshare and the number of passengers, they would be willing to share their vehicles with.

Interviews for Drivers

Homogeneous sampling was done and interviews were administered to drivers at random around Bloemfontein. This was done at car washes, fuel garages, parking lots and other areas which attracted a significant number of drivers. A total of 150 interviews were administered both manually and electronically for participants to complete.

Physical Survey

The traffic volume and direction of flow at peak times in Bloemfontein was obtained by physical traffic surveys conducted. This was done by conducting traffic counts at the major junctions entering the CBD from the suburbs at peak commute times. These counts were not only aimed at determining the number of private vehicles on the roads but most importantly the occupancy of those vehicles. This method of data collection was used to collect traffic data before and during Covid-19 by Parr, Wolshon, Renne, Murray-Tuite and Kim (2020); Sfyridis and Agnolucci (2020) used traffic counts to determine annual average daily traffic (AADT); and traffic counts were also used by Tang, 2021 in their study to determine the cost of traffic.

With Bloemfontein divided into four quadrants, the survey targeted private vehicle occupancy from each of the quadrants to the CBD. Traffic surveys were done at the intersection of Oliver Tambo Road and President Avenue; the intersection of Kellner Street and General Dan Pienaar Road; the intersection of Kolbe Avenue and President Avenue; the intersection of Nelson Mandela Drive and Furstenburg Avenue; the end of the N8 and beginning of Nelson Mandela Drive; and the intersection of Aliwal Street and Union Avenue. This is detailed further in Section 4.2 of Chapter 4.

Significance of Data Collected

The driver surveys provided an insight into the demographics of the respondents, travel patterns of various commuters in Bloemfontein, their reasons for travel as well as the commute distances and times. The survey further provides insight on the attitude of commuters towards ridesharing and the introduction of HOV infrastructure in the city. This information gives the researcher a much clearer picture on the challenges faced by commuter on a daily basis during peak travel times.

The physical traffic survey aided in obtaining quantitative data on vehicular traffic volumes during peak times and the direction of flow. This also helped in determining vehicle occupancy of private vehicles travelling at peak times.

The data collected helped in analysing the number of vehicles with single occupants on the road during peak times and the number of vehicles with more than one occupant. This data was further used in the study to determine how much traffic may be reduced if vehicle occupancy may increase and HOV may be introduced as an incentive to ridesharing.

Secondary Sources of Data

Secondary data related to the study was obtained from various sources which included the Integrated Development Plans (IDPs) for MMM, geographic information system (GIS) data as well as published and unpublished literature. This information collected was combined with the primary data in order to obtain a deeper analysis on the possibility of introducing HOV infrastructure and subsequently ridesharing as congestion mitigation measures which in turn will improve traffic flow in the city.

a) Data Analysis

The data compiled was checked for completeness and accuracy and errors eliminated by cross-checking the information before subsequently transferring it to the computer for analysis. The computer analysis was then done by employing the various tools described in the section below.

Analytical Tools

The data was processed, analysed, and modelled using analytical tools like Microsoft Excel.

Analytical Techniques

Tabulations and significance tests were used according to the requirements of the present investigation. Traffic reduction models were generated to establish various scenarios of vehicle occupancy and how much traffic is reduced under each scenario.

1.5.4 Evaluation and Validation

The accuracy and credibility of the private vehicle occupancy reduction scenarios modelled was done by doing a lot of simulations.

Simulations

The simulations done were meant to determine how much traffic may be reduced based on the willingness of drivers to ride-share and HOV infrastructure. Various simulations were done which were dependant on the number of occupants of private vehicles during peak times.

Application of the Model

Alternate plausible simulated scenarios were developed by employing the model to arrive at different feasible policy decisions.

1.6 RESULTS AND DISCUSSION

Results from data collected from the interviews, traffic surveys, detailed description of literature as well as the simulation of various traffic reduction scenarios has been done to arrive to the plausible findings of the study.

1.7 INFERENCES

Plausible inferences were drawn for developing a set of feasible policies and guidelines.

1.8 POLICIES AND RECOMMENDATIONS

A set of policy guidelines have been prepared and recommended based on the results, discussions, and inferences of this research for the enhance of HOV infrastructure as a mitigation measure for congestion in the study area.

1.9 LIMITATIONS

Limitations to the study were as follows:

- Time factor: The Masters research program is time based and this therefore limits the extensiveness of the research.
- Covid-19: The study was done at a time when the world at large was going through a pandemic and life as normal had changed. This was not only psychologically weighing down but also limiting the researcher when it came to data collection as most people were hesitant to interact.
- Limited resources: The closing of campuses due to lockdowns, accessibility to resources such as internet and the library for uninterrupted study were inaccessible resulting in the researcher having to fend for themselves for a conducive study environment.

1.10 ETHICS IN TRAFFIC SURVEYS

It is very crucial that research is conducted in an ethical manner in accordance with good research practices. According to Barrow, Brannan and Khandhar (2021), some of the issues that have been of concern in research in the past years include human dignity and the right to fair treatment and justice. It is therefore the responsibility of the researcher to ensure that participants know that they have a right to decide whether or not to participate in the research study and withdraw at any time they wish to. In addition to that, the selection of the participants should be guided by research questions and requirements and be a fair representation of the overall target population as much as possible. Participants have a right to freedom from harm, discomfort, and protection from exploitation. The researcher should enforce the privacy of participants by keeping their identities anonymous (Barrow et al., 2021). Prior to collection of data, the investigator was sensitised on ethical issues and participants in the research were informed of the purpose and implications of the study. Respondents who took part in the various surveys were also informed that participation is voluntary and assured that the information collected would remain anonymous. Reasonable caution was taken to avoid exploitation of respondents by ensuring that people approached to take part in the study were those of a sound mind and legal age to make independent decisions.

1.11 CHAPTER SCHEME

Chapter 1: The introduction, problem statement, objectives, scope of the study, research methods and limitations of the research.

Chapter 2: The review of the literature

Chapter 3: Outlines the profile of the study area with respect to background of the study area, demographics, social functions, basic infrastructure, transportation, economy, urban form as well as HOV infrastructure.

Chapter 4: Focuses on data analysis, results and discussions.

Chapter 5: The findings, discussions, proposal of policy guidelines, recommendations, and the conclusion.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

The world's habitable regions may be classified as urban areas which are heavily concentrated areas and rural areas which are denser areas (Shiraki, Matsumoto, Shigetomi, Ehara, Ochi and Ogawa 2020). The rapid urbanization in the civil world has resulted in the sharp growth of population and vehicles in cities and imposed an ever-increasing burden on the transportation infrastructures (Wang et al., 2019; Duczynski, 2018; Liu and Li, 2017). Shiraki et al. (2020) says that this trend of urbanisation is expected to continue until 2050.

Traffic congestion as defined by Vencataya, Pudaruth, Dirpal and Narain (2018) refers to the way the movement of vehicles is delayed by one another because of the limited road capacity. Traffic congestion may be viewed as an indication of economic growth or as a sign of deterioration of urban areas (Agyapong and Ojo, 2018). Wang et al. (2019) adds that traffic congestion has consequently become a substantial threat to urban cities in terms of tremendous lost time and productivity, air pollution and wasted energy.

Traffic congestion may be classified as recurrent and non-recurrent congestion. Recurrent congestion occurs at the same place and time every day whereas non-recurrent congestion is the effect of unplanned events. Traffic congestion occurs mostly during morning commute from residential areas to CBDs as users try to navigate corridors that were not designed for such traffic volumes (Duczynski, 2018; Ma and Zhang, 2017). Agyapong and Ojo (2018) say that in Ghanaian cities, traffic congestion occurs mostly at the market where there is a conflict of space by users and poor traffic management systems.

Congestion constrains mobility and reduces accessibility. For this reason, traffic congestion is an area of concern for urban areas in both developed and developing countries (Bashingi et al., 2019). Bashingi et al. (2019) further expresses that although traffic congestion is experienced in both developed and developing world countries, studies confirm that it is more prevalent in the developing world. Congestion in developing countries is associated with limited road infrastructure and lack of traffic management resources.

The most significant externalities road systems in urban areas suffer from are collisions, traffic congestion and air pollution (Vanderschuren and Baufeldt, 2018). Agyapong and Ojo (2018) state that traffic congestion is the most important infrastructure deficiency. Feikie et al. (2018) adds that traffic congestion in Bloemfontein particularly during peak hours is a leading challenge in the city which is expected to become acute in future. This is illustrated by Figure 2-1 below.

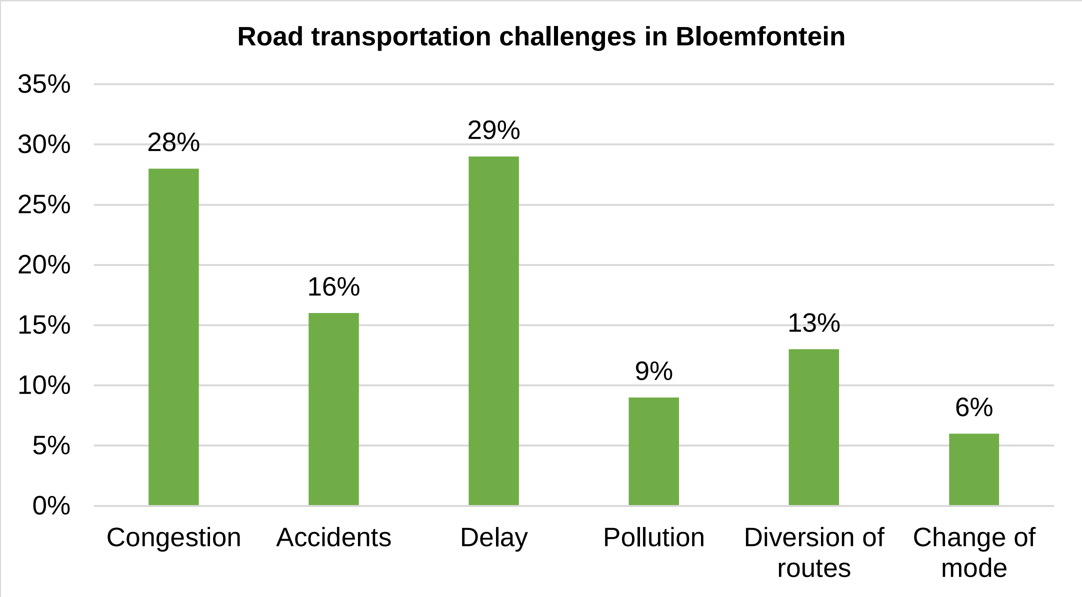


Figure 2-1: *Road transportation challenges in Bloemfontein*
(Feikie et al., 2018)

Tachet, Sagarra, Santi, Resta, Szell, Strogatz and Ratti (2017) state that the prosperity and liveability of cities is related to the effectiveness of their mobility systems. For a country of millions, traffic congestion significantly reduces the economic productivity, leads to fuel wastage and money loss (Abir, Mostafizur Rahman, Islam, Bashar and Islam 2018; Agyapong and Ojo, 2018). Feikie et al. (2018) says that in South Africa the population keeps on increasing and so is the need to provide infrastructure. According to census 2011, the population of South Africa grew by 7 million between 2001 and 2011. South Africa is experiencing continuing urbanisation that might leave 71.3% of the population living in urban areas by 2030, which is expected to reach nearly 80% by 2050 (Feikie et al., 2018). This increase in the population calls for solutions to accommodate the growth without compromising the quality and efficiency of the services. Among these is the need for efficient transportation systems and solutions that will alleviate the transport challenges that South African cities are facing (Feikie et al., 2018).

According to Fiedler et al. (2017) the increasing use of private vehicles for transportation in cities results in a growing demand for parking space and road network capacity. Between 2003 and 2013, private car ownership in South African households increased from 25% to 35% (Vanderschuren and Baufeldt, 2018). Vanderschuren and Baufeldt (2018) mention that increased mobility demand in South Africa is due to three main phenomena – the population is still growing, the number of trips per person per day is increasing and the middle class is also growing significantly. Car usage also increases as income increases because of the convenience of having a car and the inconvenience of public transportation (van Ryneveld, 2018). Fiedler et al. (2017) goes on to say that in many densely populated urban areas, the capacity of existing infrastructure is insufficient and extremely difficult to expand. Growing car ownership and congestion are a threat to transportation sustainability in urban areas globally (Bashingi et al., 2019). Bashingi et al. (2019) states that cities in the developing world have not been spared from the congestion problems due to the influx of vehicles and the subsequent increase in private vehicle ownership. Figure 2-2 below shows the vehicle registration statistics in South Africa between 2005 and 2015. Poor traffic management leads to inconvenience as it is characterized by an increase in travel time.

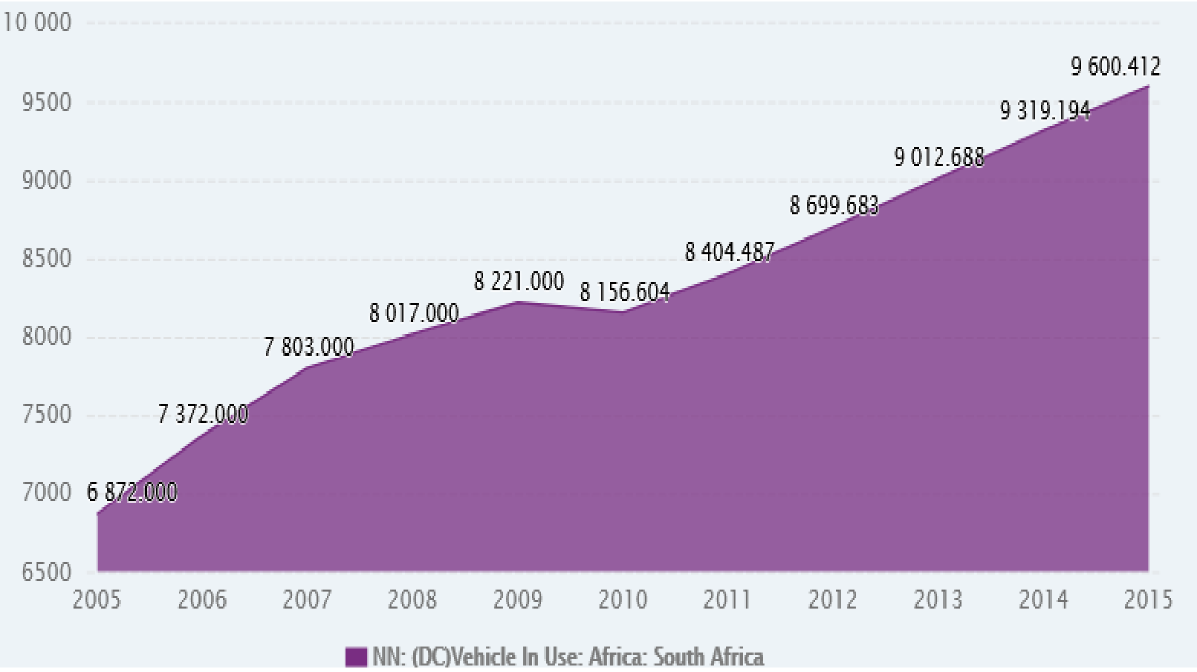


Figure 2-2: *Vehicle registration in South Africa between 2005 and 2015*
(CEIC Data, 2021)

Sustainable road transportation is found to be an integral part of sustainable development as large-scale transportation and vehicular activities are increasingly contributing to the economic, mobility, living conditions and environmental challenges of regions or cities (Feikie et al., 2018). Feikie et al. (2018) explains that the concept of sustainable road transportation in an urban area is governed by different indicators. These include among others accessibility to and quality of public transportation, level of congestion, level of carbon emissions and polluting matters, road utilization, facilities for pedestrian movement and traffic crashes. South African cities are moving towards sustainable cities, and some of the challenges that need to be addressed include alleviating congestion to ensure that the transportation systems in our cities are safe, cost effective, reliable, efficient and stick to the schedule. According to Yao et al. (2018) numerous ways have been proposed to mitigate traffic congestion which among others include carpooling and HOV lanes.

Travel demand management aims to reduce vehicle trips by increasing travel options, providing incentives and information to encourage and help individuals to modify their travel behaviour using existing infrastructure. Travel demand management therefore aims to shift the mind set of people to alternative modes of transportation options. HOV lanes are lanes that are meant to accommodate vehicles with more than one occupant (Li, Su, Sui and Zhang 2017). These lanes can help mitigate GHG emissions by promoting carpooling, reducing the number of vehicles on roads, and relieving traffic congestion (Javid, Nejat and Hayhoe 2017; Clayton, Paddeu, Parkhurst and Parkin 2020). HOV lanes attract people to travel together especially when the general-purpose (GP) lanes are congested (Li, Ma and Hale 2020). HOV infrastructure has been used to promote carpooling in countries like the United States as well as China. According to Fisch-Romitoa and Guivarch (2019) increases in future mobility require development of new infrastructure as well as upgrading of the existing ones. Infrastructure and transport mode choices may result in lower carbon emissions in both developing and developed countries (Fisch-Romitoa and Guivarch, 2019).

2.2 TRAFFIC CONGESTION IN CITIES

2.2.1 Causes of Congestion

According to Vencataya et al. (2018) there are principally two factors causing traffic congestion, namely micro level factors and macro level factors. Micro level factors are the high number of people on the roads at the same time and the overflow of vehicles on the limited road space. Macro-level factors include land use patterns, car ownership trends, and geographical economic development. Congestion is prompted at the micro-level and steered at the macro-level. Rapid increases in car ownership in addition to poor land use planning, inadequate road space, lack of regulated parking systems, bad attitude of pedestrians and motorists are some of the factors causing traffic congestions globally (Agyapong and Ojo, 2018).

A continuous increase in traffic demand on account of higher levels of urbanization, population growth, changes in population density are some of the factors that cause challenges for the road transportation system (Feikie et al., 2018). Feikie et al. (2018) states that Bloemfontein being one of the growing cities of the country offers higher order socio-economic and infrastructural facilities to the people of the central region of the country. People from the surrounding towns and rural areas commute daily to the city for their socio-economic and business needs such as attending schools and colleges, accessing health facilities, shopping, entertainment, and work. Because of the growing needs of movement of the people of the city and its surrounding areas and higher dependence on vehicular transportation, Bloemfontein faces mounting road transportation challenges in and around the city (Feikie et al., 2018).

Often public transportation systems are considered unreliable, unsafe and inconvenient. This results in people who have access to private vehicles being less interested in the use of public transportation (Bashingi et al., 2019). In a study conducted by Abir et al. (2018), it was revealed that the satisfaction levels of the commuters using buses fell mostly under the 'dissatisfied' category (78%) based on parameters like fitness of the bus and behaviour of drivers and conductors. A further survey done by Feikie et al. (2018) revealed that challenges of efficiency, reliability and security are the major reasons which deter the use of public transportation in Bloemfontein. The lack of importance given to the public transportation sector is also one of the major reasons why the public avoids travelling in buses. This in turn, results in too many private vehicles jamming up the main roads and causing losses in millions due to productive time lost stuck on the roads. Currently the city's transportation is only based on subsidised Interstate Bus Line (IBL) buses, minibus taxis, metered taxis, and private cars that have been changed to operate as taxis (Feikie et al., 2018).

The urban form of South Africa is quite dispersed, causing the average morning commute trip times to work in the five biggest metros to range between 61 and 53 minutes (van Ryneveld, 2018). Van Ryneveld (2018) further states that the urban form of South Africa was determined by the apartheid system as well as automobile driven planning. Economic activity in one area also causes influx of traffic in that area.

The low occupancy of private vehicles especially at peak times causes traffic congestion (Liang, de Almeida Correia, An and van Arem 2020). Aropet (2017) states that single occupancy vehicles are the least effective way to transport people even though they make up the majority of highway traffic. A survey conducted by Bashingi et al. (2019) revealed that psychological feeling (24%), safety (24%), efficiency (23%) and flexibility of the schedule

(19%) are the prime reasons of use of private transportation although it may not be cost effective. This is illustrated by Figure 2-3 below.

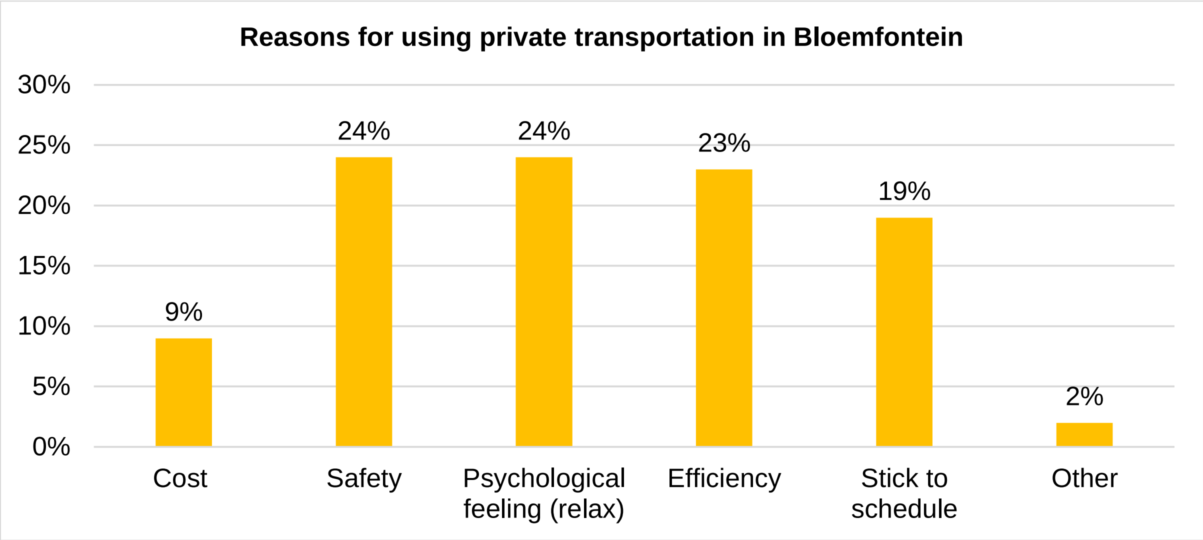


Figure 2-3: *Reasons for using private transportation in Bloemfontein*
(Feikie et al., 2018)

A survey conducted by Feikie et al. (2018) shown in Figure 2-4 below revealed that only 29% of people use public transportation while 35% use private transportation and 36% use both. This indicates that there is a large number of people using private vehicles leading to high traffic volumes and consequent congestion.

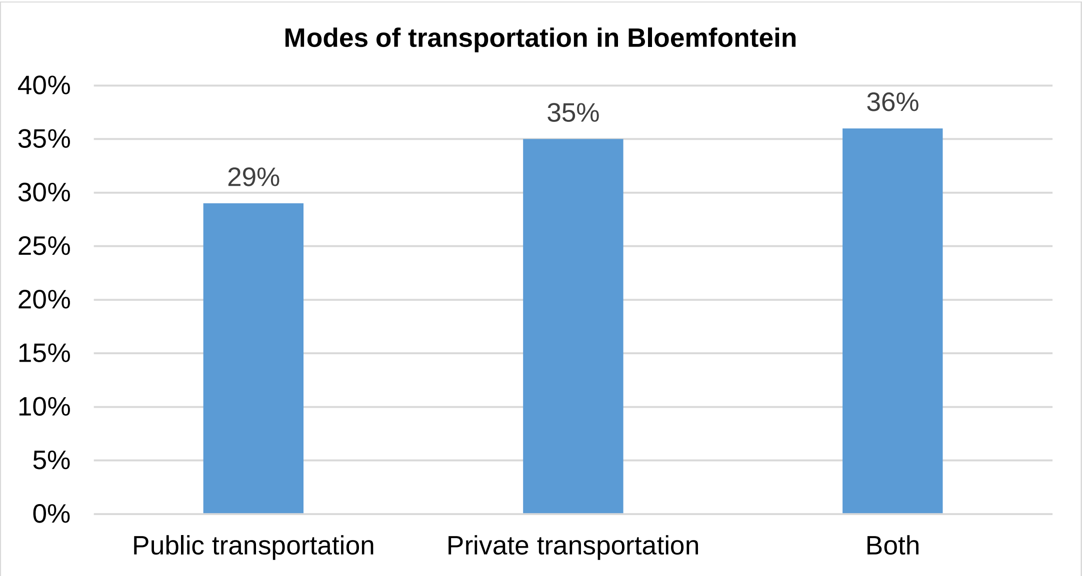


Figure 2-4: *Modes of transportation in Bloemfontein*
(Feikie et al., 2018)

Lack of accessibility of non-motorised transportation and the rapid growth of motorised transportation pose challenges to developing countries (Bashingi et al., 2019). Agyapong and Ojo (2018) say that traffic congestion may be a result of scarce road transportation facilities such as road space, parking, road signals and lack of a proper traffic management system. Traffic congestion concerns passengers and freight which share the same infrastructure.

2.2.2 Effects of Traffic Congestion

Excessive use of private vehicles has resulted in high levels of congestion, excessive carbon emissions, poor air quality and health and community degradation (Clayton et al., 2020). According to Agyapong and Ojo (2018) the effects of traffic congestion can be categorized into four main groups being environmental, economic, health and social.

Traffic congestion results in increased fuel consumption as well as massive delays, decrease in productivity due to vehicular speed reduction and reduction of sales (Agyapong and Ojo, 2018; Abir et al., 2018; Vencataya et al., 2018). Businesses that have adopted the just-in-time system are more prone to be affected by traffic congestion as it is difficult to make just-in-time deliveries efficiently. Businesses dealing with perishable products also rely a lot on travel reliability (Vencataya et al., 2018). The economic issues of private transport are identified with the diminished openness of monetarily vital goals. Abir et al. (2018) says blockage in European urban communities is evaluated to cost 100 billion euros for each year and is anticipated to increase twofold in the following decade.

The increase in traffic congestion in commuter corridors leads to high fuel consumption and air pollution (Ma & Zhang, 2017). Cars stopped in traffic produce large volumes of carbon emissions which cause global warming, fog and increased respiratory problems (Agyapong & Ojo, 2018; Stiglic, Agatz, Savelsbergh and Gradisar 2018). Shiraki et al., (2020) say that 18.8% of global carbon emissions in 2016 came from the transportation sector. Natural issues concern the outflows of lethal and unsafe substances, which, in addition to other things, add to a dangerous atmospheric deviation, brown haze and corrosive precipitation (Abir et al., 2018). Fisch-Romitoa and Guivarch (2019) state that transportation is one of the fastest growing GHG emitting sectors having undergone the highest growth in GHG emissions since 1970. GHG emissions for the transportation sector in the United States have grown faster than that of other sectors with transportation contributing about one-third of the total emissions in the U.S. (Javid et al., 2017). Javid et al. (2017) adds that a third of those emissions come from passenger cars while the other third come from light duty trucks.

Traffic congestions usually causes accidents due to drivers growing impatient and wanting to get through congested corridors faster (Vencataya et al., 2018). It was also found that traffic congestion induces a high level of stress and frustration in commuters especially drivers, as they are required to be more attentive and focused while driving in challenging conditions (Vencataya et al., 2018).

2.2.3 Mitigation Measures for Congestion

Traffic congestion in urban areas cannot be completely eliminated but may be minimised to acceptable levels (Agyapong & Ojo, 2018). Agyapong and Ojo (2018) further point that there are various ways traffic congestion may be minimised which include using speed controls, strict lane management, deterrent measures, increasing road capacity, dedicated lanes for pedestrians and cyclists as well as provision of car parks at shopping centres instead of using roadside parking.

Over the years, modal shift from private vehicle travel to public transportation and non-motorised transportation has been used to promote transportation sustainability (Bashingi et al., 2019). Vanderschuren and Baufeldt (2018) say the implementation of public transport systems is an important alternative to private car use and its externalities. Trans Milenio in Bogotá for example was credited with a 32% decrease in commute times, a 40% reduction in air pollution, and an 88% drop in traffic-related deaths along the bus rapid transit (BRT) corridors. Vencataya et al. (2018) adds that enhancing the quality of public transport services and introducing the Light Rail Transit system will improve and modernise the public transport system in Mauritius.

The government should invest in feasible infrastructural projects so that roads are less congested especially during peak hours. Improving the existing road infrastructure or even expanding the road capacity might help to handle the ever-increasing number of vehicles on the roads, at least in the short term or medium term (Vencataya et al., 2018). Building smart cities will also help to improve traffic flow on the roads. Vencataya et al. (2018) states in Mauritius smart cities will allow several offices to delocalise to other parts of the island, thus directing traffic to different parts of the island (Vencataya et al., 2018).

Lewinson and Lewinson (2019) say that an alternative to reducing single occupancy vehicles is the use of HOV where commuters share a vehicle. Ridesharing or carpooling has been considered as one of the demand management tools to reduce air pollution, fuel consumption and minimise delays (Ma & Zhang, 2017). An efficient MoD system to group people based on their departure times, origins and destination is ideal to facilitate ride-matching and in turn reduce the required number of vehicles (Lewinson and Lewinson, 2019; Fiedler et al., 2017). Carpooling may help in the reduction of vehicles on the road as well as carbon emissions due to transportation (Vencataya et al., 2018; Fiedler et al., 2017).

2.3 HIGH OCCUPANCY VEHICLE (HOV) INFRASTRUCTURE

2.3.1 What is HOV Infrastructure

Transportation is an integral part of the development of every country. Transportation investments require enormous amounts of time and money and therefore certain transportation measures can be made out of the already existing infrastructure and systems (Aropet, 2017). HOV lane refers to any special lane designated for exclusive use by high-occupancy vehicles including carpools, vanpools and buses (Shewmake, 2018; Chen, Zou, Tang, Peng, Wu and Jiang 2018; Clayton et al., 2020). HOV lanes represent a major infrastructural tool for transportation planners to control traffic demand and carpooling rates (Javid et al., 2017). HOV facilities are comprised of separate HOV roadways, HOV lanes, transit lanes, HOV direct access ramps, and flyer stops. According to WSDOT Design Manual, HOV infrastructure is designed to improve the capabilities of corridors to carry more people, provide savings and a reliable travel time for HOV lane users as well as to give commuters travel options.

2.3.2 How does HOV Infrastructure work

Li et al. (2020) states that HOV infrastructure is designed to maximise the movement of people and not vehicles to reduce traffic congestion. This maximisation of movement of people is done by encouraging people to use high-capacity modes of transport such as ridesharing when commuting. According to Kim and Park (2018), HOV lanes aim to reduce the hours people spend on congested corridors by providing carpool drivers with incentives such as reliability in travel times. Ridesharing vehicles may however use both the GP lane and the HOV lanes. The number of solo drivers and ridesharing vehicles will therefore decrease in the GP lane with the introduction of HOV infrastructure. A study conducted by Javid et al. (2017) also indicates that HOV lanes increase carpooling after factoring in cost related variables. Figure 2-5 below indicates how travel cost decreases as the capacity of the HOV lane increases.

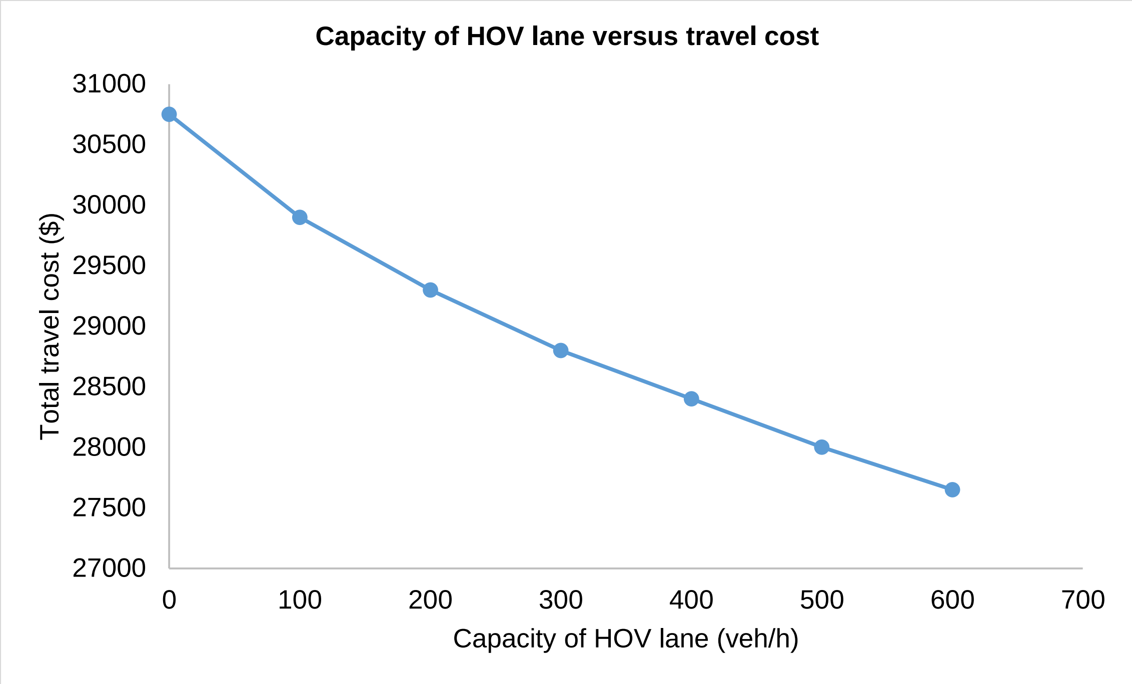


Figure 2-5: *Capacity of HOV lane versus travel cost*

(Li et al., 2020)

2.3.3 The possibility of introducing HOV Infrastructure to mid-size cities in South Africa (Bloemfontein)

According to Baffi, Turok and Vacchiani-Marcuzzo (2018) Johannesburg, Pretoria, Durban and Cape Town are the major cities of South Africa. Despite being the Judicial capital of South Africa, Bloemfontein together with Port Elizabeth and East London are considered to be the country's major secondary cities. These cities have suffered a decline in their manufacturing industries and have been struggling to diversify their economies into other industries unlike the larger cities (Baffi et al., 2018). Figure 2-6 below shows the economic diversity as well as sizes of some of the cities of South Africa.

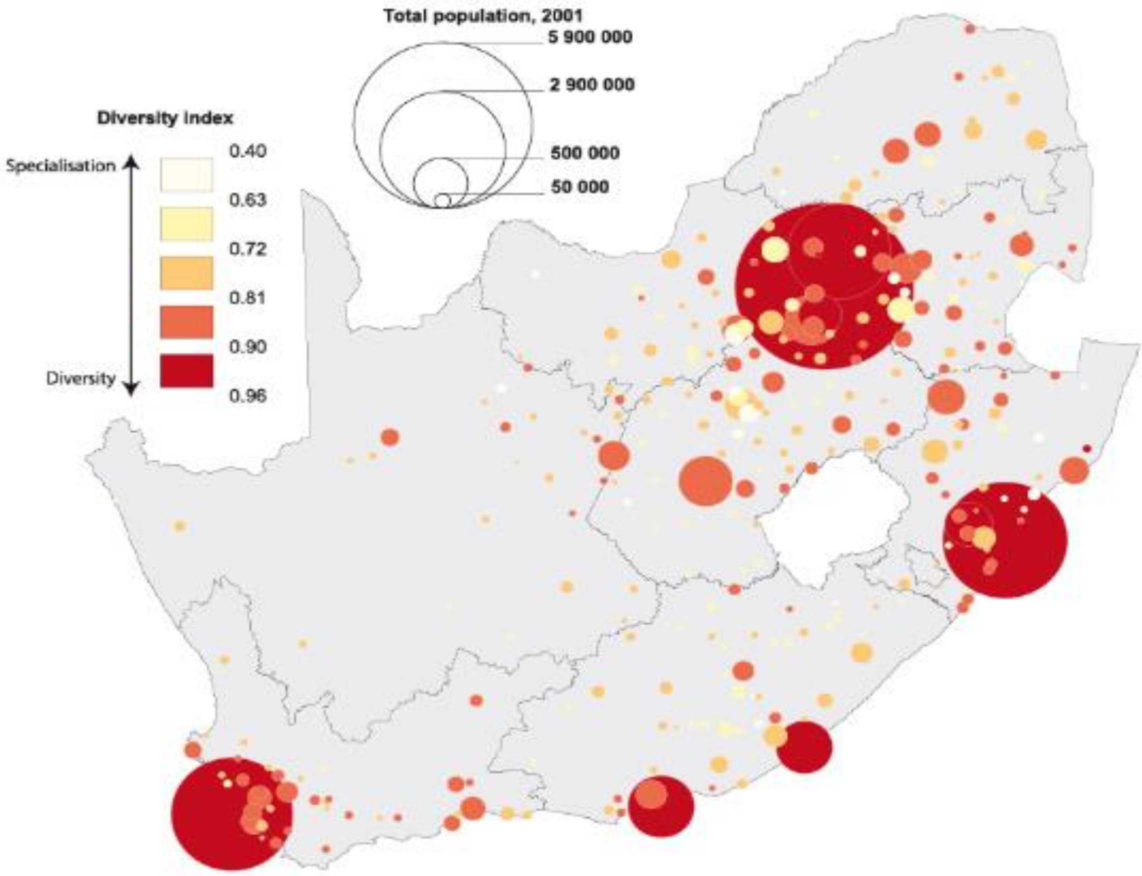


Figure 2-6; *Economic diversity and size of cities of South Africa*
(Baffi et al., 2018)

Baffi et al. (2018) notes that the South African economy has been underperforming in comparison to other middle-income countries when looking at key indicators such as exports, investment, competition innovation and productivity. Most South African cities have also been observed to be having poor economic performance in accordance with international standards. These cities suffer from high unemployment rates as well as levels of inequality and spatial differentiation due to the previous apartheid regime. Despite this, migration to urban areas in search for greener pastures continues to increase in South African cities putting a strain on the infrastructure and already strained resources.

Bloemfontein as a medium-sized city and the economic hub of Mangaung has experienced and continues to experience urbanisation as people from Botshabelo and Thaba Nchu move to the city for work, studies and other economic activities. This has made the need for sufficient transportation infrastructure and systems hard to ignore to accommodate the continuous population growth of the city (Feikie et al., 2018). Like most middle-sized cities, HOV lanes have previously not been planned for in Bloemfontein. This could however help in mitigating traffic congestion in the city by providing alternatives to road transportation. In addition to this, while other middle-sized cities have other means of commute Bloemfontein has no rail transportation for local trips. This is illustrated by table 2-1 below which shows Mangaung metropolitan has the second highest private vehicle usage percentage after Nelson Mandela Bay. Table 2-2 shows that the main reason people do not use taxis is simply because they prefer using a private vehicle. The MMM is among the top three metros in which commuters would rather stick to private transportation. This is why it is crucial to introduce HOV infrastructure to Bloemfontein to mitigate the traffic congestion that occurs as a result of this.

Table 2-1: *Ways people commute in different metros*

(van Ryneveld, 2018)

	JHB	TSH	EKU	CCT	ETH	NMB	BCM	MAN	Total
Train	151000	105000	150000	335000	78000	4000	16000	0	839000
Bus	169000	146000	64000	181000	162000	46000	19000	48000	835000
Taxi	864000	484000	578000	370000	686000	136000	167000	123000	3408000
Public transport total	**1184000**	**735000**	**792000**	**886000**	**926000**	**186000**	**202000**	**171000**	**5082000**
Car	1169000	767000	651000	1009000	546000	225000	96000	130000	4593000
Walk	772000	439000	484000	656000	638000	209000	207000	220000	3625000
Other	34000	24000	16000	34000	15000	3000	1000	6000	133000
Private transport total	**1975000**	**1230000**	**1151000**	**1699000**	**1199000**	**437000**	**304000**	**356000**	**8351000**
Total	**3159000**	**1965000**	**1943000**	**2585000**	**2125000**	**623000**	**506000**	**527000**	**13433000**

Table 2-2: *Reasons for not using a taxi*

(van Ryneveld, 2018)

Area	Not available	Prefer train	Prefer bus	Prefer private transport	Can walk	Don't travel much	Service attributes	Other
Johannesburg	3.1%	1.5%	1.4%	36.8%	5.3%	4.4%	44.4%	3.1%
Tshwane	4.9%	1.6%	1.3%	38.7%	3.7%	6.2%	41.7%	1.9%
Ekurhuleni	6.3%	1.7%	1.0%	39.7%	7.6%	6.9%	36.0%	0.8%
Cape Town	4.1%	2.4%	2.3%	36.8%	7.0%	5.5%	40.1%	1.8%
Ethekwini	13.0%	1.4%	4.1%	39.3%	3.7%	5.5%	31.9%	1.1%
Nelson Mandela	1.0%	0.5%	3.4%	62.9%	6.5%	8.9%	16.2%	0.8%
Buffalo City	2.1%	0.5%	0.0%	44.0%	10.6%	12.5%	30.1%	0.3%
Mangaung	7.0%	0.5%	4.1%	43.8%	3.9%	4.1%	32.2%	4.5%
Metro	5.1%	1.7%	1.9%	39.0%	5.8%	5.8%	38.8%	1.9%
Urban	12.1%	0.3%	1.1%	35.5%	11.8%	8.1%	28.8%	2.3%
Rural	32.6%	0.1%	6.4%	10.6%	9.3%	15.1%	23.7%	2.2%
RSA	13.0%	0.9%	2.6%	32.0%	8.3%	8.4%	32.7%	2.1%
PTNG cities	5.4%	1.6%	2.0%	39.3%	5.9%	6.2%	37.8%	2.0%

Most of the growth in car ownership globally is projected to be in developing countries (Luke, 2018). Luke (2018) says that the number of households with cars in South Africa has grown from 22.9% in 2003 to approximately 28.3% in 2017. This growth in vehicle ownership has mostly been amongst the middle class. Vehicle ownership in South Africa has been seen as a symbol of success and hence most people prefer using private vehicles to cement their status in society. Table 2-3 below shows the rise in motor vehicle ownership over the years.

Table 2-3: *Number of registered motor vehicles from 2010-2015*
(Transport statistics bulletin, 2015)

Vehicle class	2010	2011	2012	2013	2014	2015
Motorcars	5596491	5654104	6110660	6376733	6620891	6845804
Minibuses	285992	286155	285859	289078	293758	298046
Buses	47342	47658	51687	54494	56814	59116
Motorcycles	327297	329698	355633	367245	368043	367138
LDV's - Bakkies	2000915	2017827	2152779	2228559	2303113	2379251
Trucks	325019	325938	342131	350503	359762	366479
Other & Unknown	216465	216782	224050	226620	230509	232408
Total	**8799521**	**8878162**	**9522799**	**9893232**	**10232890**	**10548242**
% Annual Change	**2.9%**	**0.9%**	**7.3%**	**3.9%**	**3.4%**	**3.1%**

Improving transportation delivery services forms part of the IDP for MMM. Part of this improvement to public transportation involves introduction of the BRT system which requires proper planning as well as HOV infrastructure. Wang et al. (2019) says that HOV infrastructure has been regarded as an efficient way to minimise delays in traffic movement. Unlike single occupant vehicles, vehicles with more than one occupant have an option of driving either on the GP lane or on the HOV lane. The proper location of the HOV lane to avoid congestion bottlenecks will result in reduced travel cost especially during morning commute (Wang et al., 2019). The use of dedicated lanes to public transportation and HOVs may significantly increase the carrying capacity of the freeway.

2.3.4 Incorporating HOV lanes into existing infrastructure

Planning must be done prior to introducing HOV lanes to existing infrastructure to ensure that vehicles on the HOV lanes are able to travel at high speeds without the lane being considered congested or underutilized (Javid, Xie, Wang, Yang, Javid, Salari, 2021). HOV lanes may be classified as separated which use physical barriers and solid lines or non-separated lanes which use broken lines to separate the HOV lane from the GP lane (Xiao, Wang, Schakel, Shladover & van Arem, 2017). Xiao et al. (2017) add that separated HOV lanes may cause bottlenecks at the entry and exit whereas non-separated HOV lanes allow for flexible weaving between the HOV lane and GP lane.

The type and number of lanes to be used as HOV lanes may determine the traffic volumes and efficiency of the lanes (Javid et al. 2021). HOV lanes are usually located in the inner lanes of the freeway. Design of HOV lanes has to be in accordance with design manuals and should incorporate the lane itself, its auxiliary facilities, direct connector, ramps and local obstructions. State Departments shall help in standardizing signboards, road markings, as well as design standards (Javid et al., 2021). Javid et al. (2021) states that failure to clearly distinguish the HOV lane from the GP lane may lead to misuse of the lane. See figure 2-7 and figure 2-8 below for some signage that may be used for HOV lanes.

Figure 2-7: *Examples of overhead signage for HOV lanes*
(Javid et al., 2021)

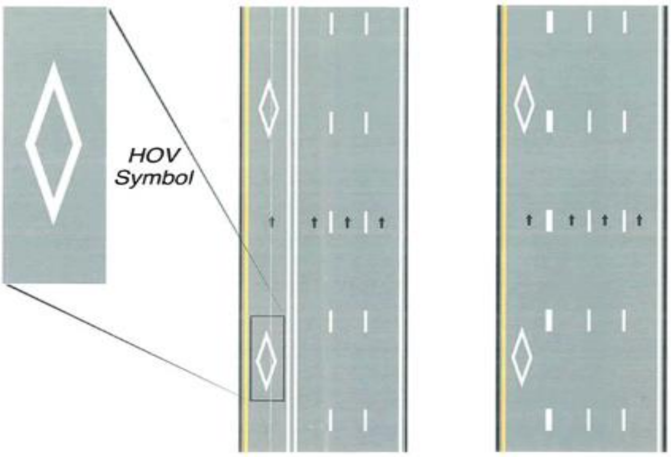


Figure 2-8: *Examples of pavement markings for HOV lanes*
(Javid et al., 2021)

Post incorporating of the HOV lane into existing infrastructure, performance monitoring should be done taking into consideration safety, vehicle volumes, level of service, impacts on the movement of people, modal shifts, reliability, travel time savings, operating speed and the environment (Javid et al., 2021). Javid et al., (2021) says that the public should be made aware of the new HOV lane and relevant authorities are to put enforcement measures in place for use of the HOV lane.

2.3.5 Will HOV infrastructure be enough of an incentive for ridesharing?

Even though introduction of HOV infrastructure may be an incentive for ridesharing, more incentives may be brought forward to increase vehicle occupancy. According to Javid et al (2021) the ability of HOV infrastructure to assist in traffic congestion reduction is dependent on specific traffic conditions. Hajhashemi, Lavieri and Nassir (2022) add that HOV lanes may reduce the average travel time but need to work with other policies such as multi-modal trips and travel behaviour. Poole (2020) states that the first HOV lanes in United States of America (USA) were used for buses and later vanpools and carpools as buses only used a fraction of the lanes even at peak times. Researchers later discovered that vehicles having 2 occupants using HOV lanes were not necessarily commuters sharing work related trips but rather families travelling together to take advantage of the faster lane. Family-pools made 75% of all journey to work carpools in 1990 and 83% in 1991 (Poole, 2020). Poole (2020) proceeds to mention that as HOV infrastructure expanded vanpools declined which might be due to dispersal of jobs in the suburbs. Hajhashemi et al. (2022) allude that privacy and detours for pick-ups and drop-offs may be hindrances to ridesharing. Literature has suggested more incentives such as occupancy-based congestion pricing and reduced fares as incentives for ridesharing (Hajhashemi et al., 2022).

2.4 RIDESHARING

2.4.1 Definition of ridesharing

Ridesharing comes in two forms which are carpooling and ride-pooling (Zhong, Zhang, Nie and Xu 2020). Carpooling is when the journey fulfils the driver's needs and the driver shares the same destination and travel costs with the rider whereas ride-pooling is whereby the driver is just a mobility service provider. Car-sharing systems involve a pool of cars that are shared among a set of users, who are usually known in advance (Enzi, Parragh and Pisinger 2020). Carpools can consist of a minimum of two people whereas vanpools carry between six to fifteen people (Cetin & Deakin, 2019). Vanderschuren and Baufeldt (2018) say that ridesharing is part of a broader concept known as 'sharing economy' and also that ridesharing fills the transport demand that was previously not served or was not served well. Ridesharing has therefore been considered an environment and society friendly means to solve several road traffic problems (Li et al., 2018).

Masoud and Jayakrishnan (2017) state that informal ridesharing is one of the first and common trip sharing methods used and may include examples such as parents taking turns in taking their kids to school and colleagues sharing a vehicle to work. In this type of ridesharing drivers own the vehicles and have personal interest in the trips taken with the added incentive of using carpool lanes (Cetin and Deakin, 2019). Transport Networking Companies (TNCs) such as Uber are the recent shared-use mobility alternatives but are not sustainable as they add to the problem of congestion and air pollution due to the empty trips required to pick up passengers. Peer-to-peer (P2P) ridesharing aims at capturing the benefits of TNCs while alleviating their adverse impact on the environment and transportation infrastructure (Masoud and Jayakrishnan, 2017).

Dynamic ridesharing works for people who do not want to commit to regular ridesharing but are willing to occasionally share a ride (Cetin and Deakin 2019). Dynamic ridesharing also requires drivers and riders to be flexible in terms of their departure and arrival times (Liang et al., 2020). To gain benefits from carpooling, a public policy may encourage travellers to discard certain travel comfort requirements, such as sensitivity to travel time to carpool with others and improve city traffic conditions (Li et al., 2018). Li et al. (2018) states that the waiting pick-up time for a carpool in a middle-sized city should not be too long.

2.4.2 Benefits of ridesharing

Ridesharing allows for travel time and travel costs reductions of both the drivers and passengers through drivers sharing empty seats in their vehicles with others who have similar itineraries and mitigating inner city congestion and environmental problems (Aïvodji, Huguenin, Huguet and Killijian 2018; Cheng, Liu, Liu and Jia, 2017. Daganzo and Ouyang, 2019, Yu, Tang and Chen 2017; Nikitas, Kougias, Alyavina, Njoya Tchouamou 2017; Li et al., 2018). Li et al. (2018) states that carpooling can be used as a way to alleviate city congestion. In a study conducted in China, ridesharing proved that it could reduce traffic congestion by an average of 30% and 24% in the morning and afternoon commute respectively.

Zhong et al. (2020) says ridesharing reduces vehicle miles travelled, minimises traffic congestion and users get to enjoy the benefits of using HOV lanes. The large capacity of the HOV lane brings benefits such as boosting the welfare of commuters and promoting carpooling. Shiraki et al. (2020) also states that to reduce vehicular emissions, it is important to increase the occupancy of vehicles through ridesharing. Light duty vehicles are found to emit more carbon emission than other land modes of transportation which are trains and buses hence the importance to shift to transportation modes with lower carbon emissions.

Graf (2017) adds that ridesharing services provide an alternative to public transportation where there is a gap by providing affordable transportation in traditionally undeserved often dangerous neighbourhoods. Stiglic, Agatz, Savelsbergh and Gradisar (2016) add that dynamic ride sharing is more convenient than public transportation yet much cheaper than taxis.

2.4.3 Performance of a ridesharing system

The performance of a ridesharing system is an important factor to motivate people to use the service (Najmi, Rey and Rashidi 2017). The matching rate, total vehicle-distance savings, total travel time savings and total finalisation time are some of the measures to rate the performance of a ridesharing system. A flexible ridesharing system should be able to provide optimal matching solutions for drivers and riders in a short period of time based on their trip information (Stiglic et al., 2016; Masoud and Jayakrishnan, 2017). Stiglic et al. (2016) states that a successful ridesharing system requires a lot of people to be enrolled to it and therefore people should be given incentives. Li et al. (2018) adds that when implemented correctly and at a large scale, carpooling may significantly mitigate traffic congestion. HOV infrastructure may therefore be used as an incentive to get more people using ridesharing.

2.4.4 How can ridesharing be motivated

Cetin and Deakin (2019) state that ridesharing programs designed to encourage commuters to ride together are supported by park and ride facilities as well as HOV infrastructure designed to bypass congestion points. Cetin and Deakin (2019) continue to state that some travellers are not for ride sharing as they believe it is not flexible and therefore users of the service are a small fraction, and most ridesharing happens between family members. Javid et al. (2017) states that carpooling could reduce vehicular emissions in various cities. Income, household size and the number of vehicles per household distinguish between solo drivers and car-poolers (Javid et al., 2017).

2.4.5 Tools and techniques to connect private vehicle users

Numerous ways may be used to connect drivers and passengers in order to facilitate ride-sharing which include apps and social media. Aïvodji et al., (2018) conducted a study which aims not only at connecting drivers and riders but also at privacy preservation. In this study, a prototype named 'SRide' was developed and implemented which worked in four steps. This prototype firstly generalises the spatiotemporal data of users; then it securely filters the data to locate possible matches; it then computes the meeting points for drivers and riders using a privacy protocol and lastly assigns drivers and riders based on their ride sharing score (Aïvodji et al., 2018).

According to Tang et al., (2019), social media may be used to connect drivers and riders and helps to bridge the ridesharing gap in various ways. Social media seeks transport information and detects hazards and incidents that have occurred or are planned for a specific road network; it may identify friends, as well as the demographics and interests of people and use that information to pair them; it analyses the driving behaviour with regards to fuel economy, times, stops and purpose; it determines the origins and destinations, and availability of space in the vehicle; and also finds the best route between pick-up and drop off points, departure times and travel costs.

Tyagi, Sharma, Bansal and Rawat (2022) suggest that a ridesharing system should have users and a proposed system. The users are the drivers and passengers whereas the proposed system comprises of the system admin, database and server. In this system the user shall send their request; the admin checks the eligibility of that request; the driver will set the starting time of the trip and availability of seats; the passenger will in response to this send the pick-up time and location after which the system will determine the best match and availability of seats will decrease as its match is made. This is illustrated by figure 2-9 below.

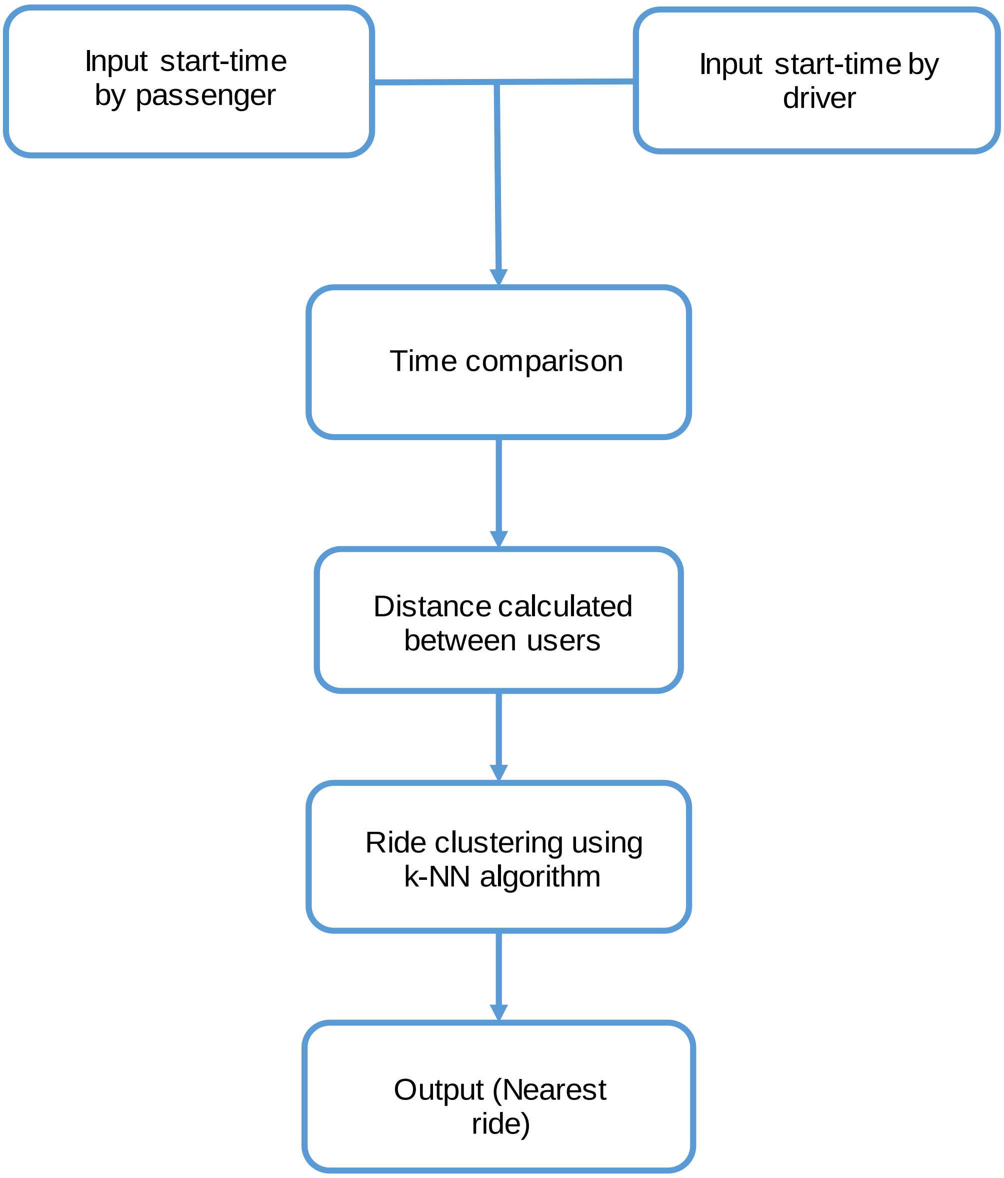


Figure 2-9 Proposed ridesharing system
(Tyagi et al., 2022)

2.5 EXISTING TRANSPORT POLICIES IN SOUTH AFRICA AND MMM

White Paper on National Transport Policy (2021) states some of the existing transportation policies meant to reduce traffic congestion in South Africa. These policies include reducing the demand for travel by single occupancy vehicles; diversifying transportation options; integration of land use and transportation planning; congestion mitigation in urban areas; and shifting of passenger transport from private to public transportation. Some of the policies suggested by Burger (2019) in the research for a sustainable transportation system in MMM include changing the commuter's transportation mode of preference; promoting the safety of commuters; educating commuters with regards to transport related matters; and collaboration between transportation and spatial planners.

2.6 CONCLUSION

- The worldwide rural-urban migration has resulted in high populations in urban areas as well as the continuous increase of vehicles putting pressure on the existing road infrastructure.
- Traffic congestion is the way movement of vehicles is delayed due to the carrying capacity of roads being exceeded. Traffic congestion takes place mostly in the mornings as people commute from their homes to work and back in the afternoons and is more prevalent in developing countries.
- The continuous urbanisation in South Africa calls for transportation systems to be put in place for effective mobility. Growing car ownership due to population increases, increase in the number of trips and income has resulted in the existing infrastructure being inadequate and an unsustainable transportation system.
- Higher levels of urbanisation, population growth, unsatisfactory public transportation, high vehicle ownership, dispersed urban form, lack of accessibility of non-motorised transportation modes and low occupancy of private vehicles are some of the factors which cause traffic congestion.
- Traffic congestion results in delays, high fuel consumption, decrease in productivity, air pollution as well as increase in the number of road accidents.
- Traffic congestion may be mitigated in a number of ways which include modal shift from private transportation to public transportation and non-motorised transportation; improving or expanding the existing road infrastructure; and ridesharing.
- HOV lanes are lanes designated for use by vehicles carrying more than one occupant. These lanes move large numbers of people with much less vehicular volumes. HOV lanes aim to reduce traffic congestion on the roads by providing drivers who carpool with incentives such as reliable travel times and reduced travel costs through the use of HOV lanes.
- Bloemfontein as a medium-sized city has experienced a decline in the manufacturing industry over the years and has been struggling to diversify its economy. in addition to this, most South African cities have been observed to have poor economic performance when graded using international standards.

This means that there is not much at disposal and therefore cost-effective ways like HOV infrastructure may be used to mitigate traffic congestion in the city.

- As the economic hub of Mangaung metro, Bloemfontein continues to experience rapid urbanisation from the surrounding areas of Botshabelo and Thaba Nchu causing high traffic volumes. Despite this, HOV lanes which could help mitigate this congestion have not been planned for Bloemfontein as well as most middle-sized cities. In addition to this, unlike most middle-sized cities, Bloemfontein has no rail transportation for commuters and could use some diversification in road transportation.
- Vehicle ownership in South Africa has been seen as a symbol of success and most people prefer using private vehicles to public transportation. The introduction of HOV infrastructure to middle sized cities could be an incentive for drivers to carpool.
- HOV infrastructure wont only motivate people to carpool but also provide infrastructure support for the roll-out of the BRT system. This will in turn increase the carrying capacity of the freeway.
- HOV lanes can be separated or non-separated and should be designed in a way that allows vehicles to travel at a high speed without being regarded as under-utilised or over-utilised. The type and number of HOV lanes to be used may be determined by traffic volumes and efficiency and clear markings are to be made to distinguish the HOV lane from the GP lane to avoid misuse.
- Introduction of HOV lanes is not enough of an incentive to convince commuters to rideshare and more incentives may be brought forward such as multi-modal trips, travel behaviour, occupancy-based congestion pricing and reduced fares.
- Ridesharing may be classified as carpooling where the driver shares the same needs as the customer and ride-pooling whereby the driver is just a mobility service provider. Ridesharing allows for decrease in travel cost, time, vehicular miles travelled, less congestion and minimised air pollution. Users of a ridesharing system also get to enjoy the benefits of using the HOV lane to bypass congested points. Ridesharing also fills the gap in public transportation where there is a need. An optimum ridesharing system needs to be able to provide a match in a short period of time and it therefore works best when a lot of people have enrolled to the system. Facilities such as HOV infrastructure and park and ride facilities may be used to encourage ridesharing.
- Drivers and passengers interested in ridesharing can connect through digital and non-digital techniques. Non-digital includes already existing personal and professional relationships whereas digital techniques include apps and social

media. Studies have been done to protect the privacy of the users of ridesharing apps. Social media has also been used to bridge the gaps in ridesharing. A ridesharing system should have passengers and drivers input their departure times, origins, destinations and lastly time and distance comparisons done to match drivers and riders to the nearest ride.

- The next chapter sheds light on the profile of the study area selected for this particular study which is Bloemfontein. The demographic profile, health and education structures, economy, basic infrastructure and housing, urban form, transportation and HOV infrastructure are discussed to justify why Bloemfontein was best suited to be the study area.
- Some of the existing transportation policies include integrating land use and transportation planning, shifting from single occupancy vehicles, congestion mitigation and educating commuters on transportation related matters.

CHAPTER 3. PROFILE OF THE STUDY AREA

3.1 INTRODUCTION

The purpose of this chapter is to provide an overview of the study area, Bloemfontein. This is done to understand the history of the area and how that has affected the way things are presently in terms of the land use, individual preferences and the transportation. An insight into Bloemfontein may also help in determining how the performance of HOV infrastructure may be improved to alleviate city congestion. The high car ownership and people choosing to commute to work alone in their private automobiles has resulted in rampant congestion growth. HOV infrastructure has been deemed as one of the many solutions to mitigating this problem. A better comprehension of this may be drawn after determining the socio-economic, demographic, ecological, environmental, transportation infrastructure and land use factors of Bloemfontein.

3.2 GENERAL OVERVIEW OF THE STUDY AREA

Bloemfontein is the capital of the Free State province as well as the judicial capital of South Africa. The city is believed to have been established in 1846 by a British army major and has grown over the years from a farm to an urban area now boasting over 30 suburbs. Bloemfontein has been poetically named the 'city of roses' because of its abundance of roses and also named 'Mangaung', a Sesotho name meaning a place of cheetahs. It is the sixth largest city in the country and centrally located in South Africa at 29.08° S, 26.15° E, lying at an elevation of 1395 m above sea level. The Free State has the North West province, Gauteng and Mpumalanga bordering it in the north; Kwazulu-Natal and Lesotho in the east; Eastern Cape in the South; and the Northern Cape on the west. In addition, Bloemfontein has the N1 bypassing it on the west, N8 running from east to west and the N6 running southwards. The city forms part of the MMM and covers an area of approximately 236.17 km^2.

Mangaung is generally flat with occasional hills and Highveld grassland. Bloemfontein has a semi-arid climate with cold summers and cold dry winters often with frost. The temperatures range between 15˚C and 31˚C in summer whereas temperature ranges for winter are between -2˚C and 17˚C as shown in Figure 3-3. Figure 3-1 below shows the location of the Free State in relation to other provinces whereas Figure 3-2 shows the national roads passing through Bloemfontein.

Figure 3-1: *Location of the Free State in relation to other provinces*

(Britannica, T. Editors of Encyclopaedia)

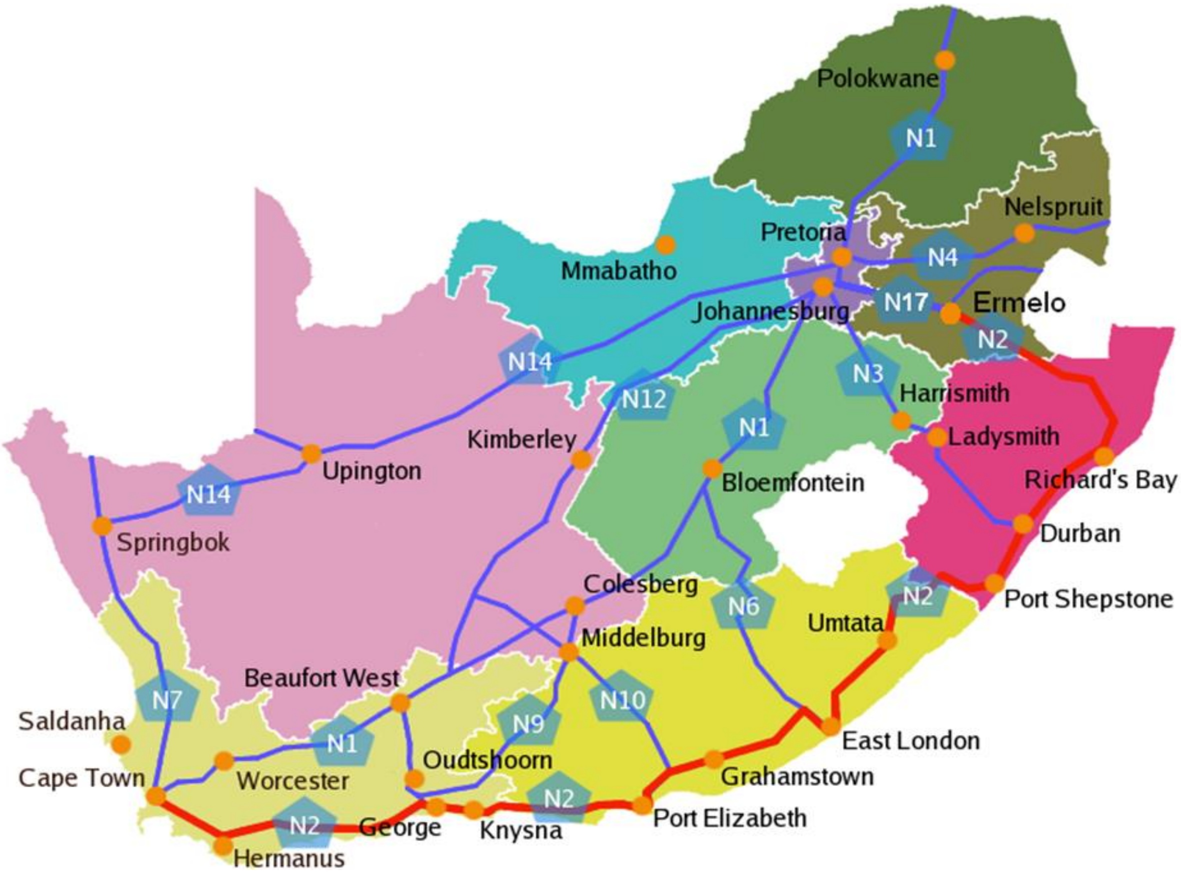


Figure 3-2: *National roads passing through Bloemfontein*

(File: South Africa roads N2.png.)

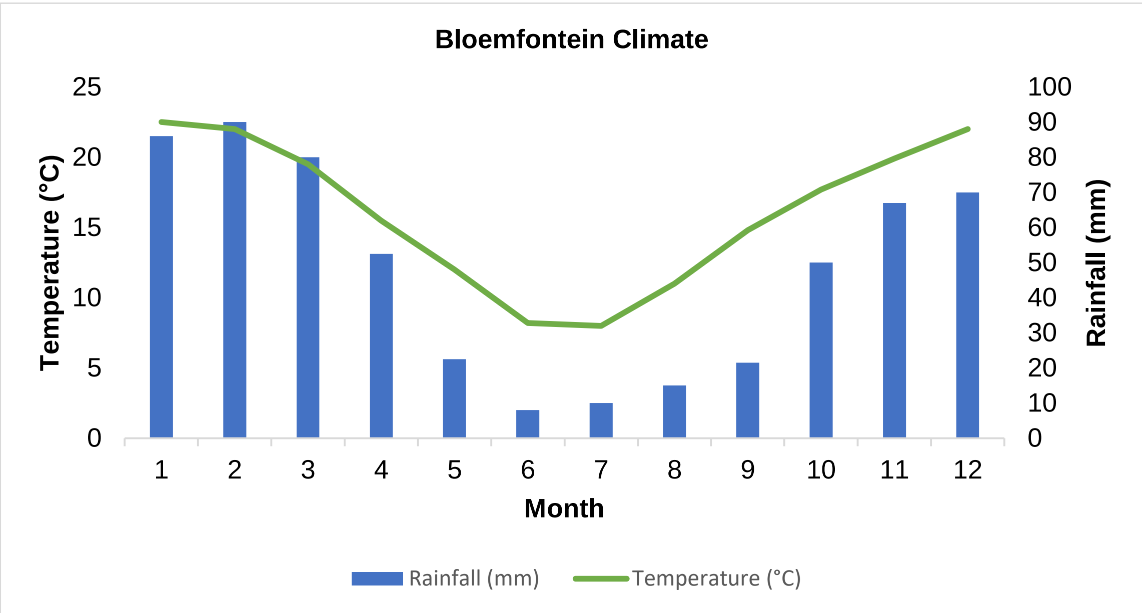


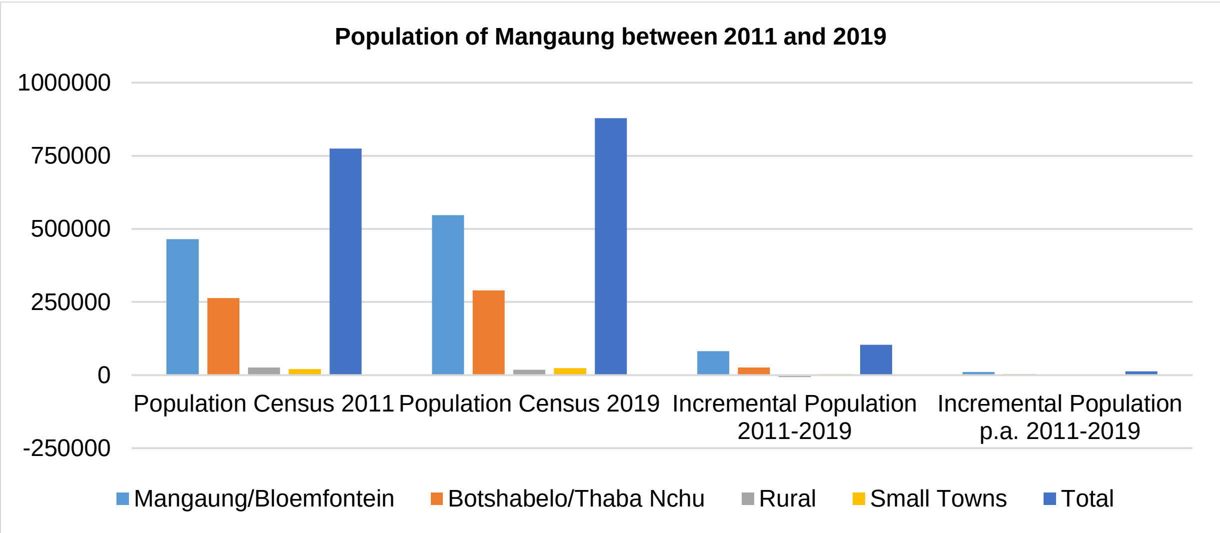
Figure 3-3: *Bloemfontein climate*

(Climate-Data.Org)

3.3 DEMOGRAPHIC PROFILE

3.3.1 Population and density of the study area

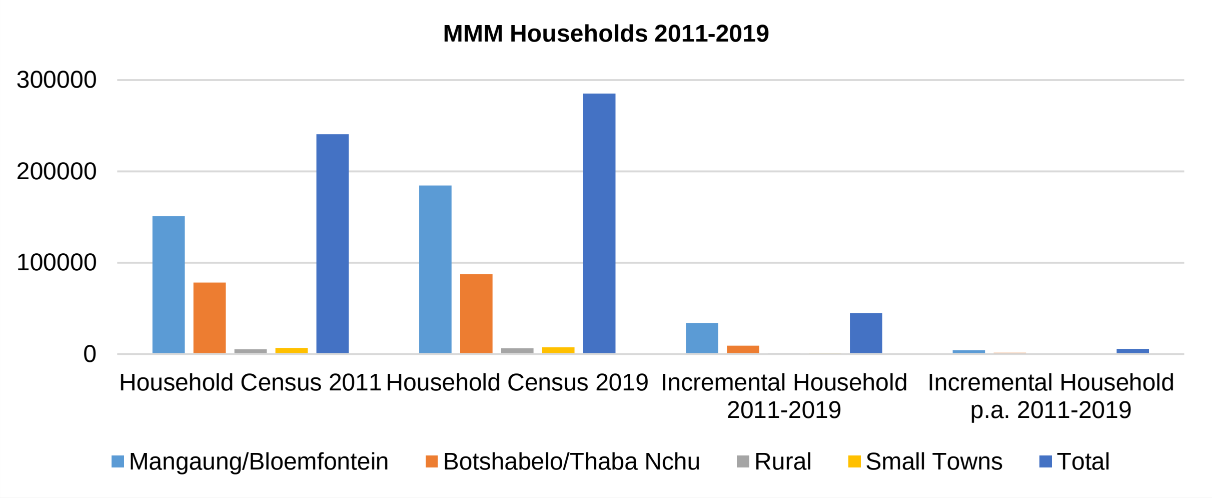
The mid-year population estimates for the Free state in July 2019 were 2 887 465 which is approximately 5% of the South African population (Statistics South Africa, 2019). The MMM had a population 878 834 people in 2019 representing 28% of the provincial population. Bloemfontein represents 62% of this with a population of 546 568 and the highest annual population increment of 2% per annum between 2011 and 2019. This has in turn resulted in an increase in the number of households in the metro which are now estimated to be 285 385. 65% of these households are located in Bloemfontein followed by Botshabelo and Thaba Nchu at 31% and 3% respectively. This is illustrated below (see Figure 3-4 and Figure 3-5).



	Population Census 2011	%	Population Census 2019	%	Incremental Population 2011-2019	Incremental Population p.a. 2011-2019	% Growth p.a. 2011-2019
Mangaung/Bloemfontein	464586	60	546568	62	81982	10248	2,2
Botshabelo/Thaba Nchu	263853	34	290055	33	26202	3275	1,2
Rural	25795	3	18515	2	-7280	-910	-3,5
Small Towns	20794	3	23696	3	2902	363	1,7
Total	775028	100	878834	100	103806	12976	1,6

Figure 3-4: *Population of Mangaung between 2011 and 2019*

(MMM Draft Reviewed Integrated Development Plan, 2020/2021)



	Household Census 2011	%	Household Census 2019	%	Incremental Household 2011-2019	Incremental Household p.a. 2011-2019	% Growth p.a. 2011-2019
Mangaung/Bloemfontein	150713	62,6	184560	64,7	33847	4231	2,8
Botshabelo/Thaba Nchu	78142	32,5	87334	30,6	9192	1149	1,5
Rural	5203	2,2	6059	2,1	856	107	2,1
Small Towns	6575	2,7	7432	2,6	857	107	1,6
Total	240633	100	285385	100	44752	5594	2,3

Figure 3-5: *Mangaung households 2011-2019*

(MMM Draft Reviewed Integrated Development Plan, 2020/2021)

Mangaung has seen consistent increase in population density from 67 people per km² in 1996 to 80 people per km² in 2018. This increase has been due to the continuous migration of people from the surrounding towns, villages and settlements to Bloemfontein in order to access services which are only available in the city, work, study and running businesses. This is shown in table 3-1. The highest population density lies in the eastern quadrant of the city where the previously marginalised communities reside and population densities are much lower in the suburbs.

Table 3-1: Population density of Mangaung

Name	Type	Seat	Area	Population	Density
		Administrative center	*Square kilometers*	*Number of people*	*People per square kilometer*
Mangaung	Metropolitan	Bloemfontein	9886	787803	80
Fezile Dabi	District	Sasolburg	20668	494777	24
Lejweleputswa	District	Welkom	32287	646920	20
Thabo Mofutsanyana	District	Phuthaditjaba	32734	779330	24
Xhariep	District	Trompsburg	34250	125884	4

3.3.2 Gender and age structure of Bloemfontein

According to Statistics South Africa (2019) 1 392 563 (48.2%) of the Free State population are male whereas 1 494 903 (51.8%) are females. Age groups 5-9 years are the major contributors of the Free State population at 9.9% followed by 10-14 years and 0-5 years at 9.7% and 9.3% respectively. The least contributors are the elderly (80+) contributing 1% to the Free State population. This is illustrated by Figure 3-6 and Table 3-2 below. 58.8% of people living in the Free State fall between the age brackets of 20-69 years. These comprises of university students, workers, business owners and the just retired who usually have active lifestyles which require them to move around a lot. People in this age bracket are also the bulk of people who own vehicles and are therefore major contributors to the daily vehicular volumes on the roads.

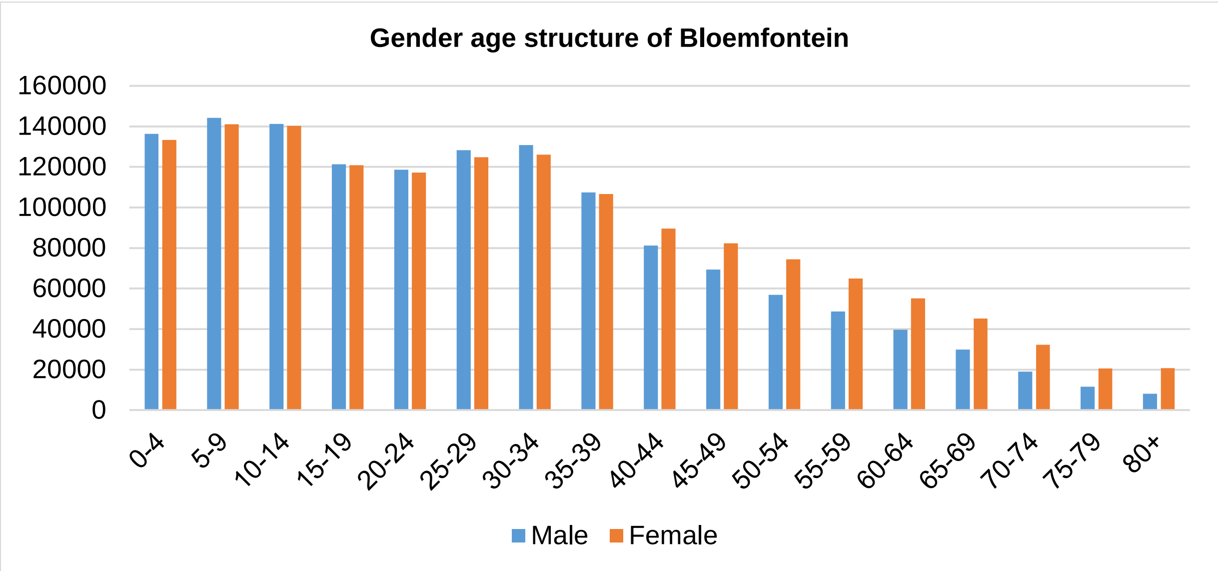


Figure 3-6: *Gender age structure of Bloemfontein*

(Statistics South Africa - Mid-Year Population Estimates, 2019)

Table 3-2: *Percentage of each age group in the Free State*

Age	Male	Female	Total No. of People	Percentage
0-4	136294	133271	269565	9,3%
5-9	144196	141022	285218	9,9%
10-14	141172	140166	281338	9,7%
15-19	121277	120753	242030	8,4%
20-24	118601	117186	235787	8,2%
25-29	128282	124777	253059	8,8%
30-34	130754	126043	256797	8,9%
35-39	107408	106692	214100	7,4%
40-44	81233	89539	170772	5,9%

45-49	69390	82226	151616	5,3%
50-54	56816	74335	131151	4,5%
55-59	48714	64995	113709	3,9%
60-64	39702	55203	94905	3,3%
65-69	29954	45139	75093	2,6%
70-74	19052	32183	51235	1,8%
75-79	11560	20602	32162	1,1%
80+	8158	20771	28929	1,0%
Total	1392563	1494903	2887466	100

3.4 SOCIAL FUNCTIONS: EDUCATION AND HEALTH STRUCTURES

In 2015, the literacy levels in South Africa stood at 94.37% meaning almost 95% of the population can read and write. Males lead at 95.4% while the literacy levels of women in the country was 93.41% (Statista, 2019:online). Bloemfontein has two universities, namely the University of the Free State and Central University of Technology which have a combined population of approximately 50 000 students. The majority of the residential areas in the city have a primary school and/or a high school which contribute to the high literacy rates in the city.

Statistics South Africa (2019) reports that the life expectancy at birth for females in South Africa is 67.7% whereas that for males is 61.5%. The life expectancy at birth for males in the Free State is reported to be 54.6% whereas that for Females is reported to be 61.3%. Life expectancy had significantly declined between 2002 and 2006 largely due to the prevalence of HIV and AIDS but the introduction of health programmes to prevent mother-child transmission and antiretroviral treatment has led to an increase in life expectancy. Figure 3-7 below shows how life expectancy has increased over the years. Bloemfontein has three public hospitals, three private hospitals as well as thirteen clinics which provide health services to the people residing in the metro.

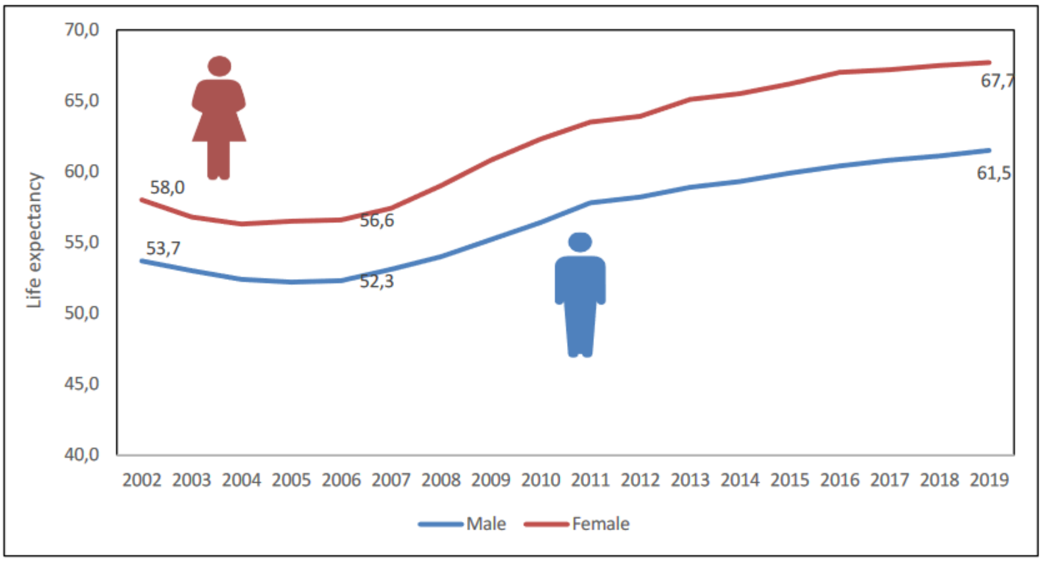


Figure 3-7: *Life expectancy by sex over time, 2002-2019*

(Statistics South Africa - Mid-year Population Estimates, 2019)

3.5 ECONOMY

The Free State is the second least contributor to the South African economy having contributed only 5% to the country's economy in 2017 as illustrated by figure 3-8. Gauteng is the highest having contributed about a third (34%) to the country's gross domestic product (GDP) whereas the Northern Cape contributed the least (2%) (Statistics South Africa, 2019: online). The Free State is best known for its agricultural and mining sector. MMM is the biggest GDP contributor in the Free State province and is regarded as one of the most diverse economies with Bloemfontein as the economic hub of the metro (MMM Integrated Development Plan, 2018/2019). The economy Bloemfontein is driven by government services, trade, finance, transport, agriculture and mining as shown in Figure 3-9 below.

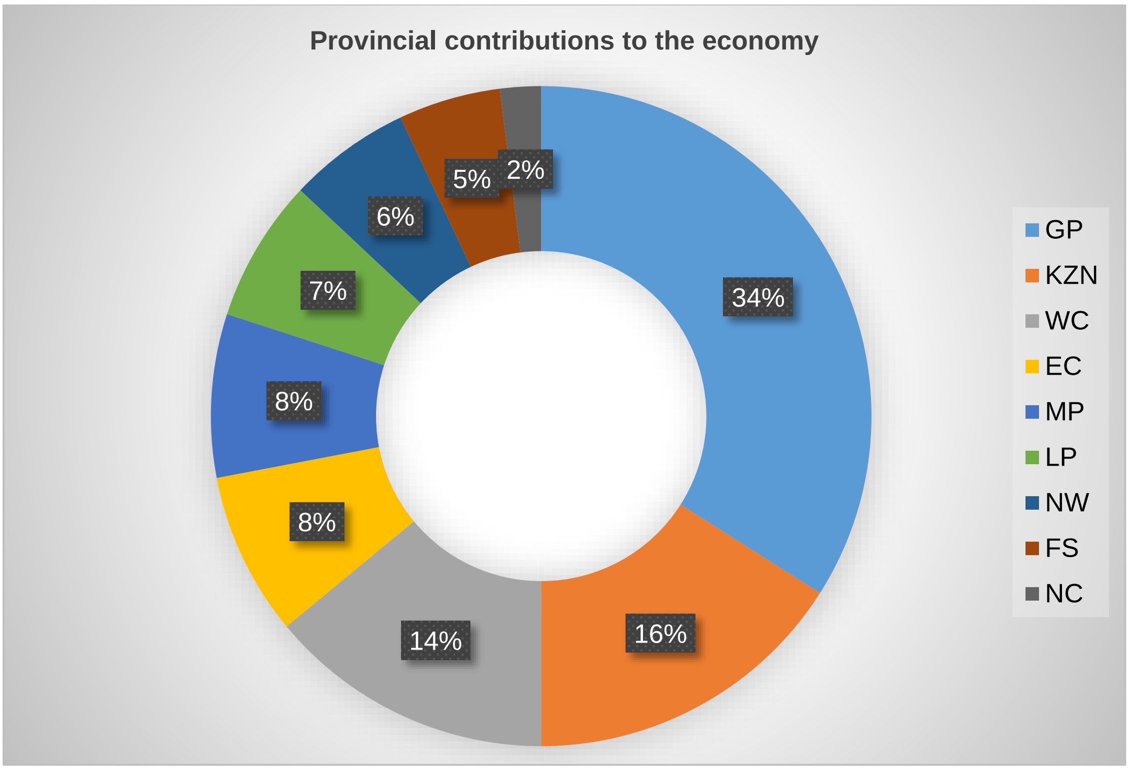


Figure 3-8: *Provincial contributions to the economy*

(Statistics South Africa, 2018)

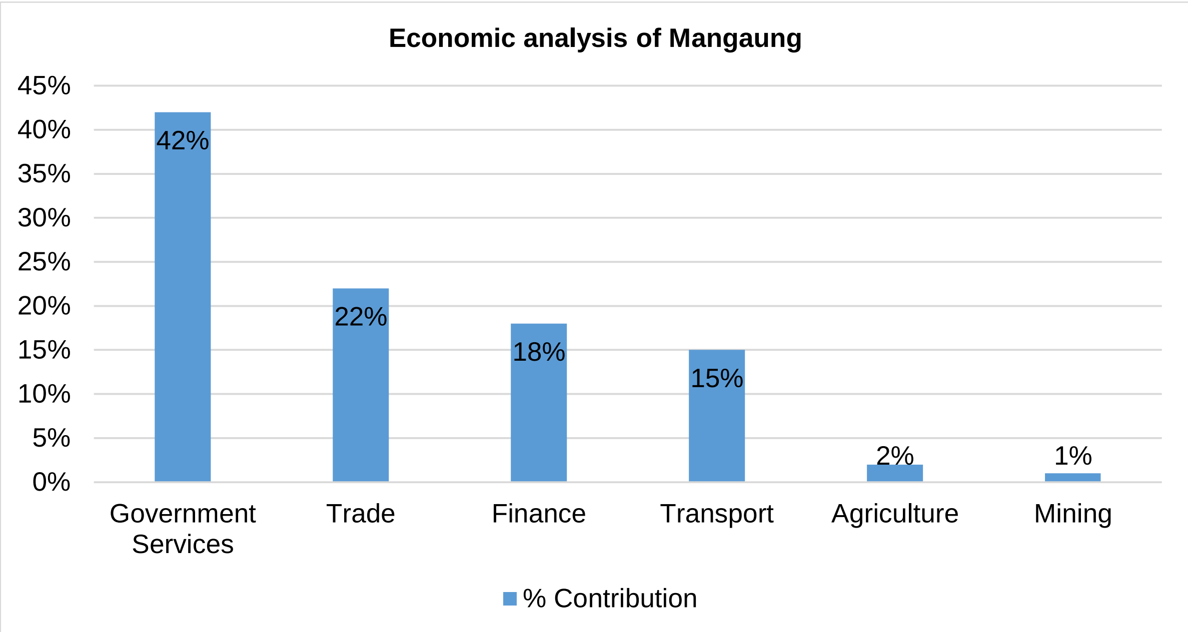
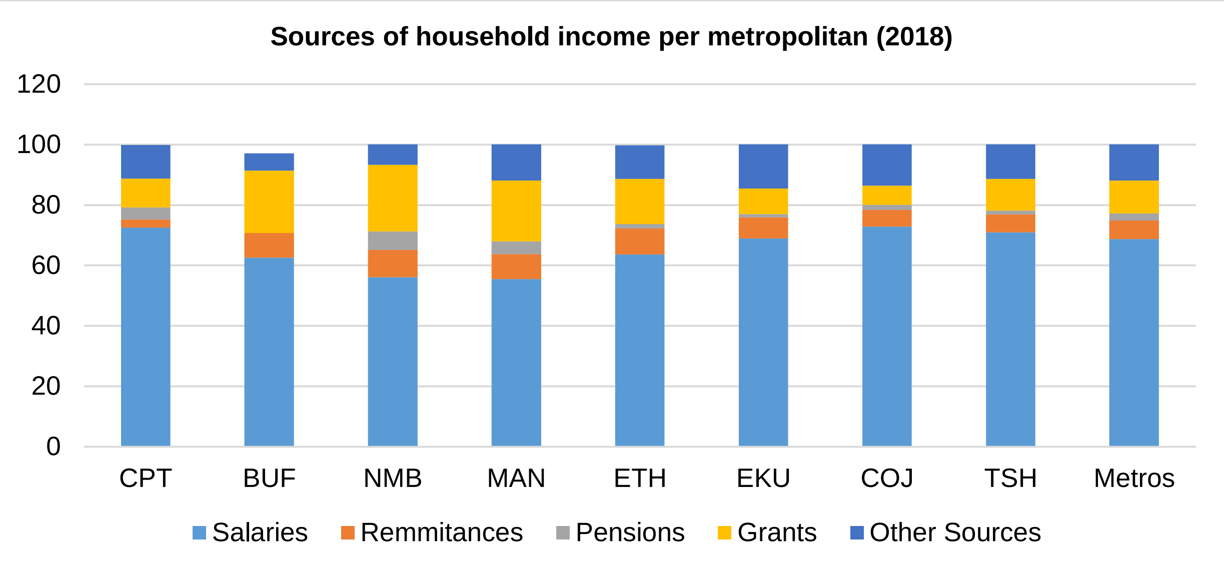


Figure 3-9: *Economic analysis of Mangaung*

(MMM Draft Reviewed Integrated Development Plan, 2020/2021)

3.5.1 Household Sources of Income

The main source of income in the MMM as shown by Figure 3-10 below is salaries with over half (55.5%) of the households in Mangaung being dependent on salaries. 20.1% of the households get their income from grants, 8.3% from remittances, 4.2% from pensions and the remaining 12% from other sources such as rental, business, sales of farming products and other services.



	CPT	BUF	NMB	MAN	ETH	EKU	COJ	TSH	Metros
Salaries	72,6	62,6	56,1	55,5	63,7	69	72,9	71	68,7
Remmitances	2,6	8,2	9	8,3	8,5	6,9	5,5	5,9	6,2
Pensions	4	0	6,2	4,2	1,5	1,1	1,7	1,3	2,3
Grants	9,6	20,6	22	20,1	15	8,5	6,3	10,5	10,9
Other Sources	11,1	5,7	6,8	12	11,1	14,6	13,7	11,4	12

Figure 3-10: *Sources of household income per metropolitan area in 2018*

(Statistics South Africa-General household survey, 2018)

3.5.2 Economic Segregation

Bloemfontein is developed around the CBD in a concentric sectoral form. The majority of the poor and previously disadvantaged communities live in the south eastern section and the north/south railway line creates a definite barrier between communities. This has distanced the poor from the economic opportunities that are mainly concentrated to the west of the railway line. Industries flank the previously disadvantaged areas and offer few job opportunities to these people while the majority have to travel up to 15km to get to the city centre.

Recently, there has been a significant transfer of services out of the Bloemfontein CBD and into the suburbs, particularly to the west, which has led to under-utilised office space in the CBD. Manufacturing is also declining in the city, which is a matter of concern (MMM Independent Development Plan, 2018/2019).

3.6 BASIC INFRASTRUCTURE AND HOUSING

The basic infrastructure facilities found in the study area include roads, railway line, airport, housing, portable water supply, electricity, telecommunication, sanitation, refuse removal and recycling. According to the General Household Survey (2018) 85.2% of the population of the Free State resides in formal dwellings; 91.1% have access to piped/tap water in their dwellings; 85.5% have access to improved sanitation; and 74.8% have their household refuse removed at least once a week. 58% of the dwellings in Bloemfontein are stand-alone houses for the occupation of single families whereas 42% are apartment flats, townhouses, duplexes and group houses.

3.7 URBAN FORM

Urban form is the relationship between land use and the urban patterns. Each area in the city differs with others in terms of their urban functions as well as unique characteristics. This section is meant to give a better comprehension of the different urban forms in Bloemfontein.

3.7.1 Urban Patterns

The original structure of Bloemfontein is centred around a strong CBD with numerous arterial roads converging there from different areas of the city. This structure accommodated a variety of different sectors and by so doing integrating opportunities. In the recent years, the western areas of Bloemfontein have experienced the most growth with major offices and retail development in the Brandwag area and more developments planned in Langenhovenpark and its surroundings. This shift to the western areas will result in an even less balanced city structure with significant traffic congestion while travel distances and time from some areas will increase, especially to and from the south-eastern areas in Bloemfontein and Botshabelo and Thaba Nchu further east. In addition to this, the infrastructure in place was not designed for high traffic volumes as few roads serve the area.

The history of apartheid in South Africa has left the country with skewed spatial patterns including Bloemfontein. This has led to the unequal distribution of resources, lack of opportunities in the disadvantaged areas and emphasis on the use of private transportation.

This limitation in economic activities in the townships forces the poor particularly blacks to travel far to access services, economic and employment centres. This has in turn led to congestion especially at peak hours when most people are moving in a similar direction.

3.7.2 Land Use

Of the three (3) urban nodes in the MMM, Bloemfontein is the primary activity node with activities ranging from retail, office, commercial and industrial activities clustered in a central core around the CBD. With the centre of the city comprising of the CBD, industries and commercial areas, most routes tend to converge in this area (MMM - Operation Plan – Phase 1 of IPTN, 2016). Economic activities in the CBD and high-income residential development are however relocating to the west. Bloemfontein is divided into 6 distinctive areas, namely the CBD, 4 quadrants, namely a north-eastern, south-eastern, south-western, and north-western quadrant, and the area beyond the urban edge/peri-urban area. Figure 3-11 below goes further to show the different suburbs in the city.

a) CBD: This area comprises of Westdene, University of the Free State and Universitas Hospital.

b) Northeastern Quadrant: This comprises of the north-eastern sector of Bloemfontein located between the Bloemfontein-Johannesburg railway line in the west and the Bloemfontein-Maseru railway line in the south; Buitesig and Ooseinde Industrial Area; the small-holding areas of Estoire, Roodewal, Olive Hill, Vaalbank Zuid, Bloemspruit and Shannon; Sunnyside area; Bloemfontein Airport and Bloemspruit Air Force Base

c) South-Eastern Quadrant: This is the area between Bloemfontein – Maseru railway line and the Bloemfontein – Cape town line. It comprises of the total Mangaung township area, Heidedal, the “old Corobrick” site, Hamilton industrial area, Ehrlich Park, the old Hamilton rifle range area, South Park Cemetery, the southern land fill site, smallholding areas of Ferreira, Bloemspruit, Shannon Valley, Grasslands and Rodenbeck as well as undeveloped land on the farms Turflaagte 881 and Liege Valley 1325.

d) South-Western Quadrant: This area is located between Bloemfontein – Cape Town railway line in the west and Bloemfontein – Dealesville road in the north. It comprises of Bloemfontein neighbourhoods of Gen. De Wet, Uitsig, Fleurdal, Fauna, Lourier Park, Pellissier, Fichardt Park, Hospital Park, Wilgehof, Gardenia Park, Universitas and Langenhoven Park. Park West, Willows and Oranjesig areas are typical transition areas surrounding the Bloemfontein CBD. Oranjesig has been developed as a mixedlight industrial and service industry area while Willows has a mixture of medium to high residential development, offices and some retailing. The area also includes the small-holding areas of Hope Valley, Bloemdal, Quaggafontein and Spitskop.

e) North-Western Quadrant: This area is located between the Bloemfontein-Dealesville Road in the south and the Bloemfontein-Johannesburg railway line in the east. It comprises the Bloemfontein neighbourhoods of Brandwag, Westdene, Arboretum, Dan Pienaar, Waverley, Heuwelsig, Hillsboro, Pentagon Park, Kiepersol, Bays Valley, Helicon Heights, Bayswater, Noordhoek, Navalsig and Hilton. The area also includes the small holdings of the Stirling, Rayton and Lilyvale areas. The Woodland Hills Wildlife Estate Development is also located inside this quadrant.

f) Area Beyond the Urban Edge and the Peri-urban area: This refers to the peri-urban and agricultural areas located outside the urban edge.

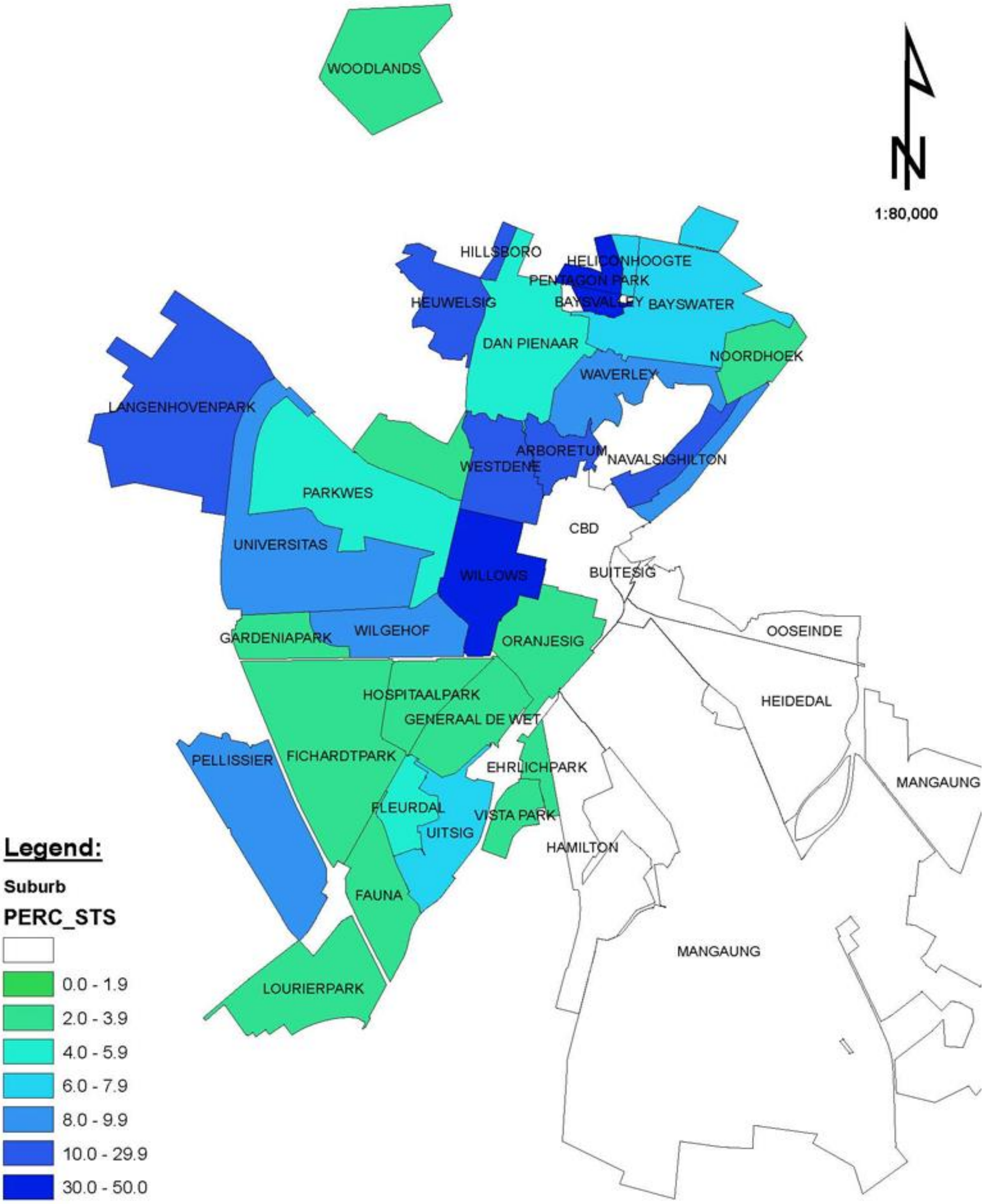


Figure 3-11: *Bloemfontein suburbs*

(Donaldson, Benn, Cambell and De Jager; 2014)

3.8 TRANSPORTATION

3.8.1 Road Networks

Due to the central location and function of Bloemfontein in the context of Free State Province, most of the provincial and national road networks converge at the City. The existing road network in the Bloemfontein urban node is characterised by a radial form with CBD being the centre. The different road classes are Class 1 roads which are National Roads/Freeways and Class 2 roads which are Arterials forming structuring elements within the urban nodes. According to MMM - Operation Plan – Phase 1 of IPTN (2016) the Bloemfontein urban node is characterised by the following key road network elements:

- ❖ Class 1 Roads: National Roads/Freeways
  - National Route N1 (connecting Gauteng to Cape Town)
  - National Route N8 (connecting Botshabelo / Thaba Nchu, Bloemfontein and Kimberly)
  - National Route N6 (connecting East London and Bloemfontein)

- ❖ Class 2 Roads: Arterials
  - Raymond Mhlaba Street (R30)
  - Kenneth Kaunda Road (R700)
  - General Dan Pienaar Road
  - Nelson Mandela Drive (R64)
  - Walter Sisulu (N8 western extension)
  - Jagersfontein / Curie / Kolbe Avenue (R706)
  - Ferreira Road
  - Church Street (M30 / N6 southern extension)
  - Dewetsdorp Road (R702)
  - Meadows Street
  - Thaba Nchu Road

3.8.2 Transportation Mode used in Bloemfontein

Currently the railway lines passing through Bloemfontein offer no passenger services within the Mangaung area and are exclusively used by Transnet Freight Rail (TFR) for freight transport and by Shosholoza Meyl for long distance passenger transport along the Johannesburg – Bloemfontein - Port Elizabeth service, the Johannesburg – Bloemfontein -

East London service and the Cape Town – Kimberley – Bloemfontein – Pietermaritzburg - Durban service (MMM - Operation Plan – Phase 1 of IPTN, 2016). This makes roads the predominant transportation mode used for commuting around Bloemfontein and the population of private vehicles the highest in comparison to other modes as shown in table 3-4. The mode mostly used by travellers around Bloemfontein is the private vehicle as shown by table 3-3 below.

Table 3-3: *Main modes of transport used to go to work in MMM*
(MMM - Operation Plan – Phase 1 of IPTN, 2016)

Origin	Bus	Car/bakkie/truck/lorry driver	Car/bakkie/truck/lorry passenger	Taxi	Walking all the way	Other
Naledi		15.48%			84.52%	
Bloemfontein		77.24%	16.24%	3.47%	2.59%	0.46%
Mangaung	2.78%	15.10%	8.19%	56.31%	14.27%	3.34%
Botshabelo	43.98%	9.32%	1.09%	18.67%	26.94%	
Thaba Nchu	33.55%	10.35%		13.01%	42.25%	0.85%
Mangaung Rural	7.55%	49.91%	14.49%	22.60%	5.45%	
Total	**10.55%**	**29.53%**	**8.44%**	**32.56%**	**17.16%**	**1.77%**

Table 3-4: *Vehicle population in South Africa*

(National Traffic Information System; 2020)

30 September 2020 - Live vehicle population as per the National Traffic Information System - eNaTIS											
Vehicle Class	**Province**									**Total**	**% of total self-propelled**
	GP	**KZN**	**WC**	**EC**	**FS**	**MP**	**NW**	**L**	**NC**		
Motor cars and station wagons	3125499	1028828	1297502	474118	320424	447337	330565	324285	131739	7480297	65,37%
Minibuses	129813	57688	37450	25620	12979	25779	20557	25918	5957	341761	2,97%
Buses, bus trains, minibuses	20468	8326	7160	4654	3405	8315	4099	7010	1809	65246	0,57%
Motorcycles, quadrucycles, tricycles	140143	30117	85126	21300	17914	17458	12522	8767	7556	340903	2,97%
LDV's, panel vans, other light load veh's GVM<+3500kg	853389	373990	340309	210074	133018	226723	157534	241692	81646	2618375	22,79%
Trucks (Heavy load vehicles GVM>3500kg)	140166	50283	46331	22563	22518	44246	17286	26955	9055	379403	3,30%
Other self-propelled vehicles	35984	31635	39993	16845	34395	27125	20797	17369	9497	233640	2,03%
Total self-propelled vehicles	**4445462**	**1580867**	**1853871**	**775174**	**544653**	**796983**	**563360**	**651996**	**247259**	**11459625**	**% of total tow vehicles**
Provincial % of total	**38,69%**	**13,76%**	**16,14%**	**6,75%**	**4,74%**	**6,94%**	**4,90%**	**5,94%**	**2,15%**	**100,00%**	
Caravans	36894	6813	18401	5083	7160	9762	6078	5464	2698	98353	8,23%
Light load trailers GVM<+3500kg	337764	82006	151514	58525	63131	66328	54159	44033	29920	887380	74,27%
Heavy load trailers GVM>3500kg	65254	24514	24597	7438	19745	39536	11108	10999	5894	209085	17,50%
Total trailers	**439912**	**113333**	**194512**	**71046**	**90036**	**115626**	**71345**	**60496**	**38512**	**1194818**	
Total provincial % of total	**36,82%**	**9,49%**	**16,28%**	**5,95%**	**7,54%**	**9,68%**	**5,97%**	**5,06%**	**3,22%**	**100,00%**	
All other and unknown vehicles	4486	2822	4313	3015	3695	3543	4089	2301	1354	29618	
Total number	**4889860**	**1697022**	**2052696**	**849235**	**638384**	**916152**	**638794**	**744793**	**287125**	**12714061**	
Provincial % of total	**38,46%**	**13,35%**	**16,15%**	**6,68%**	**5,02%**	**7,21%**	**5,02%**	**5,86%**	**2,26%**	**100,00%**	

3.8.3 Public Transportation

The existing public transportation services in Bloemfontein are the minibus taxis, the private taxis as well as bus services provided by the IBL. A small number of commuters use the private taxis whereas the bus service works on predetermined routes with a timetable. The minibus taxis work in an informal fashion as they do not drive according to schedules. Most commuters using public transportation reside in the eastern parts of the city and usually commute in the mornings and afternoon to the central and western parts of the city.

3.8.4 Trip Generating Destinations

During the morning peak hour 80% of person trips observed are towards the CBD. The majority of people commute daily to the city centre comprising of the CBD and the two universities in the Free State. The total number of public transport users across modes from the different residential areas towards the CBD during the morning peak hour total to 16 000 passengers per hour, and from the CBD ± 2400 per hour (MMM - Operation Plan – Phase 1 of IPTN, 2016). This is excluding private vehicle owners who usually commute alone to their workplaces and a few who share rides. The trip generating activities include among others retail, office, industrial/commercial activities, domestic workers, defence as well as agriculture, construction and transportation. These activities are concentrated in the central and western parts of Bloemfontein.

3.9 HIGH OCCUPANCY VEHICLE (HOV) INFRASTRUCTURE

Apartheid planning distorted settlement patterns and has resulted in a spatial landscape that is extremely inefficient and deeply divided. During apartheid, transport systems were designed to facilitate segregation. The predominant investment in infrastructure oriented to private vehicles, mainly in previously white areas, has exacerbated the poor levels of access and mobility in South African Cities. This has resulted in a context where many poor people live extraordinarily far from places of economic opportunity and are forced to travel long distances for long periods every day. (MMM - Operation Plan – Phase 1 of IPTN, 2016) With the current high private vehicle usage amongst the middle and upper classes as well as the inadequate infrastructure, traffic congestion has increased in South African cities.

A high occupancy vehicle is one that carries more than one occupant. HOV infrastructure has been introduced in some South African cities like Johannesburg and Cape Town and has been primarily used to help in implementation of the BRT system. Numerous suggestions have been made on how traffic congestion may be reduced in cities however the practicality of each solution is unique to the city in question. For this study, HOV infrastructure has been selected as a possible solution for alleviating traffic congestion in Bloemfontein.

3.9.1 Why Bloemfontein?

a) Bloemfontein is the economic hub of MMM

Bloemfontein is the economic hub of the municipality and therefore many people migrate to the city in search of better living conditions and employment opportunities. According to the Mangaung Metropolitan Municipality Integrated Development Plan (2018/2019) about 50 000 people have relocated from Botshabelo to Bloemfontein between 2007 and 2011. Bloemfontein now houses almost two thirds of the entire Mangaung Population and the population density in the city continues to increase. It is foreseen that Bloemfontein will remain the focus of future developments in the MMM which may result in more people migrating to the city and adding to the traffic congestion the city is already faced with (MMM - Operation Plan – Phase 1 of IPTN, 2016). As the economic hub, Bloemfontein needs to provide opportunities for further long-term economic growth and infrastructure to accommodate the ever-growing populations.

b) Common Transportation Mode in Bloemfontein

The mode mostly used by travellers around Bloemfontein is the private vehicle, whereas most trips from Mangaung and Botshabelo/Thaba Nchu are undertaken by walking and public transport (see Figure 3-3).

c) Occupancy of Vehicles

It is evident from the above illustration (see Figure 3-3) that there are more drivers than passengers using private vehicles in Bloemfontein and in the metro in general. This means that most people drive alone while a few vehicles accommodate passengers leading to congestion as more single occupant vehicles on the road means an increase in traffic volume.

d) Absence of HOV Infrastructure in Bloemfontein

There is currently no HOV infrastructure in Bloemfontein. HOV infrastructure may help facilitate services such as the BRT system as well as help in the promotion of ridesharing as private vehicles are the dominant mode of commuting in the city.

e) Roads being the only transportation mode used in Bloemfontein

Unlike in other metros where rail is used by people to commute to work, this is not the case in Bloemfontein. The railway line in the city is used for freight transportation as well as long distance travel. This leaves the use of road transportation as the only mode of commuting in the city and hence the traffic congestion as people residing in Bloemfontein do not have a lot of alternatives.

f) Population of Bloemfontein

The Free State has the second lowest population density in South Africa. Bloemfontein as the provincial capital has a population of 546 568 which is quiet low in comparison to the populations of other South African cities. As a middle-sized city, traffic mitigation measures like the introduction of the Gautrain currently being used in Johannesburg may not be economically practical and hence the suggestion to explore the best use of HOV infrastructure.

g) The City Structure

The original structure of Bloemfontein is centred around a strong CBD with numerous arterial roads converging there from different areas of the city. In the recent years, the western areas of Bloemfontein have experienced the most growth with major offices and retail development in the Brandwag area and more developments planned in Langenhovenpark and its surroundings. This shift to the western areas will result in an even less balanced city structure with further significant traffic congestion while travel distances and time from some areas will increase, especially to and from the south-eastern areas in Bloemfontein and Botshabelo and Thaba Nchu further east. In addition to this, the infrastructure in place was not designed for high traffic volumes as few roads serve the area for an intensive business district.

h) Concentration of Developments along Major Traffic Routes

Developments along major traffic routes such as Currie Avenue, Church Street and Nelson Mandela Avenue have led to a decline in traffic service levels. These developments coupled with the continuous illegal occupation of land has given rise to typical ribbon developments along these roads and traffic congestion. Due to these developments which have encroached the road reserve, the viable option to mitigate traffic congestion is the introduction of HOV lanes which shall be incorporated into the already existing infrastructure. Figure 3-12, Figure 3-13 and Figure 3-14 below show the developments along Currie Avenue, Nelson Mandela Drive and Oliver Tambo Road respectively.

Figure 3-12: *Currie Avenue, Bloemfontein*
(Billboard Finder, 2020)

Figure 3-13: *Nelson Mandela Drive, Bloemfontein*
(Billboard Finder, 2020)

Figure 3-14: *Oliver Tambo Road, Bloemfontein*
(123RF Limited, 2020)

3.10 SUMMARY

The analysis of the study area (Bloemfontein) revealed the following features:

- The Free State has the second lowest population density in the country with a population of approximately 878 834 in the province and 546 568 people in the provincial capital Bloemfontein.
- The major contributors to the Free State population are age groups 5-9 years at 9.9% followed by age groups 10-14 years and 0-5 years at 9.7% and 9.3% respectively. Approximately 58.8% of people living in the Free State fall between the age brackets 20-69 years which comprises of people who are vehicle owners and live active lifestyles which require them to move around a lot.
- Bloemfontein has two universities with a total student population of approximately 50 000 students. The majority of the residential areas in the city also have a primary school and/or a high school.
- Over half (55.5%) of the households in the MMM get their household income from salaries, 20.1% from grants, 8.3% from remittances, 4.2% from pensions

and the remaining 12% from other sources such as rental, business, sales of farming products or other services.

- The skewed spatial patterns in South African cities due to apartheid have resulted in long commute distances of the marginalised groups due to the segregation as well as emphasis on private transportation contributing to city congestion.
- Railway lines passing through Bloemfontein are exclusively for freight transportation and long-distance travel resulting in the primary mode of commute around the city being road transportation.
- Approximately 59% of the vehicle population in the Free State is station wagons and motor cars which subsequently results in the high use of private vehicles.
- The majority (77.24%) of people in Bloemfontein use private vehicles such as cars, pick-up trucks ('bakkies') and other light duty vehicles for their daily commutes in comparison to walking, taking buses or taxis.
- The population of Bloemfontein is not enough to warrant the use of other modes of transportation such as introduction of local commuter trains.
- Concentration of developments along major routes lead to congestion and also do not allow for traffic mitigation measures such as expansion of the road.
- The next chapter shall present the findings of other researchers on causes of congestion, impacts and mitigation measures, HOV infrastructure and ridesharing.

CHAPTER 4. IMPLEMENTATION, DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, an attempt was made to investigate the transport and travelling demographics of the study area, vehicle ownership of respondents, peak travel times and trip distribution in order to examine the possibility of using HOV infrastructure and ridesharing to mitigate traffic congestion. Survey research methods were used to collect data which was then statistically analysed to understand the travel patterns of commuters especially during peak times in the study area. Once all the data was collected, it was vetted and cross-checked to correct any discrepancies. This data was thereafter transferred to Microsoft Excel sheets where relevant statistical analyses were done. The various analyses done include the following:

- Demographics of the study area
- An analysis on vehicle ownership and carrying capacity of private vehicles
- An analysis of peak travel times, the duration of morning and afternoon travel times and distances travelled
- The origins and destinations of most trips and the purposes of travel
- An analysis of areas and roads with the most traffic in the study area
- The possibility of introducing HOV infrastructure in the study area
- An analysis of the number of people willing to ride-share.
- An analysis of the traffic counts done at busy junctions entering the CBD from residential areas
- A linear analysis of how much traffic may be reduced when increasing the vehicle occupancy under different scenarios

4.2 DATA COLLECTION

Data was collected through administration of interviews to drivers as well as traffic counts on the main intersections entering the Bloemfontein city centre from the suburbs and locations.

Interviews

Interviews were administered to drivers and vehicle owners residing in and around Bloemfontein to establish their experience on the roads during peak hour commutes. A sample of the Interview is attached as Annexure A. Homogenous sampling was used targeting private vehicle drivers after which 150 interviews were randomly administered to drivers and vehicle owners in Bloemfontein each with 16 questions aimed to determine the following:

Section 1: Demographics and the types of vehicles used by the respondents
Section 2: Peak time trips
Section 3: HOV infrastructure
Section 4: Ridesharing

The interviews were administered in areas where most drivers were expected to be found parked which included car washes, parking lots, busy streets (e.g., Ella Street in Willows) and the CBD. The interviews were completed by the respondents while waiting and in some cases the respondents preferred rather answering the questions verbally as you asked them. Interviews were also circulated using a link on google forms. A total of 41 responses were completed electronically through the link whereas the rest were done manually. Data from both the electronically and manually completed interviews was transferred to Microsoft Excel sheets and statistical analysis was done to convert the data to charts, graphs and tables.

Traffic Counts

Traffic counts were done on the major intersections feeding traffic into the Bloemfontein CBD from the suburbs and locations. The responses from the interviews together with previous experiences resulted in the selection of the exact streets for traffic counts. These counts were therefore done in areas most interview respondents considered to be highly congested especially at peak times. Traffic counts were in a year the world and South Africa were facing the Covid-19 pandemic. Despite this, these counts were done manually at a time when economic activity had returned to the new normal and schools were opened. Peak hour traffic counts were done on the intersections shown in table 4-1 which are also circled on figure 4-1 below.

Table 4-1: *Coordinates of traffic survey intersections*

Location	Coordinates	
Oliver Tambo Road and President Avenue	-29,126557	26,219446
Kellner Street and General Dan Pienaar Road	-29,108081	26,20268
Kolbe Avenue and President Avenue	-29,123923	26,211445
Nelson Mandela Drive and Furstenburg Avenue	-29,102485	26,184913
End of N8 and beginning of Nelson Mandela Drive	-29,11551	26.22675
Aliwal Street and Union Avenue	-29,101059	26,222393

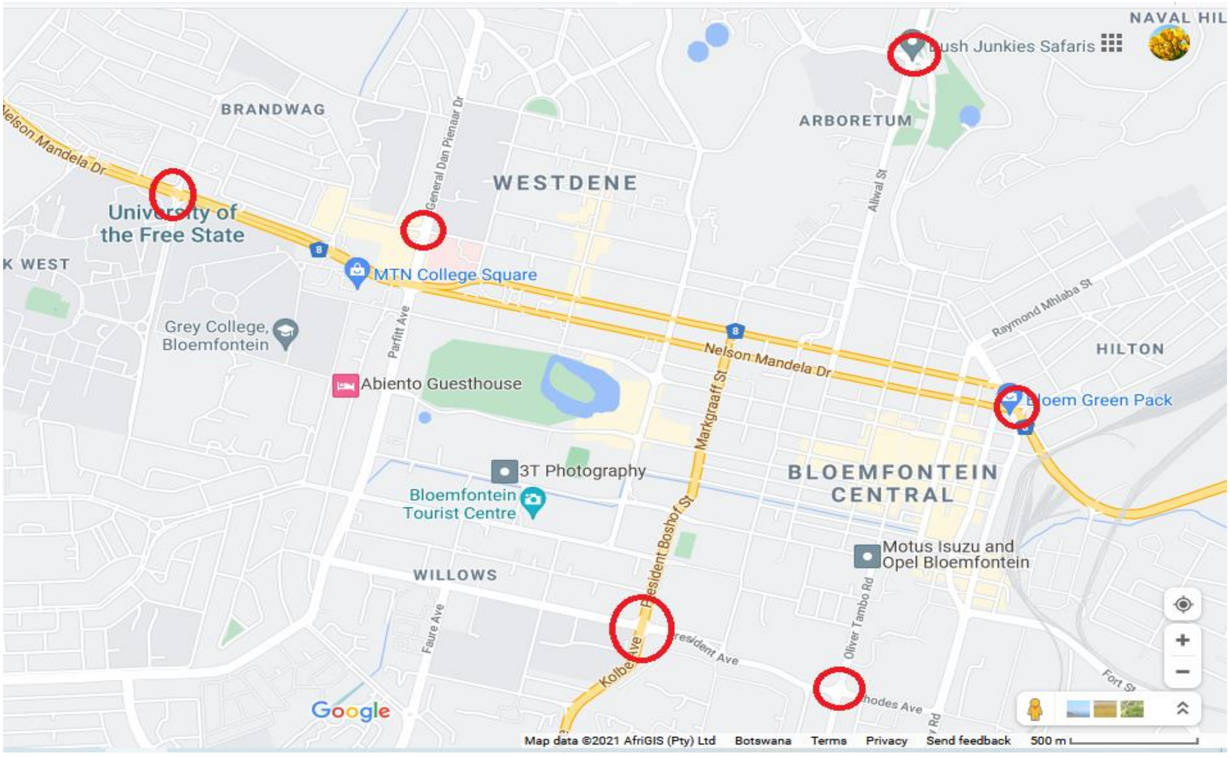


Figure 4-1: *A map of Bloemfontein showing junctions where traffic counts were conducted*

Traffic counts at the intersection of Nelson Mandela Drive and Furstenburg Avenue were done to determine the amount of traffic entering the city centre from the western suburbs which include Langenhoven Park, Tempe and Park West. Counts done at the intersection of General Dan Pienaar and Kellner Street accounted for traffic going towards the CBD from the northern and northwest suburbs which include Brandwag, Universitas, Dan Pienaar, Heuwelsig, Rayton, Hillsboro and Westdene. The intersection of Aliwal Street and Union Avenue showed counts of more traffic entering the city centre from the northern suburbs of Waverley, Navalsig, Arboretum, Baysvalley, Bayswater, Pentagon Park and Helicon Heights. Traffic counts done where the N8 ends and Nelson Mandela Drive starts represented traffic entering and leaving the CBD from the south eastern areas of Bloemfontein which included areas such as Buitesig, Oos-Einde, Bloemspruit, White City, Rykmanshoogte, Heidedal, Bloemside, Rodenbeck and Ashbury. Counts done for traffic entering for the city centre from the south and south-western areas were done at the intersection of President Avenue and Oliver Tambo Road as well as the intersection of President Avenue and Kolbe Avenue and these counts were for traffic coming from areas such as Bochabela, Batho, Phahameng, Hamilton, Oranjesig, Rocklands, Bloemanda, General de Wet, Fleurdal, Ehrlich Park, Fleurdal, Pellissier, Fiichardtpark, Hospitaal Park, Gardenia Park, Wilgehof and Willows.

4.3 DEMOGRAPHICS AND TYPES OF VEHICLES USED BY THE RESPONDENTS

4.3.1 Gender

The respondents to the interview were mostly male with only 20% of the responses received from the 150 interviews distributed coming from females and the rest from males. Even though most of the participants were male, there was no clear correlated difference in the responses gathered from the interviews. This is illustrated by Figure 4-2 below.

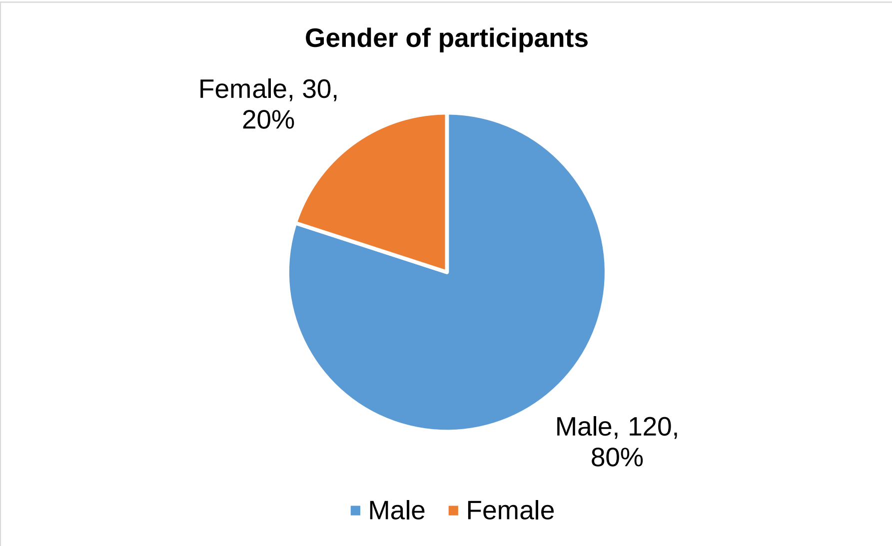


Figure 4-2: *Gender of participants*

4.3.2 Age

Of the 150 responses received, 4.7% of the respondents were over 50 years and 5.3% less than 20 years. The majority of the respondents were between 31 and 35 years which made up 23.3% of the respondents; 20% between 26 and 30 years; 18% between 36 and 40 years; 13.3% between 41 and 45 years; 12% between 20 and 25 years; and 3.3% between 46 and 50 years. This is illustrated by Figure 4-3 below.

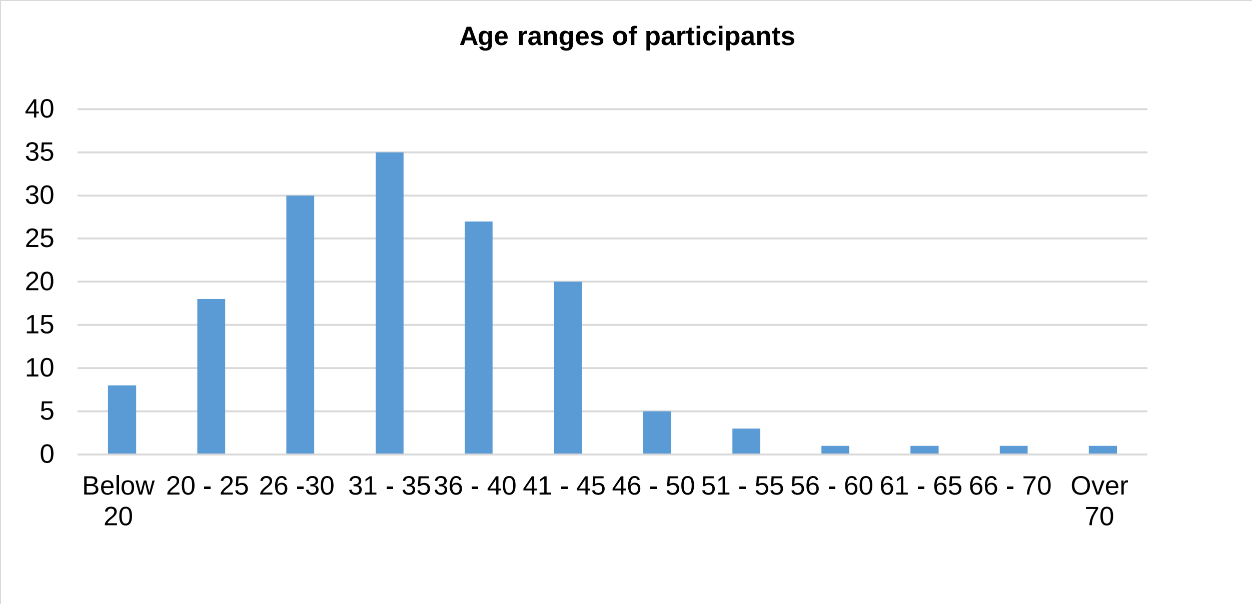


Figure 4-3: *Age ranges of participants*

4.3.3 Type of vehicle used

80% of respondents use motor cars, whereas 20% indicated they use other light duty vehicles such as pick-up trucks or bakkies as they are commonly known in South Africa (as indicated in Figure 4-4).

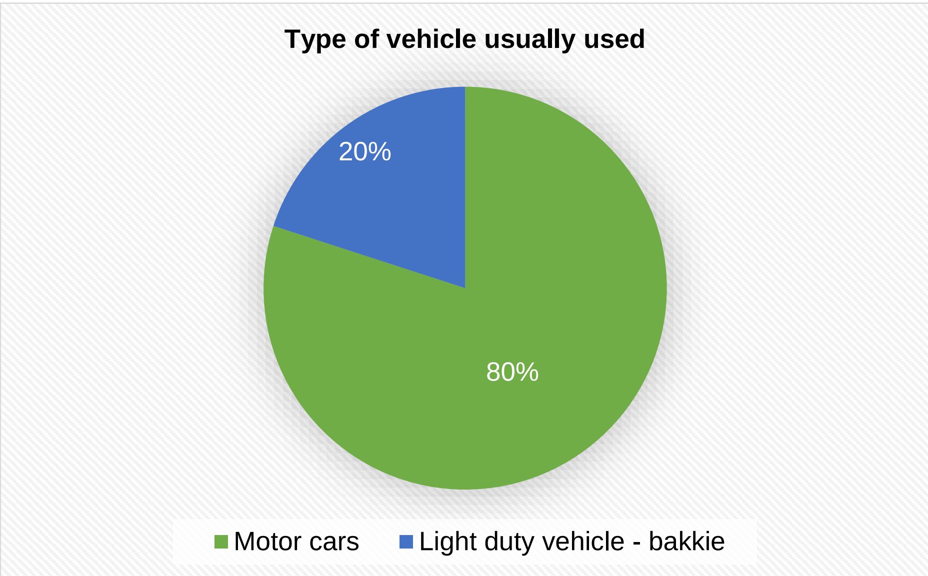


Figure 4-4: *Type of vehicle usually used*

4.3.4 Vehicle carrying capacity

103 respondents indicated that their vehicles have a carrying capacity of up to 5 people; 23 respondents use vehicles with a carrying capacity of 3 people; 15 respondents indicated their

cars may carry only 2 people whereas 9 respondents indicated their vehicles may carry as many as 7 people. This is shown in Figure 4-5 below.

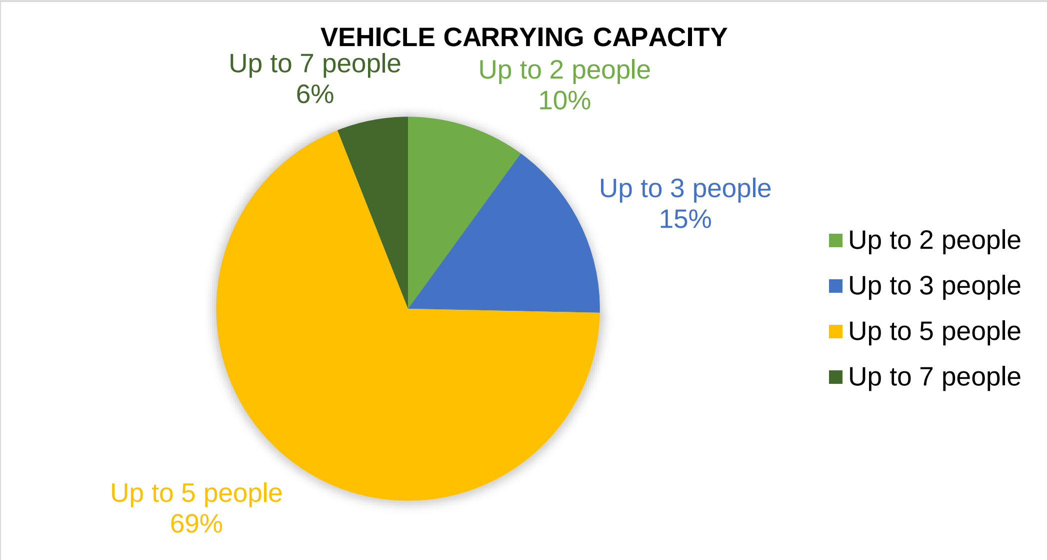


Figure 4-5: *Vehicle carrying capacity*

4.4 PEAK TIME TRIPS

4.4.1 Trips per week

Figure 4-6 below shows the number of trips taken by commuters per week in Bloemfontein. The majority of respondents indicated that they take between 6 to 10 trips and 10 to 14 trips per week respectively. 18.7% of respondents indicated they take 2 to 6 trips per week; 11.3% indicated they take 18 to 22 trips per week; 9.3% of the respondents said they take over 30 trips per week; 6.7% say they take 14 to 18 trips a week; whereas 4% and 3.3% of the respondents indicated they take 26 to 30 trips and 22 to 26 trips per week respectively.

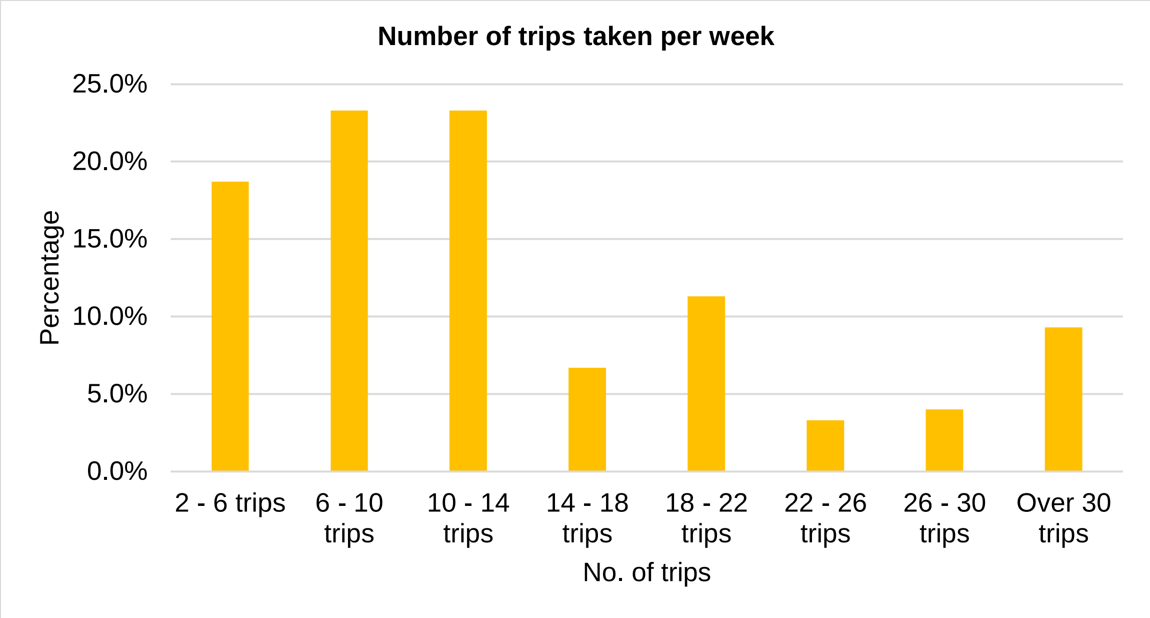


Figure 4-6: *Number of trips taken per week*

4.4.2 Travel times

The responses received from the interviews indicated that most people (19.7%) travel between 06:31 and 07:30 in the morning and 15.3% travel between 07:31 and 08:30. 8.4% of respondents indicated they start their trips before 06:30 in the morning whereas 5.9% travel between 08:31 and 09:30. In the afternoons most (12.5%) commuters seem to be travelling between 16:31 and 17:30. 10.6% indicated they travel between 15:31 and 16:30; 7.8% said they travel between 17:31 and 18:30; 6.3% travel after 18:30; 5.3% between 13:31 and 14:30; 4.4% between 14:31 and 15:30 whereas 3.8% of commuters travel between 12:30 and 13:30. This is shown by the graph in Figure 4-7 below.

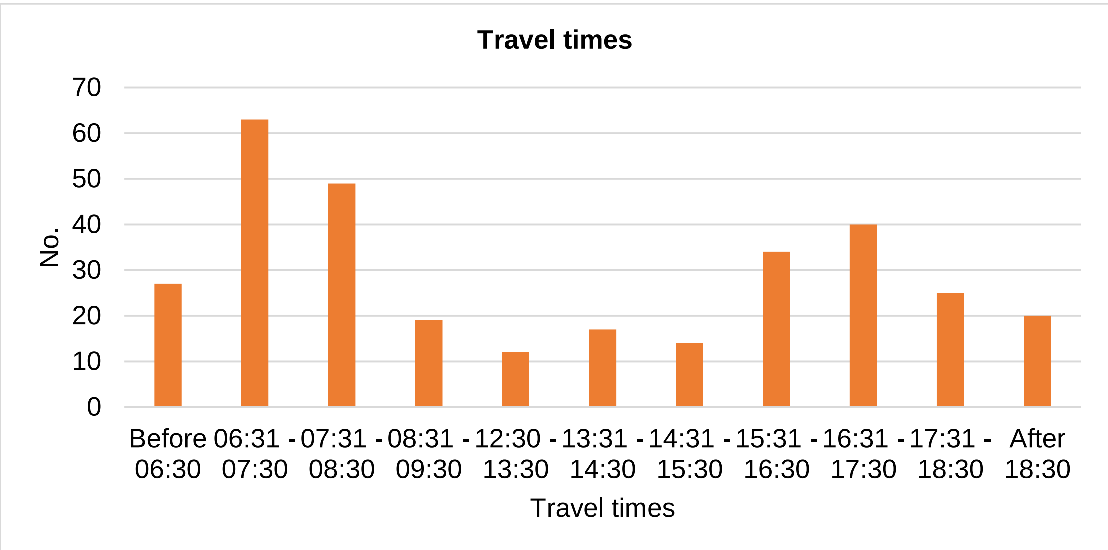


Figure 4-7: *Travel times*

4.4.3 Time taken for morning and afternoon commutes

From the 150 interviews circulated 78 respondents expressed that they take less than 30 minutes in their morning commutes, 47 take 30 minutes to an hour, 20 take an hour to one and half hours whilst 5 say they take more than 1.5 hours. For the afternoon trips 78 respondents take less than 30 minutes, 43 take 30 minutes to an hour, 22 commuters take an hour to 1.5 hours and 7 respondents indicated they take more than 1.5 hours for their afternoon trips. This is depicted in Figure 4-8 below.

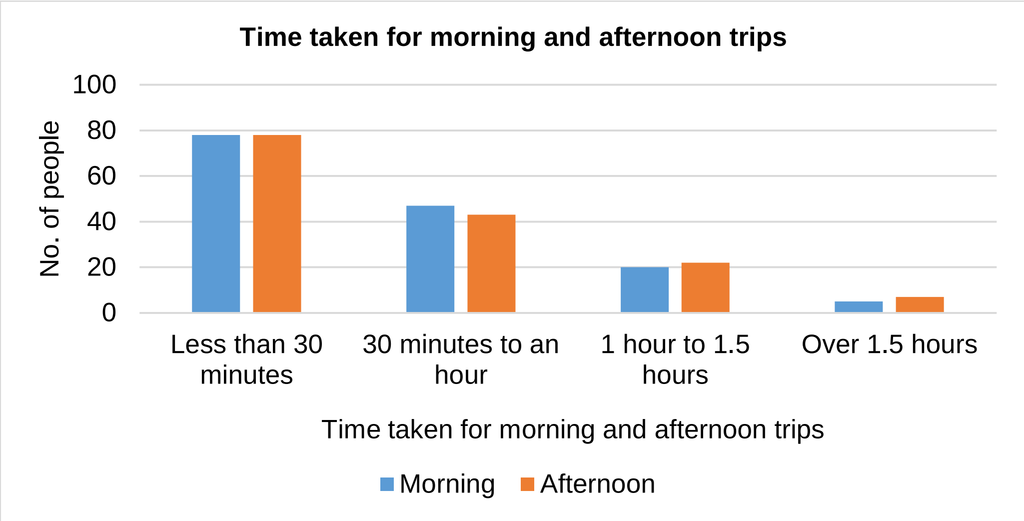


Figure 4-8: *Time taken for morning and afternoon commutes*

Even though 30min or less is a fairly reasonable time to commute from home to work, the continuous urbanisation explained in the literature review poses a risk for a longer commute time as the urban population rapidly increases. This may mean that in the next coming few years, commuters who were taking 30minutes to commute might end up taking up to an hour as vehicle ownership increases and the rate of urbanisation.

4.4.4 Average distance travelled per trip

Most (28%) commuters revealed they travel 5-10 km per trip; 23.3% say they travel over 25 km; 17.3% travel 10-15 km per trip; 12.7% travel less than 5 km; 10.7% travel 15-20 km and 8% of commuters travel between 20-25 km per trip. This is shown in Figure 4-9 below.

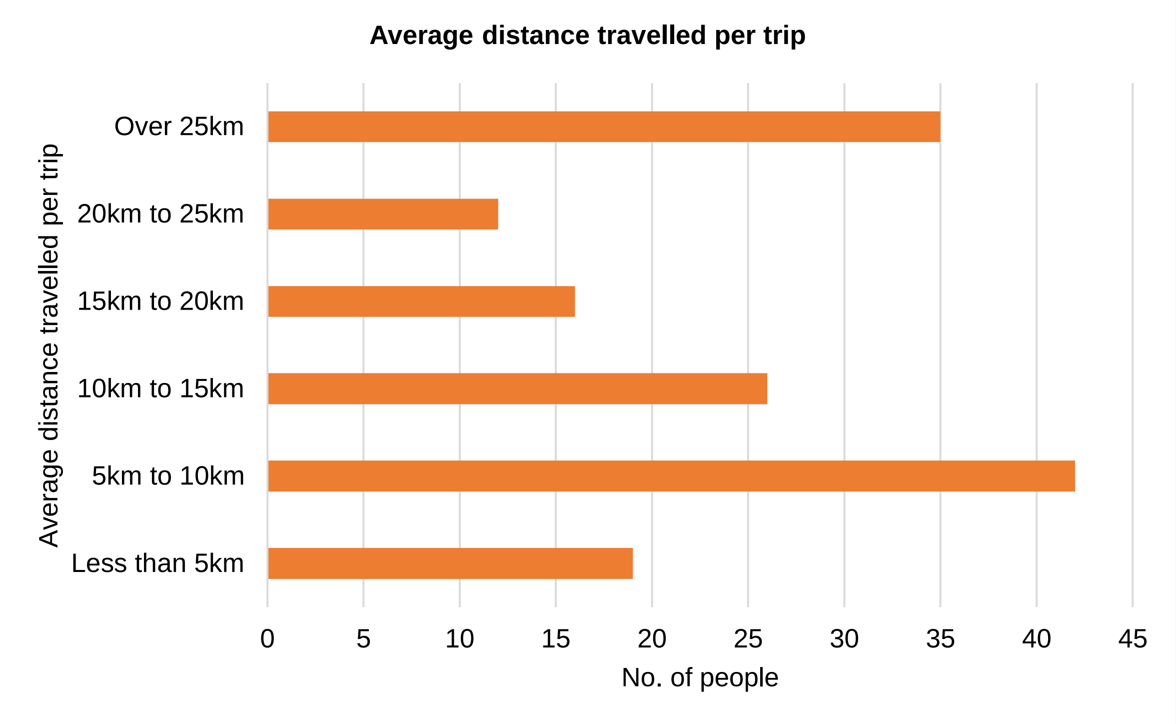


Figure 4-9: *Average distance travelled per trip*

4.4.5 Reasons for travel

Data collected indicated that 40.1% of the trips taken are to go to work, 19.9% for shopping and 15.9% for picking and dropping off children at school. Fewer trips taken by private vehicles are for the purpose of going to university, gym and conducting other activities as indicated in Figure 4-10 below that only 11.2%, 9% and 4% of the trips are taken for these purposes respectively.

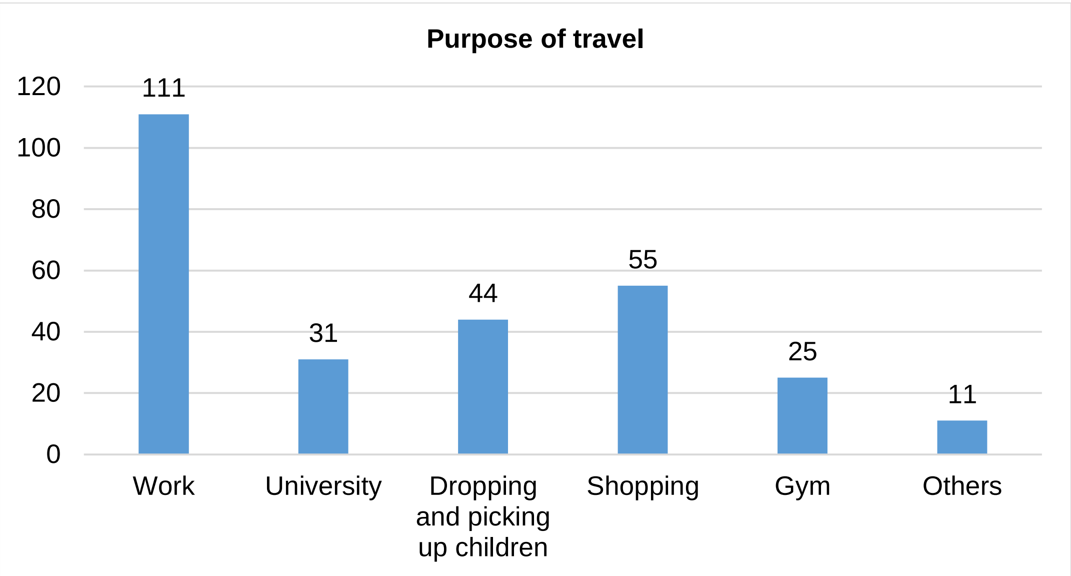


Figure 4-10: *Purpose of travel*

4.4.6 Origins and destinations of the trips taken

From the 150 responses received 22 indicated that their peak time trips are usually from Mangaung to the CBD; 7 from Langenhoven Park to the CBD; 3 from the CBD to Willows; 12 around the CBD; 4 from Batho to Willows; 4 from Batho to the CBD; another 4 from Universitas to the CBD; and 3 from Phase 2 to the CBD. The rest of the respondents showed they travel between other origins and destinations as shown in Table 4-2 below.

Table 4-2: *Origins and destinations of trips made by commuters in Bloemfontein*

Origin	Destination	No.
Rocklands	Universitas	2
Rocklands	Willows	2
Rocklands	CBD	2
Rocklands	Mangaung	1
Rocklands	Heidedal	1
Mangaung	CBD	22
Mangaung	Mangaung	2
Mangaung	Willows	1
Mangaung	Hilton	1
Langenhoven park	CBD	7
Langenhoven park	Oranjesig	1
Langenhoven park	Hilton	1
Langenhoven park	Universitas	1
Langenhoven park	Willows	1
Langenhoven park	Fauna	1
Langenhoven park	Mangaung	1
Botshabelo	Mangaung	2
Botshabelo	CBD	1
Botshabelo	Universitas	1
CBD	Welkom	1
CBD	Willows	3
CBD	Rocklands	1
CBD	CBD	12
CBD	Maselspoort	1
CBD	Bainsvlei	1
Willows	Westdene	1
Willows	CBD	2
Willows	Willows	1
Willows	Mangaung	1
Wilgehof	CBD	1
General de Wet	CBD	1
Phahameng	Oranjesig	1
Phahameng	CBD	1
Helicon Heights	Willows	1
Pellisier	Sports	1

Pellisier	Willows	1
Pellisier	CBD	1
Thaba Nchu	CBD	1
Bayswater	CBD	2
Bayswater	Universitas	1
Batho	Willows	4
Batho	CBD	4
Universitas	Willows	2
Universitas	Mangaung	1
Universitas	Universitas	1
Universitas	CBD	4
Woodlands	Willows	1
Fauna	Noordhoek	1
Fauna	Willows	1
Bloemspruit	Willows	1
Grassland	CBD	1
Grassland	Willows	1
Fichardtpark	Willows	2
Fichardtpark	CBD	2
Phase 2	CBD	3
Phase 2	Brandwag	1
Hillside view	CBD	1
Phase 6	Willows	1
Phase 6	CBD	1
Louriepark	CBD	1
Oos-Einde	CBD	1
Westdene	Fichardtpark	1
Westdene	Westdene	1
Westdene	Oos-Einde	1
Turflaagte	CBD	1
Navalsig	Willows	1
Heidedal	Willows	1
Heidedal	Bayswater	1
Heidedal	CBD	1
Bochabela	Brandwag	1
Bochabela	CBD	1
Bochabela	Oranjesig	1
Dan Pienaar	Westdene	1
Dan Pienaar	Helicon Heights	1
Phelindaba	Oranjesig	1
Pentagon Park	CBD	1
Hospital Park	CBD	1
Hospital Park	Universitas	1
Hamilton	CBD	2
Bainsvlei	CBD	1
Bains Lodge	CBD	1

Waverly	Willows	1
Bergman	Universitas	1
Brandwag	Willows	1
Bloemanda	CBD	1
Heuwelsig	Willows	1
Uitsig	Heidedal	1
Fleurdal	CBD	1

4.5 HIGH OCCUPANCY VEHICLE (HOV) INFRASTRUCTURE

4.5.1 Commuters' responses to introduction of HOV infrastructure in Bloemfontein

126 respondents indicated that they are in support of HOV infrastructure being introduced in Bloemfontein whereas 24 respondents are against it as is shown in Figure 4-11 below.

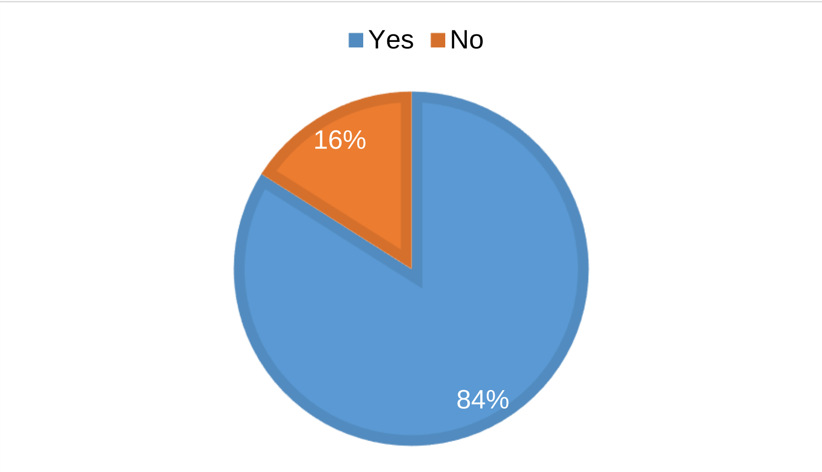


Figure 4-11: *Acceptance of HOV infrastructure*

4.5.2 Areas with the most traffic in Bloemfontein

The CBD proved to be the area with the most traffic followed by Willows and Batho as declared by 68%, 10% and 2.7% of the responses respectively. The remaining 19.3% of responses indicated that other areas with significant traffic included Brandwag, Rocklands, Hamilton, Heidedal, Sports, General de Wet, Pentagon Park, Universitas, Hospital Park, Langenhoven Park, Vista Park, Mangaung, Dan Pienaar and Westdene. Figure 4-12 below depicts the areas with the most traffic in Bloemfontein as seen by the respondents to the interviews.

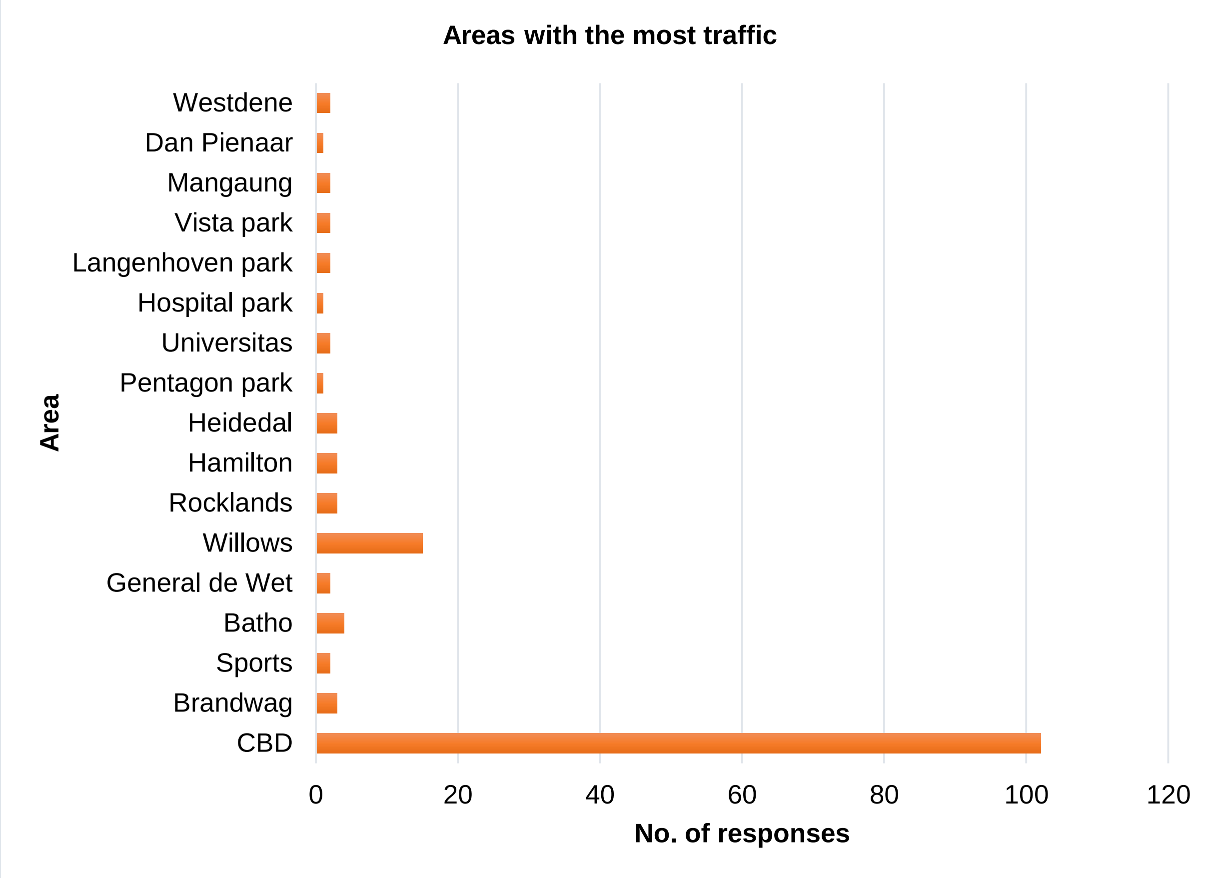


Figure 4-12: *Areas with the most traffic in Bloemfontein*

4.5.3 Recommended roads for HOV lanes

Oliver Tambo road was said to be the most congested road by 33.5% of commuters and Nelson Mandela Drive followed at 19.1% as the second most congested road in Bloemfontein. In addition to these roads, commuters recommended introduction of HOV lanes on other roads around Bloemfontein. 8% of commuters recommended introduction of HOV lanes on the Dr Belcher Road; 6.4% recommended the N8; 4.8% recommended Harvey Road; 3.7% recommended President Boshof Street; 3.7% recommended Zastron Street; 3.2% recommended Charlotte Maxeke Street; 2.7% Moshoeshoe Street; 2.7% Currie Avenue; 2.1% Fort Street; 1.6% Kolbe Avenue; 1.6% Park Road; 1.1% Raymond Mhlaba Road; 1.1% St Georges Street; and the remaining 4.8% suggested Parfitt Avenue, Penkop Crescent, Chief Moroka Crescent; Dewetsdorp Road; Victoria Road, Gascony Crescent, Lucas Steyn Road, 2nd Avenue and President Brand Street. This is shown in Figure 4-13 below.

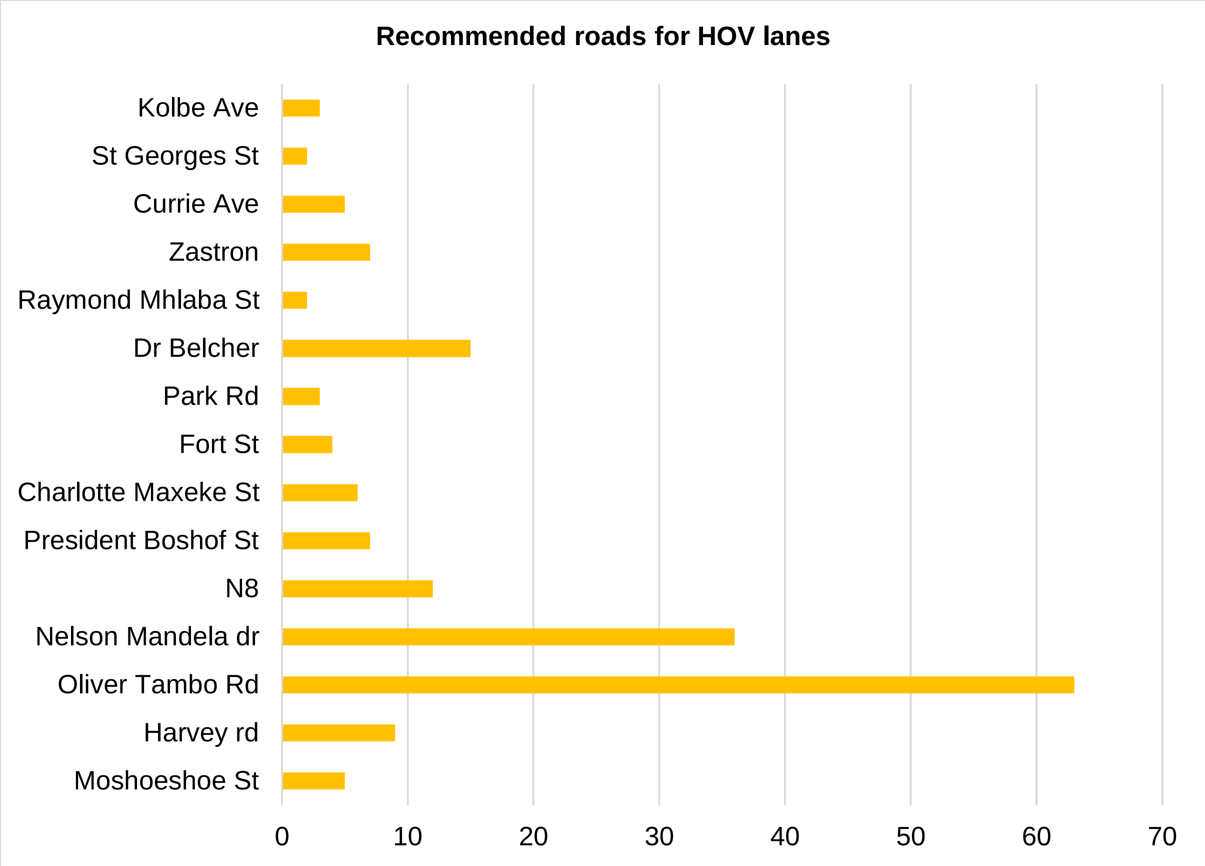


Figure 4-13: *Recommended roads for HOV lanes*

4.6 RIDESHARING

4.6.1 Openness to ridesharing

Figure 4-14 indicates that 55% of commuters are open to ridesharing, 15% are against it and 30% are neutral.

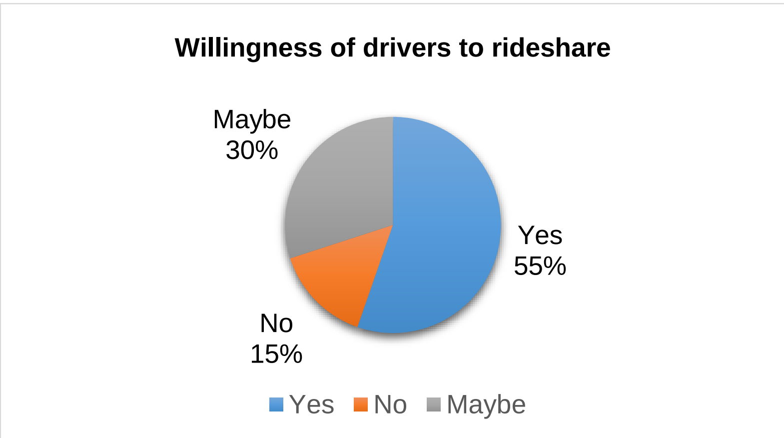


Figure 4-14: *Willingness of drivers to ride-share*

In addition to Figure 4-14, Figure 4-15 below shows the number of people drivers willing to share rides. 29 drivers indicated they will not give anyone a ride in their private car, 39 are willing to give up to 3 people a ride; 29 are willing to give up to 2 people a ride; 34 drivers are willing to give u to 4 people a ride; 11 drivers may give at least one person a ride; 3 drivers say they may share their private vehicle with up to 5 people; 2 drivers may share a ride with 6 people; another 2 drivers say they may share a ride with up to 10 people; and 1 driver may be willing to give 7 people a ride..

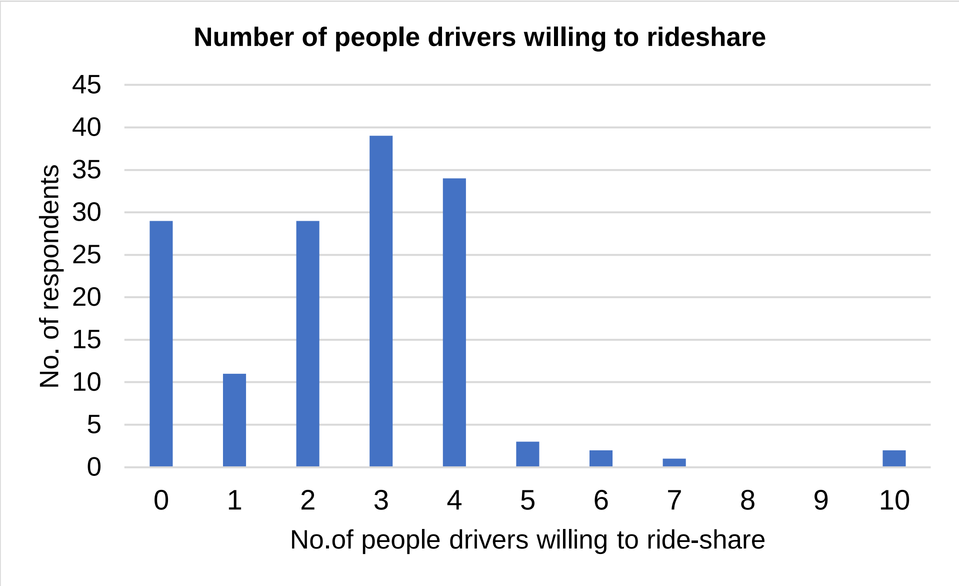


Figure 4-15: *Number of people drivers are willing to ride-share with in Bloemfontein*

4.7 TRAFFIC COUNTS

Physical traffic counts were done during peak times of working days on the busy intersections of Bloemfontein entering the CBD. Morning counts were done between 7 a.m. and 9 a.m., whereas the afternoon traffic counts were done between 4 p.m. and 6 p.m. Even though the traffic counts were done in a year the world including South Africa was hit by the Covid-19 pandemic, the data is applicable as it was done at the same time with the interviews when economic activity had returned to the new normal. The counts done are reflective of the workday traffic of the year past (2020) not the year ahead. According to the South African Pavement Engineering Manual (SAPEM) short- and long-term variations have to be done for traffic counts. Short term variations include variations between day and night traffic, variations between weekday and weekend traffic, seasonal variations and variations for exceptional periods.

a) Variations between day and night traffic

SAPEM states that for counts done between 06:00 and 18:00, data should be adjusted for night traffic. This is, nevertheless, not applicable for this study as it targets reducing peak hour traffic.

b) Variations between weekday and weekend traffic

According to SAPEM, weekday traffic is usually higher than weekend traffic and therefore the average daily equivalent (ADE) should be adjusted to a 7-day week if it was done during a 5day work week only. Traffic counts were however done for peak periods and not to determine the loading capacity in this study.

c) Adjustment for exceptional periods

It is not necessary to make adjustments for exceptional periods in this case as traffic counts were not being done for the purpose of determining loads in pavement design but rather for traffic reduction.

d) Adjustment for seasonal variation

This adjustment is also not applicable as the study is on reducing congestion on a typical day and not necessarily on every day of the year.

Derived from the 366 days in 2020, approximately 250 days were working days, 12 public holidays and 104 days were weekends. Daily traffic counts were therefore adjusted for the working days of the year 2020.

4.7.1 Intersection of Oliver Tambo Road and President Avenue

The traffic counts done at the intersection of Oliver Tambo Road and President Avenue indicated that in the mornings most traffic is from President Avenue and Oranjesig (556 250) going towards Oranjesig and the CBD (486 750) as shown in Table 4-3 below. In the afternoon most traffic was coming from the CBD and Oranjesig (541 750) going towards President Avenue and Oranjesig (581 000). This is also shown in Table 4-4 below. The difference in the totals between morning and afternoon commutes may be due to people choosing different routes on the way home and also having different knocking off times.

Table 4-3: *Morning traffic counts at the intersection of Oliver Tambo Road and President Avenue*

Vehicle Occupancy	FROM				TO			
	CBD	Rhodes Ave	President Ave	Oranjesig	CBD	Rhodes Ave	President Ave	Oranjesig
1	166250	59250	180750	199250	154000	153750	104000	193750
2	39250	51750	48750	94000	71000	46000	73500	43250
3	5500	16750	5000	18000	12750	4500	22000	6000
4	1500	5250	4250	5250	3750	3500	7000	2000
5	0	2000	750	250	250	500	2250	0
Total	**903750**				**903750**			

Table 4-4: *Afternoon traffic counts at the intersection of Oliver Tambo Road and President Avenue*

Vehicle Occupancy	FROM				TO			
	CBD	Rhodes Ave	President Ave	Oranjesig	CBD	Rhodes Ave	President Ave	Oranjesig
1	164250	114000	106500	165000	102250	82500	173500	191500
2	98750	32500	80750	69250	50750	62500	55500	112500
3	18750	8000	18250	15000	11250	12500	11250	25000
4	5000	2000	5750	4000	2500	4500	3500	6250
5	750	750	2000	1000	750	1750	1000	1000
Sub-total	**287500**	**157250**	**213250**	**254250**	**167500**	**163750**	**244750**	**336250**
Total	**912250**				**912250**			

4.7.2 Intersection of Kellner Street and General Dan Pienaar Road

Traffic counts at the intersection of Kellner Street and General Dan Pienaar Road showed that in the mornings the bulk of the traffic is from General Dan Pienaar Road (419750) going towards Parfitt Avenue (396 000). The movement of traffic is however a bit unclear in the afternoons as it seems there is a lot of traffic between Parfitt Avenue and General Dan Pienaar Road going in both directions. This is shown in Table 4-5 and Table 4-6 below.

Table 4-5: *Morning traffic counts at the intersection of Kellner Street and General Dan Pienaar Road*

Vehicle Occupancy	FROM				TO			
	CBD	Brandwag	Parfitt Ave	General Dan Pienaar Rd	CBD	Brandwag	Parfitt Ave	General Dan Pienaar Rd
1	109000	213500	196000	355000	172000	161250	327750	212500
2	32250	62500	65250	61250	52250	46500	62250	60250
3	8000	7250	10750	1500	4750	9000	3500	10250
4	1250	3250	3500	1250	2000	2000	1750	3500
5	0	750	250	750	250	0	750	750
Sub-total	**150500**	**287250**	**275750**	**419750**	**231250**	**218750**	**396000**	**287250**
Total	**1133250**				**1133250**			

Table 4-6: *Afternoon traffic counts at the intersection of Kellner Street and General Dan Pienaar Road*

Vehicle Occupancy	FROM				TO			
	CBD	Brandwag	Parfitt Ave	General Dan Pienaar Rd	CBD	Brandwag	Parfitt Ave	General Dan Pienaar Rd
1	176000	127500	328750	267500	124000	178250	315250	282250
2	55500	77000	133750	89250	62250	62750	122750	107750
3	4750	21000	15000	20000	12750	7000	23750	17250
4	1250	7000	6000	3000	3750	2250	4000	7250
5	250	1000	250	750	500	250	500	1000
Sub-total	**237750**	**233500**	**483750**	**380500**	**203250**	**250500**	**466250**	**415500**
Total	**1335500**				**1335500**			

4.7.3 Intersection of Kolbe Avenue and President Avenue

Table 4-7 below shows that in the mornings most traffic is from Kolbe Avenue (411 250) and President Boshof Street (438 500) going towards President Avenue (408 500) and President Boshof Street (493 250). In the afternoons the bulk of the traffic comes from President Boshof Street (697 750) going towards Kolbe Avenue (679 000) as presented in Table 4-8.

Table 4-7: *Morning traffic counts at the intersection of Kolbe Avenue and President Avenue*

Vehicle Occupancy	FROM				TO			
	Victoria Rd	President Ave	Kolbe Ave	President Boshof St	Victoria Rd	President Ave	Kolbe Ave	President Boshof St
1	230500	161500	320500	342000	90250	330000	270000	364250
2	52500	110000	81250	81000	66500	70000	77500	110750
3	3500	28500	7750	12000	18750	6000	13000	14000
4	1250	12000	1750	2750	7750	2250	4000	3750
5	0	3000	0	750	2500	250	500	500
Sub-total	**287750**	**315000**	**411250**	**438500**	**185750**	**408500**	**365000**	**493250**
Total	**1452500**				**1452500**			

Table 4-8: *Afternoon traffic counts at the intersection of Kolbe Avenue and President Avenue*

Vehicle Occupancy	FROM				TO			
	Victoria Rd	President Ave	Kolbe Ave	President Boshof St	Victoria Rd	President Ave	Kolbe Ave	President Boshof St
1	100000	334750	236250	469750	191000	179250	465750	304750
2	74250	119000	95500	182750	72500	113500	170500	115250
3	18750	26750	9500	36250	14000	26500	33500	17000
4	6750	10000	2750	6000	5500	8250	7000	4750
5	1250	1000	0	3000	500	2250	2250	250
Sub-total	**201000**	**491500**	**344000**	**697750**	**283500**	**329750**	**679000**	**442000**
Total	**1734250**				**1734250**			

4.7.4 Intersection of Nelson Mandela Drive and Furstenburg Avenue

The traffic counts on this intersection indicate that in the mornings the majority of traffic is from Langenhoven Park (685 000) going to the CBD (588 000) and in the afternoons the majority of the traffic is from the CBD (407 000) going to Langenhoven Park (482 250). This indicates that most people commute to the CBD in the morning and back to residential areas like Langenhoven Park in the afternoons as illustrated in Table 4-9 and Table 4-10 below.

Table 4-9: *Morning traffic counts at the intersection of Nelson Mandela Drive and Furstenburg Avenue*

Vehicle Occupancy	FROM				TO			
	CBD	Univer-sitas	Langen-hoven Park	Tempe	CBD	Univer-sitas	Langen-hoven Park	Tempe
1	248250	31000	533500	122500	468500	63000	232000	171750
2	71500	6500	120500	31250	96250	14250	62250	57000
3	8500	2000	27250	2750	19000	2250	7000	12250

4	2250	750	3250	1000	3750	0	2000	1250
5	750	250	500	0	500	0	500	750
Sub-total	**331250**	**40500**	**685000**	**157500**	**588000**	**79500**	**303750**	**243000**
Total	**1214250**				**1214250**			

Table 4-10: *Afternoon traffic counts at the intersection of Nelson Mandela Drive and Furstenburg Avenue*

Vehicle Occupancy	**FROM**				**TO**			
	CBD	**Universitas**	**Langen-hoven Park**	**Tempe**	**CBD**	**Universitas**	**Langen-hoven Park**	**Tempe**
1	284750	21250	224250	118000	199500	10000	347750	91000
2	106750	8750	95750	48500	100000	4250	118500	37000
3	13000	1750	14000	5500	14250	500	13250	6250
4	2500	500	3500	1750	3750	250	2750	1500
5	0	0	2250	0	2250	0	0	0
Sub-total	**407000**	**32250**	**339750**	**173750**	**319750**	**15000**	**482250**	**135750**
Total	**952750**				**952750**			

4.7.5 End of N8 and beginning of Nelson Mandela Drive

The traffic counts done at the end of the N8 and beginning of Nelson Mandela Drive indicate that the bulk of the morning traffic comes from Nelson Mandela Drive going into the N8. This, however, seems to be the case even in the afternoons with 502 750 vehicles coming from Nelson Mandela Drive and 538 000 vehicles going on the N8. This is shown in Table 4-11 and Table 4-12 below.

Table 4-11: *Morning traffic counts at the end of N8 and beginning of Nelson Mandela Drive*

Vehicle Occupancy	**FROM**			**TO**			
	Nelson Mandela Dr.	**Glen Weg**	**N8**	**Nelson Mandela Dr.**	**Glen Weg**	**N8**	**Berg Rd**
1	437000	48500	336000	252500	21000	413500	134000
2	101000	14000	150250	105750	7000	92250	60250
3	7750	3250	35000	22750	250	9000	14000
4	1750	1000	13250	4250	250	1500	10000
5	250	0	3500	1000	0	0	3250
Sub-total	**547750**	**66750**	**538000**	**386250**	**28500**	**516250**	**221500**
Total	**1152500**			**1152500**			

Table 4-12: *Afternoon traffic counts at the end of N8 and beginning of Nelson Mandela Drive*

Vehicle Occupancy	FROM			TO			
	Nelson Mandela Dr.	Glen Weg	N8	Nelson Mandela Dr.	Glen Weg	N8	Berg Rd
1	308750	44500	299750	250750	6750	318750	76750
2	163750	41250	142250	114250	2750	181000	49250
3	23500	9750	30000	22750	0	27250	13250
4	6500	6000	8250	5750	0	10000	5000
5	250	1000	3500	2250	0	1000	1500
Sub-total	**502750**	**102500**	**483750**	**395750**	**9500**	**538000**	**145750**
Total	**1089000**			**1089000**			

4.7.6 Intersection of Aliwal Street and Union Avenue

Traffic counts done at this intersection indicate that in the mornings the bulk of the traffic goes to Aliwal Street (395 750) from Milner Road (579 500) and in the afternoon the bulk of the traffic is from Aliwal Street (320 500) going to Milner Road (510 000). The difference in the number of cars in morning and afternoon commutes may be as a result of commuters leaving work at different times and also attending to other activities after work like shopping and gym. This is illustrated in Table 4-13 and Table 4-14 below.

Table 4-13: *Morning traffic counts at the intersection of Aliwal Street and Union Avenue*

Vehicle Occupancy	FROM				TO			
	Union Ave	Aliwal St.	Harry Smith Rd	Milner Rd	Union Ave	Aliwal St.	Harry Smith Rd	Milner Rd
1	75500	167500	212500	480750	210250	320750	186250	219500
2	55750	47250	51750	86500	35000	65750	70250	70250
3	13750	4500	4500	10500	3000	8250	12500	9500
4	3500	500	500	1250	250	750	2500	1750
5	500	0	0	500	0	250	500	250
Sub-total	**149000**	**219750**	**269250**	**579500**	**248500**	**395750**	**272000**	**301250**
Total	**1217500**				**1217500**			

Table 4-14: *Afternoon traffic counts at the intersection of Aliwal Street and Union Avenue*

Vehicle Occupancy	FROM				TO			
	Union Ave	Aliwal St.	Harry Smith Rd	Milner Rd	Union Ave	Aliwal St.	Harry Smith Rd	Milner Rd
1	170000	243000	167000	183000	71000	120750	202250	366000
2	46500	69750	85750	79250	45250	56250	58000	124750
3	6500	5500	16250	16250	8750	12500	8250	15000
4	1750	1750	3500	4250	2750	2250	2500	3750
5	0	500	750	1250	1250	750	0	500

Sub-total	**224750**	**320500**	**273250**	**284000**	**129000**	**192500**	**271000**	**510000**
Total	**1102500**				**1102500**			

4.8 DATA ANALYSIS

4.8.1 Interviews

Interviews were done prior to the traffic counts in order to get direction of the problematic areas from the regular commuters. Figure 4-7 shows that most people travel between 06:31 and 08:30 in the morning and between 15:31 and 17:30 in the afternoon. Traffic counts were therefore done between 07:00 and 09:00 in the mornings and between 16:00 and 18:00 in the afternoon. In addition to this, the CBD proved to have the most traffic congestion seconded by Willows as illustrated by Figure 4-12. Figure 4-13 shows that Oliver Tambo Road, Nelson Mandela Drive, Dr Belcher, N8 and Harvey Road were some of the problematic roads amongst others. Counts were consequently done at various junctions entering the CBD from various residential areas of Bloemfontein.

4.8.2 Traffic Counts

The data collected indicates that 55% of commuters support the introduction of HOV infrastructure whereas 30% seem undecided and 15% are against it as shown by Figure 4-14. Figure 4-15 furthermore illustrates the number of people each driver is willing to share a ride with. Different ridesharing scenarios were developed based on the combined results of the interviews and physical surveys. Each scenario developed, relates to possible reduction in traffic if ridesharing was to be implemented.

a) Scenario 1 to Scenario 8

Scenarios 1-8 illustrate how much traffic may be reduced if the 55% of commuters in support of the introduction of HOV infrastructure may start to share rides resulting in a 55% shift in vehicle occupancy

b) Scenario 9 to Scenario 16

Scenarios 9-16 illustrate how much traffic may be reduced if the 30% of commuters who were undecided may be convinced to support the introduction of HOV infrastructure and ride-share adding to the 55% who would have already been ridesharing. This means that there will be an 85% shift in vehicle occupancy under different scenarios.

c) Scenario 17 to Scenario 22

Scenarios 17-22 show how much traffic may be reduced if vehicle occupancy may increase by different percentages as shown on figure 4-15. Even though only 22 simulations have been done, more scenarios can be done to determine the reduction in traffic.

4.9 TRAFFIC REDUCTION SIMULATIONS

Scenario 1

This illustrates how much traffic could be decreased if 55% of drivers who are alone could split the cost of a ride with one additional passenger, bringing the vehicle's occupancy up to 2. However, the number of vehicles with 3, 4, and 5 passengers will not change.

Scenario 2

This illustrates how much traffic could be reduced if 55% of commuters in vehicles with a maximum capacity of 2 occupants could add 1 passenger and make their car a 3-occupant vehicle. There will be the same number of vehicles with 1, 4, and 5 occupants.

Scenario 3

This illustrates how much traffic could be alleviated if 55% of commuters in cars with a limit of 3 passengers would make their cars 4 passengers. There are still the same number of vehicles with 1, 2, and 5 occupants.

Scenario 4

This illustrates how much traffic could be cut if 55% of commuters in cars with a maximum seating capacity of 4 could make their cars 5 occupants. Vehicles with 1, 2, and 3 passengers will not change.

Scenario 5

This illustrates how much traffic could be reduced if 55% of vehicles with both 1 and 2 occupants switched to having at least 3 people inside. There will be the same number of vehicles with 4 and 5 passengers.

Scenario 6

This shows how much traffic could be reduced if 55% of the vehicles with 2 and 3 occupants could start having at least 4 occupants. Vehicles having 1 and 5 occupants will remain the same.

Scenario 7

This illustrates how much traffic could be reduced if 55% of the vehicles having 3 and 4 occupants could start having at least 5 occupants. There will be no change in the number of vehicles having 1 and 2 occupants.

Scenario 8

This illustrates how much traffic could be reduced if all 55% of the vehicles with 1, 2, 3, and 4 passengers began to have at least 5 passengers.

Scenario 9

This shows how much traffic could be reduced if 85% of drivers who are travelling alone share a ride with 1 passenger and increase the vehicle occupancy to 2. Vehicles having 3, 4 and 5 occupants will remain the same.

Scenario 10

This illustrates how much traffic could be cut if 85% of commuters in vehicles with a maximum capacity of 2 occupants could add 1 passenger and make their car a 3-occupant vehicle. There will be the same number of vehicles with 1, 4, and 5 occupants.

Scenario 11

This illustrates how much traffic could be reduced if 85% of commuters in cars with a maximum of 3 passengers would increase it to 4 passengers. There will be the same number of vehicles with 1, 2, and 5 occupants.

Scenario 12

This illustrates how much traffic might be cut if 85% of commuters in cars that can only fit 4 people increased the number of passengers to 5. The same number of vehicles with 1, 2, and 3 occupants will continue to be used.

Scenario 13

This shows how much traffic could be reduced if 85% of the vehicles with both 1 and 2 occupants switched to having at least 3 occupants. There will remain the same number of vehicles with 4 and 5 people.

Scenario 14

This illustrates how much traffic could be cut if 85% of vehicles with 2 and 3 occupants switched to having at least 4 occupants. While the others vary, the number of vehicles with 1 and 5 occupants will stay the same.

Scenario 15

This shows how much traffic could be reduced if 85% of the vehicles with 3 and 4 occupants begin to have at least 5 occupants. Vehicles with 1 and 2 occupants will remain unchanged.

Scenario 16

This illustrates how much traffic could be decreased if all of the vehicles with 1, 2, 3, and 4 occupants switched to having at least 5 people inside.

Scenario 17

This illustrates how much traffic could be reduced if 7% of commuters who didn't rideshare before allowed at least one passenger in their private vehicles. This will not alter for vehicles with 3, 4, and 5 occupants.

Scenario 18

This illustrates how much traffic could be reduced if 19 % of commuters who currently commute in vehicles with 2 people could increase it to 3 occupants. However, the quantity of vehicles with 1, 4, and 5 occupants will not change.

Scenario 19

This illustrates how much traffic could be reduced if 26 % of vehicles with 3 passengers could now carry 4. Vehicles with 1, 2, and 5 passengers will not change.

Scenario 20

This illustrates how much traffic could be reduced if 23% of vehicles with 4 passengers switched to 5 passengers. There will be the same number of vehicles with 1, 2, and 3 occupants.

Scenario 21

This demonstrates how much traffic could be decreased if 7% of lone commuters switched to vehicles that could hold 2 people at once. 19% of commuters in cars with 2 passengers rise to 3 passengers, 26% of cars with 3 passengers now have 4 passengers, and 23% of cars with 4 passengers increase to 5 passengers.

Scenario 22

This illustrates how much traffic could be reduced if 7 % of vehicles with 1 occupant, 19 % with 2 occupants, 26 % with 3 occupants, and 23 % with 4 occupants could all start carrying 5 occupants.

The total average hourly traffic was obtained as shown in Table 4-15 below.

Table 4-15: *Determination of average hourly counts per junction*

Vehicle Occupancy	Total morning counts	Total afternoon counts	Hourly morning counts	Hourly afternoon counts	Average hourly counts per junction
1	a	f	= a/2	= f/2	$=((a/2)+(f/2))/2$
2	b	g	= b/2	= g/2	= ((b/2) + (g/2))/2
3	c	h	= c/2	= h/2	= ((c/2) + (h/2))/2
4	d	i	= d/2	= i/2	= ((d/2) + (i/2))/2
5	e	j	= e/2	= j/2	= ((e/2) + (j/2))/2

The percentage of traffic reduced for each scenario was calculated as shown on equation 1 below.

$$\%\ reduction\ for\ Scenario\ X = \frac{total\ hourly\ average\ counts - total\ for\ Scenario\ X}{Total\ hourly\ average\ counts}\ x\ 100\ \ldots\ldots Eq.1$$

The formulas used in calculating traffic reduction for Scenarios 1 – 8 and those for showing traffic reductions for Scenarios 9 – 16 as well as traffic reductions for Scenarios 17 – 22 are shown in Table 4-16, Table 4-17 and Table 4-18 respectively below.

Table 4-16: *Formulas used to determine traffic reduction for scenario 1 to scenario 8*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	a	=0,45*a	a	a	a	=0,45*a	a	a	=0,45*a
2	b	=b+((0,55*a)/2)	=0,45*b	b	b	=0,45*b	=0,45*b	b	=0,45*b
3	c	c	=c+((0,55*b*2)/3)	=0,45*c	c	=c+((0,55*a)/3)+((0,55*b*2)/3)	=0,45*c	=0,45*c	=0,45*c
4	d	d	d	=d+((0,55*c*3)/4)	=0,45*d	d	=d+((0,55*b*2)/4)+((0,55*c*3)/4)	=0,45*d	=0,45*d
5	e	e	e	e	=e+((0,55*d*4)/5)	e	e	=e+((0,55*c*3)/5)+((0,55*d*4)/5)	=e+((0,55*a)/5)+((0,55*b*2)/5)+((0,55*c*3)/5)+((0,55*d*4)/5)
Total	**=a + b + c + d + e**	**=f + j + c + d + e**	**=a + g + k + d + e**	**=a + b + h + l + e**	**=a + b + c + i + m**	**=f + g + n + d + e**	**=a + g + h + o + e**	**=a + b + h + l + p**	**=f + g + h + i + q**

f = 0,45*a

g = 0,45*b

h = 0,45*c

i = 0,45*d

j = b + ((0,55*a)/2)

k = c + ((0,55*b*2)/3)

l = d + ((0,55*c*3)/4)

m = e + ((0,55*d*4)/5)

n = c + ((0,55*a)/3) + ((0,55*b*2)/3)

o = d + ((0,55*b*2)/4) + ((0,55*c*3)/4)

p = e + ((0,55*c*3)/5) + ((0,55*d*4)/5)

q = e + ((0,55*a)/5) + ((0,55*b*2)/5) + ((0,55*c*3)/5) + ((0,55*d*4)/5)

Table 4-17: *Formulas used to determine traffic reduction for scenario 9 to scenario 16*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	a	=0,15*a	a	a	a	=0,15*a	a	a	=0,15*a
2	b	=b+((0,85*a)/2)	=0,15*b	b	b	=0,15*b	=0,15*b	b	=0,15*b
3	c	c	=c+((0,85*b *2)/3)	=0,15*c	c	=c+((0,85*a)/3) +((0,85*b*2)/3)	=0,15*c	=0,15*c	=0,15*c
4	d	d	d	=d+((0,85*c* 3)/4)	=0,15*d	d	=d+((0,85*b*2)/4) +((0,85*c*3)/4)	=0,15*d	=0,15*d
5	e	e	e	e	=e+((0,85*d*4)/5)	e	e	=e+((0,85*c*3)/ 5)+((0,85*d*4)/ 5)	=e+((0,85*a)/5)+((0, 85*b*2)/5)+((0,85*c* 3)/5)+((0,85*d*4)/5)
Total	**=a + b + c + d + e**	**=f + j + c + d + e**	**=a + g + k + d + e**	**=a + b + h + l + e**	**=a + b + c + i + m**	**=f + g + n + d + e**	**=a + g + h + o + e**	**=a + b + h + l + p**	**=f + g + h + i + q**

f = 0,15*a

g = 0,15*b

h = 0,15*c

i = 0,15*d

j = b + ((0,85*a)/2)

k = c + ((0,85*b*2)/3)

l = d + ((0,85*c*3)/4)

m = e + ((0,85*d*4)/5)

n = c + ((0,85*a)/3) + ((0,85*b*2)/3)

o = d + ((0,85*b*2)/4) + ((0,85*c*3)/4)

p = e + ((0,85*c*3)/5) + ((0,85*d*4)/5)

q = e + ((0,85*a)/5) + ((0,85*b*2)/5) + ((0,85*c*3)/5) + ((0,85*d*4)/5)

Table 4-18: *Formulas used to determine traffic reduction for scenario 17 to scenario 22*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	a	=0,93*a	a	a	a	=0,93*a	=0,93*a
2	b	=b+((0,07*a)/2)	=0,81*b	b	b	=((0,07*b)/2)+(0,81*b)	=0,81*b
3	c	c	=c+((0,19*b *2)/3)	=0,74*c	c	=((0,19*b*2)/3)+(0,74*c)	=0,74*c
4	d	d	d	=d+((0,26*c *3)/4)	=0,77*d	=((0,26*c*3)/4)+(0,77*d)	=0,77*d
5	e	e	e	e	=e+((0,23*d*4)/5)	=((0,23*d*4)/5)+e	=e+((0,07*a)/5)+((0,19*b*2)/5)+((0,26*c *3)/5)+((0,23*d*4)/5)
Total	**=a + b + c + d + e**	**=f + j + c + d + e**	**=a + g + k + d + e**	**=a + b + h + l + e**	**=a + b + c + i + m**	**=f + n + o + p + q**	**=f + g + h + i + r**

f = 0,93*a

g = 0,81*b

h = 0,74*c

i = 0,77*d

j = b + ((0,07*a)/2)

k = c + ((0,19*b*2)/3)

l = d + ((0,26*c*3)/4

m = e + ((0,23*d*4)/5)

n = (0,07*b)/2) + (0,81*b)

o = ((0,19*b*2)/3) + (0,74*c)

p = ((0,26*c*3)/4) + (0,777*c)

q = ((0,23*d*4)/5) + e

r = e + ((0,07*a)/5) + ((0,19*b*2)/5) +((0,26*c*3)/5) + ((0,23*d*4)/5)

4.9.1 Possible traffic reduction scenarios for the intersection of Oliver Tambo Road and President Avenue

According to table 4-19 traffic could be reduced by 17,5% under Scenario 1, 5,2% under Scenario 2, 0,8% under Scenario 3, 0,2% under Scenario 4, 28,5% under Scenario 5, 8,6% under Scenario 6, 1,5% under Scenario 7 and 38,8% under Scenario 8.

Table 4-19: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the intersection of Oliver Tambo Road and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	1155	520	1155	1155	1155	520	1155	1155	520
2	515	833	232	515	515	232	232	515	232
3	105	105	294	47	105	506	47	47	47
4	33	33	33	76	15	33	218	15	15
5	8	8	8	8	23	8	8	57	298
Total	**1816**	**1498**	**1722**	**1802**	**1812**	**1298**	**1660**	**1789**	**1111**

Scenarios 9 to 16 in Table 4-20 show how traffic could be reduced if there is an 88% shift in vehicle occupancy under different circumstances. Traffic could be reduced by 27,0% in Scenario 9, 8,0% in Scenario 10, 1,2% in Scenario 11, 0,3% in Scenario 12, 44,1% in Scenario 13, 13,3% in Scenario 14, 2,3% in Scenario 15 and 60,0% in Scenario 16.

Table 4-20: *Traffic reduction possibilities Scenario 9 to Scenario 16 at the intersection of Nelson Mandela Drive and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	1155	173	1155	1155	1155	173	1155	1155	173
2	515	1006	77	515	515	77	77	515	77
3	105	105	397	16	105	724	16	16	16
4	33	33	33	100	5	33	319	5	5
5	8	8	8	8	30	8	8	84	455
Total	**1816**	**1325**	**1670**	**1794**	**1810**	**1016**	**1575**	**1775**	**727**

Table 4-21 below shows that traffic might be reduced by 2,2% under Scenario 17; 1,8% under Scenario 18; 0,4% under Scenario 19; 0,1% under Scenario 20; 4,5% under Scenario 21 and 7,5% under Scenario 22.

Table 4-21: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the intersection of Oliver Tambo Road and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	1155	1074	1155	1155	1155	1074	1074
2	515	555	417	515	515	458	417
3	105	105	170	78	105	143	78
4	33	33	33	53	25	46	25
5	8	8	8	8	14	14	86
Total	**1816**	**1776**	**1783**	**1809**	**1814**	**1735**	**1680**

4.9.2 Possible traffic reduction scenarios for the intersection of Kellner Street and General Dan Pienaar Road

Traffic is seen to be reduced by 19,8% in Scenario 1; 4,5% in Scenario 2; 0,5% in Scenario 3; 0,1% in Scenario 4; 30,6% in Scenario 5; 6,9% in Scenario 6; 0,9% in Scenario 7 and 40,2% under Scenario 8. This is illustrated by Table 4-22 below.

Table 4-22: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the intersection of Kellner Street and General Dan Pienaar Road*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	1773	798	1773	1773	1773	798	1773	1773	798
2	577	1065	260	577	577	260	260	577	260
3	88	88	300	40	88	625	40	40	40
4	27	27	27	63	12	27	222	12	12
5	4	4	4	4	16	4	4	45	367
Total	**2469**	**1981**	**2363**	**2457**	**2466**	**1713**	**2298**	**2447**	**1476**

Table 4-23 below reveals that traffic could well be reduced by 30,5% under Scenario 9; 6,6% under Scenario 10; 0,8% under Scenario 11; 0,2% under Scenario 12; 47,3% under Scenario 13; 10,7% under Scenario 14; 1,4% under Scenario 15 and 62,1% under Scenario 16.

Table 4-23: *Traffic reduction possibilities for Scenario 9 to Scenario 16 at the intersection of Kellner Street and General Dan Pienaar Road*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	1773	266	1773	1773	1773	266	1773	1773	266
2	577	1331	87	577	577	87	87	577	87
3	88	88	415	13	88	917	13	13	13
4	27	27	27	83	4	27	328	4	4
5	4	4	4	4	22	4	4	67	565
Total	**2469**	**1715**	**2306**	**2450**	**2464**	**1301**	**2205**	**2434**	**935**

Scenario 17 shows a traffic reduction of 2,5%; 1,5% reduction is seen at scenario 18; 0,2% at scenario 19; traffic reduction is insignificant at scenario 20; 4,1% at scenario 21 and 7,1% at scenario 22. This is displayed in Table 4-24 below.

Table 4-24: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the intersection of Kellner Street and General Dan Pienaar Road*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	1773	1649	1773	1773	1773	1649	1649
2	577	639	467	577	577	529	467
3	88	88	161	65	88	138	65
4	27	27	27	44	21	38	21
5	4	4	4	4	9	9	91
Total	**2469**	**2407**	**2432**	**2463**	**2468**	**2363**	**2294**

4.9.3 Possible traffic reduction scenarios for the intersection of Kolbe Avenue and President Avenue

Scenario 1 below shows a traffic reduction of 19,0%; a reduction of 4,6% with Scenario 2; 0,6% in Scenario 3; 0,2% in Scenario 4; 29,8% in Scenario 5; 7,5% in Scenario 6; 1,1% in Scenario 7 and 39,7% with Scenario 8. This is displayed in Table 4-25 below.

Table 4-25: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the intersection of Kolbe Avenue and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	2195	988	2195	2195	2195	988	2195	2195	988
2	796	1400	358	796	796	358	358	796	358
3	143	143	435	64	143	837	64	64	64
4	43	43	43	102	19	43	321	19	19
5	9	9	9	9	28	9	9	75	492
Total	**3186**	**2582**	**3040**	**3166**	**3181**	**2235**	**2947**	**3150**	**1921**

According to Table 4-26 below traffic could be reduced by 29,3% under Scenario 9; 7,1% under Scenario 10; 0,9% under Scenario 11; 0,2% under Scenario 12; 46,1% under Scenario 13; 11,6% under Scenario 14; 1,8% under Scenario 15 and 61,3% with Scenario 16.

Table 4-26: *Traffic reduction possibilities for Scenario 9 to Scenario 16 at the intersection of Kolbe Avenue and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	2195	329	2195	2195	2195	329	2195	2195	329
2	796	1729	119	796	796	119	119	796	119
3	143	143	594	21	143	1216	21	21	21
4	43	43	43	134	6	43	472	6	6
5	9	9	9	9	38	9	9	111	755
Total	**3186**	**2253**	**2960**	**3156**	**3179**	**1717**	**2817**	**3130**	**1232**

According to Table 4-27 traffic could be reduced by 2,4% in Scenario 17; 1,6% in Scenario 18; 0,3% in Scenario 19; 0,1% in Scenario 20; 4,4% in Scenario 21 and 7,3% under Scenario 22.

Table 4-27: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the intersection of Kolbe Avenue and President Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	2195	2041	2195	2195	2195	2041	2041
2	796	873	645	796	796	722	645
3	143	143	244	106	143	207	106

4	43	43	43	71	33	61	33
5	9	9	9	9	17	17	130
Total	**3186**	**3109**	**3136**	**3177**	**3184**	**3047**	**2955**

4.9.4 Possible traffic reduction scenarios for the intersection of Nelson Mandela Drive and Furstenburg Avenue

In Table 4-28 below, traffic reduction is seen to be 20,1% under Scenario 1; 4,1% under Scenario 2; 0,5% under Scenario 3; 0,1% under Scenario 4; 30,9% under Scenario 5; 6,7% under Scenario 6; 0,8% under Scenario 7 and 40,4% in Scenario 8.

Table 4-28: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the intersection of Nelson Mandela Drive and Furstenburg Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	1584	713	1584	1584	1584	713	1584	1584	713
2	490	926	221	490	490	221	221	490	221
3	75	75	255	34	75	545	34	34	34
4	16	16	16	47	7	16	182	7	7
5	4	4	4	4	11	4	4	36	318
Total	**2169**	**1733**	**2079**	**2159**	**2167**	**1498**	**2024**	**2151**	**1292**

Traffic reduction is displayed in Table 4-29 below as 31,0% under Scenario 9; 6,4% under Scenario 10; 0,7% under Scenario 11; 0,1% under Scenario 12; 47,7% under Scenario 13; 10,3% under Scenario 14; 1,3% under Scenario 15 and 62,5% under Scenario 16.

Table 4-29: *Traffic reduction possibilities for Scenario 9 to Scenario 16 at the intersection of Nelson Mandela Drive and Furstenburg Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	1584	238	1584	1584	1584	238	1584	1584	238
2	490	1163	74	490	490	74	74	490	74
3	75	75	353	11	75	801	11	11	11
4	16	16	16	64	2	16	272	2	2
5	4	4	4	4	15	4	4	53	489
Total	**2169**	**1496**	**2030**	**2153**	**2166**	**1133**	**1945**	**2141**	**814**

Traffic reduction of 2,5% is seen under Scenario 17; 1,4% under Scenario 18; 0,2% under Scenario 19; 0,0% under Scenario 20; 4,2% under Scenario 21 and 7,1% under Scenario 22. This is shown in Table 4-30 below.

Table 4-30: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the intersection of Nelson Mandela Drive and Furstenburg Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	1584	1473	1584	1584	1584	1473	1473
2	490	545	397	490	490	452	397
3	75	75	137	56	75	118	56
4	16	16	16	31	12	27	12
5	4	4	4	4	7	7	78
Total	**2169**	**2114**	**2138**	**2164**	**2168**	**2077**	**2016**

4.9.5 Possible traffic reduction scenarios for the intersection of Nelson Mandela Drive and N8

According to Table 4-31 below traffic reduction is seen to be 18,1% in Scenario 1; 5,0% in Scenario 2; 0,7% in Scenario 3; 0,2% in Scenario 4; 29,1% in Scenario 5; 8,2% in Scenario 6; 1,2% in Scenario 7 and 39,2% under Scenario 8.

Table 4-31: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the end of N8 and beginning of Nelson Mandela Drive*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	1475	664	1475	1475	1475	664	1475	1475	664
2	613	1019	276	613	613	276	276	613	276
3	109	109	334	49	109	604	49	49	49
4	37	37	37	82	17	37	251	17	17
5	9	9	9	9	25	9	9	61	358
Total	**2243**	**1837**	**2131**	**2228**	**2239**	**1590**	**2059**	**2215**	**1364**

Table 4-32 below shows a traffic reduction of 28,0%, 7,8%, 1,0%, 0,3%, 45,0%, 12,7%, 1,9% and 60,6% in Scenario 9, Scenario 10, Scenario 11, Scenario 12, Scenario 13, Scenario 14, Scenario 15 and Scenario 16 respectively.

Table 4-32: Traffic *reduction possibilities for Scenario 9 to Scenario 16 at the end of N8 and beginning of Nelson Mandela Drive*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	1475	221	1475	1475	1475	221	1475	1475	221
2	613	1240	92	613	613	92	92	613	92
3	109	109	456	16	109	874	16	16	16
4	37	37	37	106	6	37	367	6	6
5	9	9	9	9	34	9	9	90	549
Total	**2243**	**1616**	**2069**	**2220**	**2237**	**1233**	**1959**	**2200**	**884**

Traffic could well be reduced by 2,3%, 1,7%, 0,3%, 0,1%, 4,4% and 7,4% in Scenario 17, Scenario 18, Scenario 19, Scenario 20, Scenario 21 and Scenario 22 respectively. This is shown in Table 4-33 below.

Table 4-33: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the end of N8 and beginning of Nelson Mandela Drive*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	1475	1372	1475	1475	1475	1372	1372
2	613	665	497	613	613	548	497
3	109	109	187	81	109	158	81
4	37	37	37	58	28	50	28
5	9	9	9	9	16	16	100
Total	**2243**	**2191**	**2204**	**2236**	**2241**	**2144**	**2077**

4.9.6 Possible traffic reduction scenarios for the intersection of Aliwal Street and Union Avenue

Scenario 1, Scenario 2, Scenario 3, Scenario 4, Scenario 5, Scenario 6, Scenario 7 and Scenario 8 show traffic reductions of 20,1%, 4,1%, 0,5%, 0,1%, 31,0%, 6,7%, 0,8% and 40,5% respectively. This is illustrated in Table 4-34 below.

Table 4-34: *Traffic reduction possibilities for Scenario 1 to Scenario 8 at the intersection of Aliwal Street and Union Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1	1699	765	1699	1699	1699	765	1699	1699	765
2	523	990	235	523	523	235	235	523	235
3	78	78	270	35	78	581	35	35	35
4	17	17	17	49	8	17	193	8	8
5	4	4	4	4	11	4	4	37	339
Total	**2321**	**1854**	**2225**	**2310**	**2319**	**1602**	**2166**	**2302**	**1382**

It is clear from Table 4-35 below, that there is a traffic reduction of 31,1% under Scenario 9; 6,4% under Scenario 10; 0,7% under Scenario 11; 0,1% under Scenario 12; 47,9% under Scenario 13; 10,3% under Scenario 14; 1,2% under Scenario 15 and 62,5% under Scenario 16.

Table 4-35: *Traffic reduction possibilities for Scenario 9 to Scenario 16 at the intersection of Aliwal Street and Union Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
1	1699	255	1699	1699	1699	255	1699	1699	255
2	523	1245	78	523	523	78	78	523	78
3	78	78	374	12	78	856	12	12	12
4	17	17	17	67	3	17	289	3	3
5	4	4	4	4	16	4	4	55	522
Total	**2321**	**1599**	**2173**	**2304**	**2318**	**1210**	**2082**	**2292**	**870**

Scenario 17 in Table 4-36 below shows a possible traffic reduction of 2,5%; 1,4% under Scenario 18; 0,2% under Scenario 19; Scenario 20 doesn't show a significant change; 4,2% under Scenario 21 and 7,1% under Scenario 22.

Table 4-36: *Traffic reduction possibilities for Scenario 17 to Scenario 22 at the intersection of Aliwal Street and Union Avenue*

Vehicle Occupancy	Average Hourly Counts	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
1	1699	1580	1699	1699	1699	1580	1580
2	523	582	424	523	523	483	424
3	78	78	144	58	78	124	58
4	17	17	17	32	13	28	13
5	4	4	4	4	7	7	83
Total	**2321**	**2262**	**2288**	**2316**	**2320**	**2223**	**2157**

4.10 AVERAGE TRAFFIC REDUCTION FOR ALL JUNCTIONS

The average traffic that could well be reduced on all junctions assessed was seen to be 19,1% under Scenario 1; 4,6% under Scenario 2; 0,6% under Scenario 3; 0,2% under Scenario 4; 30,0% under Scenario 5; 7,4% under Scenario 6; 1,1% under Scenario 7 and 39,8% under Scenario 8. In the case whereby 85% of commuters might be swayed to ride-share the average traffic reduction at all junctions assessed could be reduced by 29,5% in Scenario 9; 7,1% in Scenario 10; 0,9% in Scenario 11; 0,2% in Scenario 12; 46,4% in Scenario 13; 11,5% in Scenario 14; 1,7% in Scenario 15 and 61,5% under Scenario 16. In the case whereby vehicle occupancy is increased by different percentages, traffic could well be reduced by an average of 2,4% under Scenario 17; 1,6% under Scenario 18; 0,3% under Scenario 19; 0,1% under Scenario 20; 4,3% under Scenario 21 and 7,3% under Scenario 22. This is shown in Table 4-37 below.

Indicated in Table 4-37 below, it is clear that most traffic reduction is seen when 55% of commuters in vehicles having 1, 2, 3 or 4 occupants increase their vehicle occupancies to 5 occupants per vehicle. This is indicated by Scenario 8 which shows an average traffic reduction of 39,8%. An average traffic reduction of 30% is seen in the case whereby vehicles carrying 1 and 2 occupants now start carrying 3 occupants. The third highest traffic reduction when there is a 55% shift in vehicle occupancy is seen when 55% of commuters in single occupancy vehicle start to now have at least one passenger. More traffic may be reduced when more (85%) commuters are convinced to ride-share. This traffic reduction however still shows that the most traffic could well be reduced when commuters switch to vehicles with an occupancy of 5, when vehicles having an occupancy of 1 and 2 could start having an occupancy of at least 3 and when 85% of vehicles having one occupant carry at least one passenger as seen with the 61,5% traffic reduction shown in Scenario 16; 46,4% traffic reduction shown in Scenario 13 and 29,5% traffic reduction shown in Scenario 9 respectively.

However, traffic is reduced by less than 10% in situations when there is a low shift in vehicle occupancy, particularly single occupancy, as shown by scenarios 17 to 22. This demonstrates that there are fewer private vehicles on the roads the higher the vehicle occupancy. Therefore, ridesharing can help reduce single occupancy vehicles during peak hours while also improving private vehicle occupancy.

Table 4-37: *Average traffic that may be reduced in all junctions per scenario*

Vehicle occupancy scenarios	% Traffic reduction						Average % traffic reduction
	Oliver Tambo Rd. & President Ave.	Kellner St. & General Dan Pienaar Rd.	Kolbe Ave. & President Ave.	Nelson Mandela Dr. & Furstenburg Ave.	Nelson Mandela Dr. & N8	Aliwal Str. & Union Ave.	
Scenario 1	17,5	19,8	19,0	20,1	18,1	20,1	19,1
Scenario 2	5,2	4,5	4,6	4,1	5,0	4,1	4,6
Scenario 3	0,8	0,5	0,6	0,5	0,7	0,5	0,6
Scenario 4	0,2	0,1	0,2	0,1	0,2	0,1	0,2
Scenario 5	28,5	30,6	29,8	30,9	29,1	31,0	30,0
Scenario 6	8,6	6,9	7,5	6,7	8,2	6,7	7,4
Scenario 7	1,5	0,9	1,1	0,8	1,2	0,8	1,1
Scenario 8	38,8	40,2	39,7	40,4	39,2	40,5	39,8
Scenario 9	27,0	30,5	29,3	31,0	28,0	31,1	29,5
Scenario 10	8,0	6,6	7,1	6,4	7,8	6,4	7,1
Scenario 11	1,2	0,8	0,9	0,7	1,0	0,7	0,9
Scenario 12	0,3	0,2	0,2	0,1	0,3	0,1	0,2
Scenario 13	44,1	47,3	46,1	47,7	45,0	47,9	46,4
Scenario 14	13,3	10,7	11,6	10,3	12,7	10,3	11,5
Scenario 15	2,3	1,4	1,8	1,3	1,9	1,2	1,7
Scenario 16	60,0	62,1	61,3	62,5	60,6	62,5	61,5
Scenario 17	2,2	2,5	2,4	2,5	2,3	2,5	2,4
Scenario 18	1,8	1,5	1,6	1,4	1,7	1,4	1,6
Scenario 19	0,4	0,2	0,3	0,2	0,3	0,2	0,3
Scenario 20	0,1	0	0,1	0	0,1	0	0,1
Scenario 21	4,5	4,1	4,4	4,2	4,4	4,2	4,3
Scenario 22	7,5	7,1	7,3	7,1	7,4	7,1	7,3

4.11 SUMMARY OF FINDINGS

The following findings were reached after analysing the data with regards to demographics and vehicles of respondents, peak time trips, HOV infrastructure, ridesharing and traffic counts. The majority of the responses were obtained from males and most respondents fell between the age brackets of 20 to 45 years.

- Motor cars with a carrying capacity of 5 people are the dominant mode of private transportation used.
- Most respondents indicated that they take between 6 and 14 trips per week.
- Morning peak times were seen to be between 06:30 and 08:30 whereas the peak travel times in the afternoon were found to be between 15:31 and 17:30.
- Commuters indicated they mostly take less than 30 minutes to travel 5-10 km during their morning and afternoon trips which are usually to travel to work.
- Most trips taken during peak times are from the township to the CBD.
- The CBD experiences the most congestion in Bloemfontein with Oliver Tambo Road carrying the lion's share of this congestion and recommended for conversion to HOV road followed by Nelson Mandela Drive and Dr Belcher Road coming in at third position.
- Just over half (55%) of the drivers are open to share a ride with most responses indicating they can share a ride with 3 people while 15% are against ridesharing and 30% are neutral.
- Traffic counts indicated that movement of traffic in the morning is from residential areas to the CBD and from the CBD to residential areas in the afternoon. The highest movement comes from the townships to the CBD followed by some 12 people out of 50 saying they usually just move around the CBD and the remaining indicating commutes from other suburbs to the CBD and other destination around the study area.
- The highest combination of traffic counts for both morning and afternoon trips were found to be at the intersection of Kolbe Avenue and President Avenue (12747) followed by Kellner Street and General Dan Pienaar Road with a total of 9875 vehicles; Aliwal Street and Union Avenue standing at 9280 vehicles; Nelson Mandela Drive and N8 at 8966 vehicles; Nelson Mandela Drive and Furstenburg Avenue at 8668 vehicles and Oliver Tambo Road and President Avenue at 7264 vehicles.
- Traffic could well be reduced by up to 39,8% when there is a 55% shift in vehicle occupancy and 61,5% when there is a 88% shift and vehicle occupancy. The most significant traffic reduction is seen when there are less vehicles having 1 or 2 occupants and more having 5 occupants.

- The next chapter shows recommendations, guidelines and policies which were developed after the data was collected and analysed in this chapter. The chapter also suggests the possible research areas scholars may take in order to solve the problem of mobility and improve the performance of HOV infrastructure.

CHAPTER 5. FINDINGS, POLICY GUIDELINES, AND CONCLUSION

5.1 INTRODUCTION

The development of a set of planning and design guidelines to reduce congestion, improve mobility and encourage the use of HOV in Bloemfontein, South Africa required an investigation that evaluated the peak commute trips, problem areas during those peak times and the possibility of improving mobility on the most congested roads. Therefore, several types of analysis, including a literature review, the analysis of data from completed surveys, and the analysis of secondary data, were done at various stages for the goal of this study. The amount of possible traffic reduction that can occur as a result of the introduction of HOV infrastructure in Bloemfontein was then evaluated.

In this chapter, inferences are drawn from the results of the analyses conducted followed by the development of a planning concept for the reduction of traffic congestion at peak times. The inferences drawn and development concept were used to evolve policy guidelines and plausible recommendations for the reduction of congestion at peak times through the use of HOV infrastructure in the roads of the study area. These inferences are presented in the following section.

5.2 INFERENCES FROM LITERATURE REVIEW

The following inferences can be made:

- Urbanization has resulted in a sharp population growth in cities and a surge in vehicles which has become a burden on the transportation infrastructure.
- Traffic congestion is the way the movement of vehicles is delayed due to the limited road capacity. Congestion may be a sign of economic growth or deterioration of urban areas.
- Recurrent congestion occurs at the same time and place every day whereas non-recurrent congestion is a result of unplanned events.
- Traffic congestion occurs mostly during morning commutes from residential areas to the CBD and from the CBD to residential areas in the afternoon.

- Traffic congestion is an area of concern in both developing and developed cities as it constrains mobility and reduces accessibility. Even though it is a concern in both developed and developing world countries, traffic congestion is more prevalent in cities of developing countries.
- South Africa is experiencing high population increases and urbanization which is anticipated to leave 71.3% of the population leaving in urban areas by 2020. This increase calls for the need to improve urban infrastructure and other solutions to accommodate growth without compromising the quality and efficiency of services.
- Car ownership has tremendously increased in South Africa and the increased use of private vehicles in cities results in the growing demand for parking spaces and road network capacity. Growing car ownership and congestion are a threat to transportation stability in urban areas globally.
- People in Bloemfontein use private cars as their main means of commuting with around 77% of the population using their private vehicles for their daily commutes.
- In 2020, vehicle ownership in the Free State stood at 544 653 with motor cars and station wagons making the majority of this at 320 424 seconded by light duty vehicles at 133 018.
- Causes of traffic congestion may be classified as micro-level factors and macro-level factors. Macro-level factors include land use, car ownership trends and geographical economic development. Micro-level factors are high number of people and vehicles on the roads at the same time resulting in overflow of vehicles on the limited road space.
- Public transportation is often regarded as unreliable, unsafe and inconvenient and people with access to private vehicles therefore are less interested in using public transportation.
- The dispersed urban form of South Africa as an effect of the apartheid system and automobile driven planning has resulted in long commute times as economic activities are usually concentrated in one area.
- The low occupancy of private vehicles at peak times also causes traffic congestion.
- Lack of accessibility of non-motorized transportation and the rapid growth of motorized transportation are a growing concern for developing cities.
- Excessive use of private vehicles has resulted in high levels of congestion, excessive carbon emissions, poor air quality and health and community degradation.
- Traffic congestion results in increased fuel congestion, massive delays and reduced productivity.
- Cars stopped in traffic release a lot of carbon emissions which cause global warming, fog and respiratory diseases.

- Traffic congestion also results in stress and frustration in drivers who end up getting in accidents due to impatience.
    - There are various ways to mitigate traffic congestion which include modal shift from private to public transportation, improving and expanding the existing road infrastructure, dedicated lanes for pedestrians and cyclists, reducing single occupancy vehicles through the introduction of HOV lanes and ridesharing.
    - HOV lanes are special lanes designated for use by HOVs including carpools and buses. HOV infrastructure is therefore designed to reduce congestion by maximizing the movement of people and not vehicles.
    - HOV lanes provide an incentive to ridesharing by giving commuters reliable travel time as they get to use the less congested lane but also have an option to use the GP lanes. This will result in a decrease in the number of solo drivers and vehicles on the roads.
    - The South African economy has been underperforming in comparison to other middle-income countries when looking at key indicators such as exports, investment, competition innovation and productivity and therefore cost-effective congestion mitigation measure need to take precedence.
    - While medium-sized cities have other means of commute, some medium-sized cities like Bloemfontein have no rail transportation for local trips. This results in high use of private vehicles, and it is therefore crucial to introduce HOV infrastructure as most people seem to be inclined to using private transportation than taxis.
    - Part of improving transportation sustainability is introducing the BRT system and this requires proper planning as well as HOV infrastructure. The proper location of HOV infrastructure in order to avoid congestion bottlenecks will result in reduced travel costs during morning commutes.
    - Ridesharing may be categorized as carpooling which is when the journey fulfils the driver's needs and ride-pooling whereby the driver is just the service provider. Ridesharing is therefore an environment and society friendly means to solve several road traffic problems.
    - P2P ridesharing aims to capture the benefits of TNCs like Uber while reducing their adverse impact on the environment and transportation infrastructure. It allows for travel time and cost reduction for both drivers and passengers and mitigates city congestion as users get to enjoy the benefits of using HOV lanes. Ridesharing also provides an alternative to public transportation where there is a gap.

- A flexible ridesharing system should be able to match drivers and riders in a short period of time based on their trip information and therefore requires a lot of people to be enrolled to it.
- Park and ride facilities and HOV infrastructure designed to bypass congestion points are some of the incentives that may be used to encourage commuters to share rides.
- Bloemfontein was selected as the study area because it is experiencing rapid urbanisation like most middle-sized cities across the globe, has no other modes of transportation besides road and is in a developing country.

5.3 INFERENCES FROM SURVEYS, TRAFFIC COUNTS AND DATA ANALYSIS

The inferences drawn from the various surveys conducted in the study area are presented below:

- 150 interviews were prepared and administered around Bloemfontein to drivers and vehicle owners.
- 80% of the respondents were male and 20% female. This however did not have any clear impact on the responses received.
- Of the 150 responses received 35 respondents were between 31 and 35 years, 30 were between 26 and 30 years, 27 between 36 and 40 years, 20 between 41 and 45 years, 18 between 20 and 25 years, 8 below 20 years, 5 between 46 and 50 years and 3 between 51 and 55 years. The remaining 4 respondents were above 55 years.
- The majority (80%) of the people use motor cars and only 20% indicated they use pickup trucks ('bakkies').
- Most (69%) private vehicles in the study area can carry up to 5 people. 15% of the vehicles were said to carry up to 3 people, 10% up to 2 people and 6% had a carrying capacity of up to 7 people.
- The number of trips taken by most commuters (46,7%) range between 6 and 14 trips per week. 18,7% of commuters make 2 to 6 trips per week, 11,3% take 18 to 22 trips per week, 6,7% take 14 to 18 trips, 3,3% take 22 to 26 trips, 4% take between 26 and 30 trips whereas 9,3% of commuters take over 30 trips weekly.
- The morning peak travel times are between 06:31 and 08:30. Traffic then drops after 08:30 and starts peaking again in the afternoon between 15:31 and 17:30 after which less people are travelling.
- The majority of commuters take less than 30 minutes for their morning and afternoon commutes. 47 commuters take 30 minutes to an hour in their morning commutes and

43 commuters take 30 minutes to an hour in their afternoon commutes. The number of commuters taking an hour to 1.5 hours for morning and afternoon trips is 20 and 22 respectively. There are only 5 and 7 people taking over 1.5 hours for their morning and afternoon trips respectively.

- 42 people travel an average distance of 5-10 km per trip, 35 travel over 25 km, 26 travel 10-15 km, 19 travel less than 5 km, 16 travel 15-20 km and 12 travel an average distance of 20-25 km.
- Work trips are the most popular (40,1%) followed by shopping (19,9%), dropping and picking children from school (15,9%), university (11,2%), gym (9%) and others (4%).
- The majority (14,7%) of the trips taken during peak time commutes are from the township to the CBD. 8% of trips taken are around the CBD, 4,7% from Langenhoven Park to the CBD, 2% from Phase 2 to the CBD, 2,7% from Batho to the CBD, 2,7% from Batho to Willows and another 2,7% from Universitas to the CBD. Most of the remaining 62.5% of the trips originate from different parts of Bloemfontein with the majority coming from the Southwestern Quadrant followed by the Southeastern Quadrant going to South Western quadrant of Bloemfontein and the CBD.
- Most respondents (84%) are for the introduction of HOV infrastructure and 16% of the respondents are against it.
- The CBD experiences the most traffic as stated by 68% of the people followed by Willows at 10% and Batho location at 2.7%. Other areas experiencing significant traffic are Heidedal, Hamilton, Brandwag and Rocklands.
- Introduction of HOV infrastructure is recommended for Oliver Tambo Road (33.5%), Nelson Mandela Drive (19.1%), Dr. Belcher Road (8%), N8 (6.4%) and Harvey Road (4.8%) among others.
- About 55% of the commuters in Bloemfontein are open to ridesharing, 15% are against it whereas 30% are in between.
- Of the 150 responses received 39 people are willing to ride-share with 3 people, 34 are willing to ride-share with 4 people, 29 are willing to share the vehicle with 2 people, 11 are willing to share a ride with at least 1 person whereas 29 are not willing to share their vehicles. The remaining 8 respondents indicated they are willing to share their rides with 5 people or more.
- Based on the information gathered from the interviews, it was determined where traffic surveys might be carried out to learn more about Bloemfontein's traffic patterns and vehicle occupancy. The surveys were conducted at the intersection of Oliver Tambo Road and President Avenue; intersection of Kolbe

Avenue and Victoria Road; intersection of Nelson Mandela Drive and Furstenburg Avenue; end of Nelson Mandela Drive and beginning of N8; intersection of General Dan Pienaar Drive and Kellner Street and intersection of Aliwal Street and Union Avenue.

- Different simulations were done to show how traffic may be reduced and different vehicle occupancy scenarios.
- Traffic counts showed that the majority of the traffic goes towards the CBD in the mornings from residential areas and from the CBD in the afternoons.
- Traffic may be reduced by 39,7% when there is a 55% shift in vehicle occupancy and up to 61,5% when there is an 85% shift in vehicle occupancy.
- The most traffic reduction happens when single occupancy vehicles and vehicles with one passenger are reduced on the roads and more vehicles start having an occupancy of up to 5 commuters.

This investigation shows that the main aspect which determines the number of cars on the roads is vehicle occupancy. Vehicle occupancy as well as HOV infrastructure are therefore crucial parameters in trying to mitigate traffic congestion in cities as HOV infrastructure is a cost-effective way to mitigate traffic congestion. Investigations showed that the higher the number of occupants in the car the less the number of cars on the roads. It was found that traffic may be reduced by up to 39,7% if there is a 55% shift in vehicle occupancy and up to 61,5% if there is an 85% shift in vehicle occupancy. The most traffic was seen to be reduced when a significant number of single occupancy vehicles started travelling with passengers. HOV infrastructure may therefore play a crucial role as an incentive to ridesharing as it gives vehicles having more than one occupant the privilege to use the HOV lane. This gives commuters in high occupancy lanes the liberty to choose between using the GP lane and HOV lane whereas single occupancy vehicles are restricted to the GP lane.

5.4 PLANNING CONCEPT

A concept to enhance mobility and reduce traffic congestion has been devised for the study area. This concept is based on the two major parameters influencing traffic flow which are road infrastructure and the number of private vehicles on the roads. This investigation reveals that the improved usage of HOV infrastructure as well as ridesharing may decongest the roads, enhance mobility of the study area, decrease the carbon footprint, reduce fuel costs and improve the sustainability of cities. Improvement of HOV infrastructure and implementation of ridesharing will however require effective planning and policy interventions.

In order to develop a broad set of policy guidelines and plausible recommendations, the following broad planning concept strategies have been adopted:

1. Centralization of economic activities to the CBD resulted in a lot of movement in that area hence congestion in the roads accessing the CBD. With the high rate of urbanization and inadequate road infrastructure, roads leading to the CBD have proven to be insufficient to carry the traffic. Appropriate policy interventions therefore have to be put in place for the identification of key arterial roads to the CBD.
2. Congestion has proven to be around the CBD of the study area which is built up already and has no space for expansion of roads infrastructure. HOV infrastructure may therefore be introduced on the busy streets and incorporated into the already existing infrastructure. Designs and implantation of such therefore needs to take place.
3. Policies have to be put in place to ensure the end user is informed on how the HOV infrastructure works as well as to monitor the proper use of it in order to get the intended results of reduced congestion.
4. Private vehicles were major contributors to traffic congestion as most have only one occupant. With the inadequate public transportation as well as personal preference not to use public transport by commuters, measures should therefore be devised to encourage ridesharing amongst commuters.
5. For HOV infrastructure and ridesharing to be effective in reducing traffic congestion in the study area, they have to be properly used. Appropriate policies and measures should therefore be put in place to monitor their proper usage.

5.5 ALTERNATIVE POLICIES

A number of alternative policies have been devised based on this planning concept and the different simulated scenarios for improvement of HOV infrastructure and introduction of ridesharing as a mitigation to traffic reduction. These are presented below:

- Policy 1 – A policy to identify streets that can accommodate HOV lanes. This will be the streets that were already identified in the surveys as being congested and may be able to accommodate a HOV lane.
- Policy 2 – A policy to ensure designs and implementation plans are done on how to incorporate HOV lanes into the already existing key arterial roads to the CBD.
- Policy 3 – A policy to educate the public on the proper use of HOV infrastructure as well as ridesharing.

- Policy 4 – A policy that states that private vehicles carrying a minimum of 2 passengers are to be permitted to use HOV infrastructure with the option to switch to GP lanes if they wish to do so. These private vehicles shall have the privilege to use the HOV lane together with other public transportation.
- Policy 5 – A policy to introduce the BRT system in middle sized cities to fully take advantage of the new HOV infrastructure introduced and support high occupancy private vehicles in mitigating congestion.
- Policy 6 – A policy to give vehicle owners and drivers who ride share incentives such as discounted car license fees.
- Policy 7 - A policy to sensitize commuters on the use HOV infrastructure and to try and have an 85% shift in vehicle occupancy which may result in traffic reduction of up to 61.5%.
- Policy 8 – A policy to ensure that the vehicles using HOV lanes are indeed public transportation and private vehicles carrying the stipulated number of occupants. Law breakers shall be liable to a fine determined by the law enforcement officers in their traffic act.
- Policy 9 – A policy to install traffic cameras in the city along routes with HOV lanes to ensure only vehicles that meet the requirements for HOV lane use them.
- Policy 10 – A policy to develop an application to facilitate in connecting drivers and passengers who would like to rideshare.

5.5.1 Recommended Policies

Based on the detailed analysis of the various policies, it was observed that policy number 7 would yield better results in terms of reducing traffic congestion in middle sized cities. The policy has been devised looking at the fact that the population of middle-sized cities together with the economy of developing countries like South Africa does not favor mass transit systems. It was devised after findings and scenarios showed that the introduction of HOV infrastructure and promotion of ridesharing may significantly reduce traffic congestion and therefore communities need to be informed of these and how they could be of benefit to them. This policy together with other policies will not only result in the reduction of private vehicles on the roads but also facilitate the BRT system and help improve public transportation.

5.6 PLAUSIBLE PLANNING GUIDELINES AND RECOMMENDATIONS

The goal of this study was to find solutions to Bloemfontein's traffic problems, make plans for future road congestion, and enhance mobility. After the analysis of various factors, literature, findings from interviews and data from traffic counts, the following recommendations are proposed for reducing traffic congestion in addition to the policy guidelines presented above:

- Major arterial roads accessing the CBD and experiencing the most traffic congestion need to be identified.
- The routes identified as the most congested around the city need to be assessed to determine whether they may be able to accommodate HOV lanes or not.
- Designs have to be done as to how HOV infrastructure may be incorporated into the already existing roads. These designs shall include the design of HOV lanes as well as installation of monitoring cameras.
- Competent contractors are to be engaged to execute the construction of HOV lanes while trying to keep disruption of everyday traffic flow to a minimum.
- The newly HOV lanes will be constructed to fit perfectly into the already existing infrastructure and offer a seamless transmission between general lanes and HOV lanes while still showing clear boundaries of the two.
- The community shall be made aware of the new infrastructure as well as ridesharing and how this can help in reducing congestion especially at peak times through media platforms like local radio stations as well as social media.
- Incentives shall be provided for drivers and vehicle owners who ride-share and use HOV lanes.
- HOV infrastructure will be monitored to ensure it is used by the rightful patron and thereby functions optimally to achieve the desired results. Offenders of this system will be sentenced accordingly.
- Commuters to ride-share might initially be colleagues, family members or friends travelling in similar directions. This will however ultimately extend to strangers having similar trip origins and destinations. The connection of drivers shall be facilitated by a system designed to connect drivers which commuters will be required to register on in large numbers for easy pairing.

5.7 CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

The rapid urbanization resulting in traffic congestion in middle sized cities warranted an investigation to determine how traffic congestion may be reduced in cities of developing economies. In this research data from interviews was analyzed and various scenarios formulated from traffic counts to analyze the problem and explore plausible policies and planning guidelines as a way to mitigate the problem. The objective of the investigation was to determine the biggest cause of traffic congestion in middle sized cities, the impacts of that congestion as well as the possible mitigation measures after considering all factors in order to come up with appropriate policy and planning guidelines to improve mobility and accessibility of transportation infrastructure.

Interviews were used for the collection of data from drivers and vehicle owners for this purpose and subsequent statistical analyses were conducted. Traffic counts were also conducted, and various simulated scenarios were developed under various conditions to assist in engineering policies and interventions that may help to reduce congestion in middle sized cities. The analyses revealed that infrastructure and vehicle occupancy are the most influential parameters of traffic congestion. Traffic congestion was seen to reduce significantly as vehicle occupancy increased with the most reduction observed when the vehicle occupancy reached the maximum capacity of cars. The analyses also revealed that the CBD and access roads to it are the most congested in the city. In addition to this, most private vehicles were observed to only have one occupant. A number of alternate policies and plausible planning guidelines were therefore developed based on the simulated model results. It was observed that the policy which combines having an 85% shift in vehicle occupancy and educating the public on the importance of HOV infrastructure and ridesharing resulted in traffic reduction of up to 61.5%. Concurrently other policies are needed to ensure that HOV infrastructure is utilized by the vehicles intended for it and measures are put in place for law breakers.

The investigations however had certain limitations which included a limited number of respondents to the interviews. The data collection happened during a Covid-19 year where physical contact with people was kept to a minimum and therefore people were a bit hesitant to physically take part in answering the interviews. Electronic interviews were also circulated but the responses received were also not much. In addition to this, the scope of the study was restricted to Bloemfontein and not extended to other middle-sized cities in the country. In order to generalize the implications of this research, similar investigations in other cities need to be conducted and extensive surveys done.

The study offers more opportunities for further research which include:

- The investigation of how the introduction of HOV infrastructure and ridesharing affect the life span of roads.
- The investigation on the detailed design of HOV lanes to incorporate into existing infrastructure.
- The investigation of how drivers may be connected to facilitate ridesharing.

However, it is anticipated that traffic congestion in Bloemfontein and other cities with a high percentage of residents who travel by private vehicle will be greatly decreased if the existing realistic policies and planning guidelines generated by the current inquiry are put into practice. As a result, the usability and accessibility of roadways will significantly increase.

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ANNEXURE A (INTERVIEW QUESTIONS)

A STUDY ON THE POSIBILITY OF INTRODUCING HIGH OCCUPANCY VEHICLE (HOV) INFRASTRUCTURE IN BLOEMFONTEIN

1. Gender:
    - Male:
    - Female:

2. Age:
   ………………………………………………………………………………………………

3. Type of vehicle usually used
    - Motor cars
    - Light duty vehicle – bakkie
    - Motorcycle
    - Minibus
    - Bus
    - Others ………………….

4. How many trips do you take per weekday (if your trips are going to work and back 5times a week, it means you take an average of 10 trips per week)?
    - 2-6 trips
    - 6-10 trips
    - 10-14 trips
    - 14-18 trips
    - 18-22 trips
    - 22-26 trips
    - 26-30 trips
    - Over 30 trips

5. What are the usual travel times for the morning and afternoon trips taken (please make more than one selection)?
    - Before 06:30
    - 06:31 – 07:30
    - 07:31 – 08:30
    - 08:31 – 09:30
    - 12:30 – 13:30
    - 13:31 – 14:30

- 14:31 – 15:30
- 15:31 – 16:30
- 16:31 – 17:30
- 17:31 – 18:30
- After 18:30

6. State the average time taken for your morning and afternoon commutes.

   Morning
   - Less than 30 minutes
   - 30 minutes to an hour
   - 1 hour to 1.5 hours
   - Over 1.5 hours

   Afternoon
   - Less than 30 minutes
   - 30 minutes to an hour
   - 1 hour to 1.5 hours
   - Over 1.5 hours

7. What is the average distance travelled per trip (in kilometres)?
   - Less than 5 km
   - 5 km to 10 km
   - 10 km to 15 km
   - 15 km to 20 km
   - 20 km to 25 km
   - Over 25 km

8. What is the usual purpose of travel (you can make more than one selection)?
   - Work
   - University
   - Dropping and picking children from school
   - Shopping
   - Gym
   - Others…………………

9. What is the usual origin and destination of your morning and afternoon trips (e.g. Bayswater to CBD, CBD to Mangaung)?

…………………………………………………………………………………………………

……………………………………………………………………………………………….

10. Would you accept high occupancy vehicle infrastructure if it was introduced and meant cost and time savings to you as a commuter?
    - Yes
    - No

11. Which areas do you experience the most traffic at in your peak hour commutes (e.g., CBD, Willows)?

    ………………………………………………………………………………………………..

12. Which roads would you recommend introduction of high occupancy vehicle (HOV) lanes to in Bloemfontein (street name e.g., Church Street)?

    ………………………………………………………………………………………………..

13. Would you be open to carpooling if high occupancy vehicle lanes were introduced in Bloemfontein?
    - Yes
    - No
    - Maybe

14. What is the carrying capacity of your vehicle?
    - Up to 2 people
    - Up to 3 people
    - Up to 5 people
    - Up to 7 people

15. How many people can you be willing to share a ride with if you are open to ridesharing?

……………………………………………………………………………………………………..

16. Any other comments

………………………………………………………………………………………………………

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ANNEXURE B (INTERSECTION OF OLIVER TAMBO ROAD AND PRESIDENT AVENUE)

INTERSECTION OF OLIVER TAMBO ROAD AND PRESIDENT AVENUE

DATE: ……………………. **TIME:** ………………

No.	Direction											
	Bloem Central → Rhodes Ave				Bloem Central → Oranjesig				Bloem Central → President Ave			
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INTERSECTION OF OLIVER TAMBO ROAD AND PRESIDENT AVENUE

DATE: ……………………… **TIME:** ………………

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INTERSECTION OF OLIVER TAMBO ROAD AND PRESIDENT AVENUE

DATE: ……………………… **TIME:** ………………

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INTERSECTION OF OLIVER TAMBO ROAD AND PRESIDENT AVENUE

DATE: ……………………… **TIME:** ………………

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ANNEXURE C (INTERSECTION OF GENERAL DAN PIENAAR DRIVE AND KELLNER STREET)

INTERSECTION OF GENERAL DAN PIENAAR DRIVE AND KELLNER STREET

DATE: ……………………..   **TIME:** ………………

No.	Direction											
	Bloem Central → Parfitt Ave				Bloem Central → Brandwag				Bloem Central → General Dan Pienaar Rd			
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INTERSECTION OF GENERAL DAN PIENAAR DRIVE AND KELLNER STREET

DATE: ……………………… **TIME:** ………………

No.	Direction											
	Brandwag → General Dan Pienaar				Brandwag → Bloem Central				Brandwag → Parfitt Ave			
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INTERSECTION OF GENERAL DAN PIENAAR DRIVE AND KELLNER STREET

DATE: …………………….. **TIME:** ………………

No.	Direction											
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INTERSECTION OF GENERAL DAN PIENAAR DRIVE AND KELLNER STREET

DATE: ……………………. **TIME:** ………………

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ANNEXURE D (INTERSECTION OF NELSON MANDELA DRIVE AND FURSTENBURG ROAD)

INTERSECTION OF NELSON MANDELA DRIVE AND FURSTENBURG ROAD

DATE: …………………….. **TIME:** ………………

No.	Direction											
	Bloem gate → Universitas				Bloem gate → Langenhoven Park				Bloem gate → Tempe			
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INTERSECTION OF NELSON MANDELA DRIVE AND FURSTENBURG ROAD

DATE: ………………………   **TIME:** ………………

No.	Direction											
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INTERSECTION OF NELSON MANDELA DRIVE AND FURSTENBURG ROAD

DATE: ……………………. **TIME:** ………………

No.	Direction											
	Tempe → Bloem gate				Tempe → Universitas				Tempe → Langenhoven Park			
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INTERSECTION OF NELSON MANDELA DRIVE AND FURSTENBURG ROAD

DATE: ……………………. **TIME:** ………………

No.	Direction											
	Universitas → Langenhoven Park				Universitas → Tempe				Universitas → Bloemgate			
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ANNEXURE E (INTERSECTION OF PRESIDENT AVENUE AND KOLBE AVENUE)

Central University of Technology, Free State

INTERSECTION OF PRESIDENT AVENUE AND KOLBE AVENUE

DATE: ……………………. **TIME:** ………………

No.	Direction											
	Kolbe Ave → Victoria Rd				Kolbe Ave → President Boshof St				Kolbe Ave → President Ave			
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INTERSECTION OF PRESIDENT AVENUE AND KOLBE AVENUE

DATE: ……………………. **TIME:** ………………

No.	Direction											
	Victoria Rd → President Boshof St				Victoria Rd → President Ave				Victoria Rd → Kolbe Ave			
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INTERSECTION OF PRESIDENT AVENUE AND KOLBE AVENUE

DATE: …………………….   **TIME:** ………………

No.	Direction											
	President Ave →Kolbe Ave				President Ave →Victoria Rd				President Ave → President Boshof St			
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INTERSECTION OF PRESIDENT AVENUE AND KOLBE AVENUE

DATE: …………………….. **TIME:** ………………

No.	Direction											
	President Boshof St → Victoria Rd				President Boshof St → Kolbe				President Boshof St → President Ave			
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ANNEXURE F (INTERSECTION OF ALIWAL STREET AND UNION AVENUE)

INTERSECTION OF ALIWAL STREET AND UNION AVENUE

DATE: ……………………..   **TIME:** ………………

No.	Direction											
	Aliwal St → Harry Smith St				Aliwal St → Milner Rd				Aliwal St → Union Ave			
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<u>**INTERSECTION OF ALIWAL STREET AND UNION AVENUE**</u>

DATE: ……………………… **TIME:** ………………

No.	Direction											
	Harry Smith St → Milner Rd				Harry Smith St → Union Ave				Harry Smith St → Aliwal St			
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INTERSECTION OF ALIWAL STREET AND UNION AVENUE

DATE: ………………………   **TIME:** ………………

No.	Direction											
	Union Ave → Aliwal St				Union Ave → Harry Smith St				Union Ave → Milner Rd			
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INTERSECTION OF ALIWAL STREET AND UNION AVENUE

DATE: ……………………… **TIME:** ………………

No.	Direction											
	Milner Rd → Union Ave				Milner Rd → Aliwal St				Milner Rd → Harry Smith S			
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ANNEXURE G (BEGINNING OF N8 AND END OF NELSON MANDELA DRIVE)

INTERSECTION OF NELSON MANDELA DRIVE, BERG ROAD & GLEN WEG

DATE: ……………………… **TIME:** ………………

No.	Direction						
	N8			Glen Weg	Alexandra Ave		
	N8 → Central Park	N8 → Nelson Mandela Dr.	N8 → Alexandra Ave	Glen Weg → N8	Alexandra Ave → Glen Weg	Alexandra Ave → Nelson Mandela Dr.	Alexandra Ave → N8
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