UPGRADING OF MILNER AND KLIPFONTEIN ROAD SOUTHBOUND APPROACH TO ALLEVIATE TRAFFIC ISSUES

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DEDICATION

Over the last two years, I have been working towards completing my Masters in Engineering, specialising, in Transport studies at the University of Cape Town. The dissertation is submitted as my last submission. The dissertation has required long hours of research, report writing and has often tested my patience and determination. Through support and motivation provided to me, I was able to complete my dissertation in one year.

I would like to extend my gratitude to my supervisor, Marianne Vanderschuren, who has provided me with guidance throughout the process. I would also like to offer my gratitude to my husband, Tarique Fredericks and my family who have provided me with motivation and assisted me when I was unable to handle all my responsibilities. All the words of wisdom and time allocated to helping me, has not gone unnoticed.

STUDENT DECLARATION

I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own. This thesis/dissertation has been submitted to the Turnitin module (or equivalent similarity and originality checking software) and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

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December 2019

EXECUTIVE SUMMARY

Introduction

The population of the world is increasing at a rate of 1.07% each year. In order to accommodate this growth, quality and efficiency of services need to be improved. This includes improving the quality and efficiency of the transportation services, as a country's sustainability is reliant upon these systems. In many countries, the increase in population has congested the CBD areas, forcing people to migrate outside of the CBD. This has resulted in urban sprawl.

However, the apartheid era has resulted in urban sprawl in South Africa, which left many people living along the periphery, close to the industrial areas and a distance away from the CBD. One of the biggest challenges people living outside of the CBD area experience, is a poor and unreliable public transport system. It is difficult for people to access other areas and this has increased the number of private vehicles on the road.

According to a list of the top 10 countries with the highest public transport ridership, that was developed by Worldatlas.com (2019), Kenya has the highest public transport ridership. Of the total population, 63% of the people use public transport. Furthermore, the other 9 countries mentioned have ridership volumes ranging from 53% to 57%. This proves that 40% to 50% of the population in other countries is still using private vehicles above public transport and this is still considered high.

Research Problem

The use of private vehicles in South Africa has been on the rise. As a result, the congestion levels on the roads have increased. This has resulted in longer travel times, busier roads and an increase in road accidents as drivers spend more time travelling to and from destinations.

Milner and Klipfontein Road is located in Mowbray. The intersection is surrounded by a shopping mall, a hospital, a clinic, a school and a number of other amenities. Therefore, the traffic travelling through this intersection daily is relatively high. The southbound approach of Milner and Klipfontein Road intersection, however, has the highest volume of traffic operating through the intersection daily, as it connects the M5 highway (Class 2) and Raapenberg Road (Class 3) to Klipfontein Road (Class 3).

The southbound approach is a three-lane approach, of which one lane is a short turning lane. With high volumes of traffic operating through this approach daily, the road tends to get very congested, especially during the peak period. The high congestion levels have resulted in a number of other issues, which include longer travel times from Alexandra and Raapenberg Road intersection to Milner and Klipfontein Road intersection, vehicles struggling to change lanes due to limited gap length available and spilling of traffic onto Raapenberg Road.

This study will, therefore, focus on finding suitable measures to assist with alleviating the congestion as well the other issues currently being experienced along the southbound approach of Milner and Klipfontein Road.

Literature Review

It is important to manage the transport system as this affects the economy of the country. There are two types of traffic congestion and they are either recurrent or non-recurrent. Traffic congestion is a result of having too many vehicles on the road i.e. when the demand is larger than the supply. It is, therefore, necessary to improve the quality of a road or an intersection.

There are three types of intersection designs and they include: priority control, traffic signals and rotary movement control. It is important to determine the most efficient way for an intersection to operate by determining the way in which conflicting volumes will be served. To avoid undesirable delays and deal with large volumes of traffic, signalised or rotary movement is often preferred.

At signalised intersections, it is important to measure the effectiveness of an intersection by evaluating its performance and the design of the signal process as this can affect the time of travel, choice of route, mode of transport and If the route will be completed. To measure the effectiveness of the signalised intersection, the following elements must be assessed: the capacity, the volume to capacity ratio, the delay and the queue length. The Level of Service (LOS) also plays an important role in determining the operation of the intersection and provides the engineer or designer with information related to the type of flow or movement at each approach and intersection.

The signal design plays an important role in the operation of the intersection too. It is important to ensure that the signal timing is correct as this can affect the flow of traffic. There are different signal controls that can be implemented, and they include, semi actuated, fully actuated and fixed timing. To retime a signalised intersection is considered the most cost-effective method of redesign.

Phasing of the intersection is important as this can affect the level of service of operation of the intersection. To determine which phasing is necessary, the following must be assessed: the number of road accidents, the sight distance available, the geometry of the road, speeds of vehicles, the total volumes and the operation of the intersection.

Unsignalised intersections are generally not preferred as volumes and speeds differ at each approach. High accident statistics are expected. This affects the overall capacity and operation of an intersection.

Rotary movement control which refers to roundabouts or traffic circles, can handle larger volumes of traffic and reduce conflicting movements. They are therefore, considered much safer than other forms of at-grade intersections.

The literature review will provide more detail regarding traffic congestion, intersection design and measuring the effectiveness of an intersection.

Data collection and Analysis

The site investigation was undertaken on 20 February 2019 between the AM peak (6:00 and 8:30) and the PM peak (16:00 and 18:30), to determine the extent of the traffic congestion currently being experienced, along the southbound approach of Milner and Klipfontein Road. Based on the findings, the PM peak period was considered the "worst case scenario".

A traffic count was not required; as previous traffic count data was available from the City of Cape Town records. A full traffic count was completed in 2017 for the entire intersection.

A travel time survey was undertaken on Wednesday, 24 July 2019 between 16:00 and 18:00. The runs were calculated at 10-minute intervals. The data obtained from this survey was validated against the traffic count survey to determine whether the data obtained from City of Cape Town records, was indeed correct. It should be noted that the travel time survey was only completed during the PM peak, as the majority of traffic travel along that approach (direction towards home), during the PM peak. It was also confirmed to be the time of day when traffic was the worst.

During the process of the travel time survey, a separate survey was completed to determine the direction in which vehicles were travelling. The vehicles were monitored from where they entered the southbound approach (M5 highway or Raapenberg Road), whether they stayed in the lane they entered the approach or whether they changed lanes. This survey would determine the destination of travel. Furthermore, vehicles changing lanes, were also further monitored, to determine if they were undertaking this movement legally or illegally. A solid white line, located approximately 200m away from the signalized Milner and Klipfontein intersection, separates the two lanes entering from M5 highway and Raapenberg Road. It prevents vehicles from changing lanes when unsafe to do so.

The data was captured in Sidra and Junction to assess the delay and level of service at the intersection and specifically along the southbound approach of Milner and Klipfontein Road intersection.

Results and findings

The southbound approach is a three-lane approach. It comprises of a left lane, which is used for straight ahead movements and left turning movements, a middle lane used for straight ahead movements and a short right turn lane.

The traffic count data that was obtained from the City of Cape Town records for 2017, established that a high volume of traffic passed through Milner and Klipfontein Road intersection daily. The peak periods of the day had a variation in the volumes of traffic along each approach, except for the southbound approach, which had high volumes of traffic at both peak periods. Majority of the traffic enters from either M5 highway or Raapenberg Road and exits onto Milner or Klipfontein Road eastbound.

The signal phasing at the intersection comprises 4 phases, with no priority given to the southbound approach eastbound movements, even though the highest traffic volumes travelling in that direction. This has resulted in traffic congestion and a backlog of traffic onto Raapenberg Road. As a result, vehicles take longer than necessary to reach the intersection. The travel time survey investigated vehicles travelling from Alexandra and Raapenberg Road towards Milner and Klipfontein Road. The total distance is 1.2km in length. On average, a driver driving at a speed of 60km/hr. (length of road is short, and it bends), should take 3 minutes and 20 seconds to complete this stretch of road. This total time is inclusive of the signal system. It took vehicles more than 7 minutes to complete the 1.2km distance.

The road accident statistics also indicate that a high number of accidents take place at Milner and Klipfontein Road intersection. Over the latest five-year period, a total of 256 accidents took place at the intersection. Of the 256 accidents, 53% of the accidents took place along the southbound approach.

Furthermore, the directional survey also established that majority of the vehicles entering from both Raapenberg and the M5 highway, were travelling eastbound along Klipfontein Road. Majority of the vehicles changing lanes, have however, done this legally (not crossing the solid line). As a result, many vehicles were merged between two lanes, obstructing oncoming vehicles.

Proposed Mitigating Measures

It is evident from the results that there is a need for mitigating measures. High volumes of traffic are experienced along the southbound approach, with a high portion of this traffic wanting to make use of the left lane. Limited gaps are available for changing lanes, travel time is longer than expected and spilling of traffic is occurring on Raapenberg Road all due to high congestion levels along the southbound approach.

It is therefore proposed that a roundabout be constructed at Milner and Klipfontein Road intersection to reduce conflicting movements, improve the delay and LOS of the intersection and reduce the issues currently being experienced along the southbound approach.

Recommendations

It is recommended that a proper design be completed to understand the proper effects in terms of operation of the intersection by implementation of a roundabout. Further research should be undertaken to determine the effect of the roundabout on the AM peak.

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1. INTRODUCTION

1.1. Background to the study

According to the World Population census, there are currently 7.7 billion people in the world. The growing rate of the population is approximately 82 million people each year. According to the census, China has the highest population with 1.4 billion people, followed by India who has 1.37 billion people and the USA who has 330 million people (Worldometers.info, 2019).

According to the South Africa's census data of 2011, between 2001 and 2011 the total population increased by 7 million people (Statssa, 2019). As the population increases, solutions to accommodate this growth are required to ensure that the quality and efficiency of services are not compromised. This includes the need for an efficient transportation system and solutions to assist with alleviating any transport related issues that the country is facing (Feikie, et al, 2018).

It is important to note that the sustainable development of a country and sustainable transport system influence the success of one another. The vehicular and transport services affect the economy, mobility, quality of life and living conditions as well as the environmental conditions of a country (Feikie, et al, 2018).

The United Nations has stated that South Africa is dealing with "continuing urbanization" (Feikie, et al, 2018). It is estimated that by 2030, 71.3% of South Africans will be living in urban areas. By 2050, the total population percentage living in these urban areas will have increased to 80%. As a result of poor public transport system in many parts of South Africa, there is a high number of private vehicles use which has led to transportation challenges such as traffic congestion and an increase in road accidents (Feikie, et al, 2018).

It is, therefore, necessary that the transport systems in South Africa be improved to reduce the challenges that the country is facing and assist with the growing population.

1.2. Research problem

Cape Town experiences high levels of congestion daily, especially during peak hours. Cape Town is ranked 95th in the world for the most congested city (INRIX, 2019). The high levels of congestion are a result of many things, some of them include, but are not limited to the following: low public transport ridership, poor traffic management, poor infrastructure, incorrect use of traffic engineering methods and high accident statistics (Aropet, 2017).

Milner and Klipfontein Road intersection located in Mowbray is used daily, as it provides access to many surrounding areas. The southbound approach carries traffic from Blackriver Parkway and the M5 highway. High volumes of traffic are generally experienced during the PM peak period. As a result of the layout of the lanes, the type of intersection, the phasing of the signals and high volumes of traffic, congestion often occurs and this resulted in a number of issues including spilling traffic onto Raapenberg Road, longer travel times, vehicles unable to switch lanes with ease and high accident statistics.

This study will, therefore, focus on finding a suitable solution to assist with alleviating some or all of the issues experienced along Milner and Klipfontein Road southbound approach.

1.3. Objectives

The main objective of this study is to investigate the extent of the issues experienced along Milner and Klipfontein Road southbound approach and find suitable mitigating measures that could assist with alleviating all or some of the issues experienced. The objectives are detailed further below.

- To determine the existing congestion levels along Milner and Klipfontein Road and specifically, the southbound approach and its effects on the surrounding transport network.
- To undertake traffic surveys which includes a traffic count survey at Milner and Klipfontein Road intersection, travel time survey and a directional survey along the southbound approach.
- To find suitable research that relates to traffic congestion and its effects on the surrounding transport network.
- To find suitable research that relate to the other issues also experienced along the southbound approach that include reducing travel time, accident statistics, spilling of traffic onto nearby roadways and to allow vehicles to move more freely when changing lanes.
- To complete an analysis using the survey results to determine the effects of congestion on the southbound approach and surrounding transport network.

- To identify measures that will be used to assist with alleviating congestion and other issues that are being experienced along the southbound approach.
- To provide suitable solutions and recommendations that can be used in this study and further research

The research will focus on determining the causes of congestion both locally and internationally. Furthermore, the study will focus on quantifying the number of private vehicle users, the reasons why public transport use is limited and how land use management affects the transportation system both locally and internationally. The study will conclude with finding suitable measures that can be implemented in a general sense that can assist with alleviating congestion.

1.4. Research and methodology

Start of project

A proposal was drawn up identifying the research problem and its objectives. It was submitted for approval. Once approval was given, the research regarding the topic of this project was undertaken.

Literature Review

The literature review focused specifically on the following:

- Land use planning and identifying the needs to develop a sustainable transport system.
- The volumes of private vehicle use and the state of public transport systems both locally and internationally.
- What is congestion and what measures can be implemented?
- Determining how to measure the operation of an intersection.
- Providing theory on the type of signalised intersection including its design, controls and layout of an approach, as well as, the impact of a roundabout on an intersection.
- Providing suitable methods to mitigate congestion and other issues experienced as a result of congestion, at an intersection and which of these mitigating measures are considered feasible for this intersection.
- The rate of road accidents and how to alleviate these issues.

Data collection and analysis

Various surveys were undertaken that will assist with collecting all necessary data and they include:

- A full traffic count of Milner and Klipfontein Road intersection
- A travel time survey to determine the time vehicles take to travel from Alexandra and Raapenberg Road intersection to Milner and Klipfontein Road intersection during the PM peak
- Directional survey to determine in which direction most of the vehicles are travelling from both Blackriver Parkway and M5 highway.
- Road accidents statistics of the southbound approach was assessed to determine the main type of accident as this will provide detail into what other issues there may be.
- The results of the traffic counts were captured into SIDRA 5.0 which was used to determine the LOS of the intersection using the background traffic and future traffic. The latest version of SIDRA 5.0 was not used as a trial version for version 5.0 was only available.
- Junctions was used as an additional modelling software. Junction consists of three modules that include Arcady 9 (Roundabout Module), Picady 9 (Priority Intersection Module) and Oscady 9 (Signalised intersection Module).
- The data was captured in both software programs and the output produced the level of service, delay and queue length experienced along each approach. Two modeling software's were used to ensure proper analysis of the data. The results were validated against the existing field data and summarised in the analysis of data portion of the report.

Mitigating measures and alternatives

Research into various mitigating measures at the approach was investigated, to determine which option would be feasible. These measures are based on the research obtained in the Literature Review. The mitigating measures were included in both SIDRA 5.0 and Junctions software using the initial data to determine the effects. The results are discussed in the **Results and Findings** portion of the report. These measures provided allow the study to meet the objectives stated previously. Suitable recommendations have also been provided.

1.5. Scope and limitations

The main scope of this study is as follows:

- Milner and Klipfontein Road southbound approach was identified as the study area as high levels of congestion is experienced along this portion of the road.
- A traffic count survey results provided insight into the levels of congestion experienced during the AM and PM peak period. The results identified the PM peak hour as the “worst case scenario”.
- The congestion experienced has impacted surrounding roads and caused a number of other issues along the southbound approach. These issues include longer travel times, high volumes of vehicles wanting to change lanes but are unable to due to high congestion levels and a number of accidents occurring along this portion of the road.
- More surveys were initiated to collect the necessary data and determine the extent of the issues experienced. These surveys include a travel time survey, travel directional survey. Road accident statistics were also obtained to provide insight into the type of accidents that occur at the intersection.
- Mitigating measures were identified to assist with alleviating the issues experienced along the study area. The mitigating measures were analyzed using SIDRA 5.0 to determine its effects on the southbound approach.
- The study was concluded, and suitable recommendations were identified.

Due to time and financial constraints, there were a few limitations regarding this study, and they include:

- The surveys that were completed, were only done during the PM peak (16:00 to 18h30). The site assessment and traffic count results confirmed that the worst of the traffic occurred during the PM peak hour.
- The study area was limited to one approach at one intersection. No further research could be undertaken at other intersections or approaches to determine the extent of traffic congestion issues along the surrounding roads. This does not provide a clear indication as to what effects the implementation of the proposed mitigating measures will have on the surrounding road network.
- The study only allowed for certain surveys to be undertaken such as travel time survey, traffic count survey and a travel direction survey. Further research can be undertaken to

determine rat running as this was observed during the site investigation but requires an extensive survey to be completed (such as a number plate survey).

- A complete design (i.e. to engineering standards) could not be completed that provided measures that could be implemented to assist with traffic congestion and other various issues along the study area due to time constraints.
- Junctions and SIDRA were the only available options as modelling software as no other trial versions for 32-bit pc were available. Vissim was originally the ideal choice in conjunction with SIDRA, but the supplier did not have a version available to work on older pcs.

1.6. Content of the report

Chapter 2, 3 and 4 – Literature Review

These chapters' focuses on finding suitable literature that relates to traffic congestion, intersection design, measuring operation of an intersection as well as land use planning and management, locally and internationally. It will detail measures that can be implemented to assist with transport related issues, specifically congestion, all over the world.

Chapter 6 – Case Study

Chapter 6 introduces the study area and why this specific area was chosen in relation to the objectives stated in Chapter 2.

Chapter 7 – Research and Methodology

Chapter 7 introduces the research method used to undertake this study and how the objectives of the study will be achieved. These include site investigation, type of surveys that were undertaken and how the results obtained were going to be analyzed and presented.

Chapter 8 – Findings and Results

Chapter 8 focuses on the results of the surveys, where it is analyzed and presented in a suitable form. It provides insight into the type of traffic experienced at the study area such as traffic congestion levels, travel time along a specific portion of the road to reach the investigated area, which direction vehicles were travelling and the effects of congestion on the surrounding road network (i.e. Raapenberg Road). It also provides insight into the effects of a driver's behavior (such as changing lanes), can have on the road network. Proposed mitigating measures are provided in this portion of the report.

Chapter 9 - Conclusion and recommendations

Chapter 9 is a summary of what has occurred during the process of the study. It further provides suitable recommendations in relation to the Literature Review which could assist with alleviating some or all of the issues experienced at this study area.

2. LAND-USE PLANNING AND MANAGEMENT

The basis of this investigation focuses on traffic congestion levels that are being experienced along the southbound approach at Milner and Klipfontein Road intersection.

2.1. Introduction

To develop an understanding and meet the objectives of this study, a number of topics were chosen and researched. The information provided has been presented in such a way as to provide a logical representation of the content.

A transportation network and its infrastructure have a vital role in the social and economic impact of a country. If the network functions in an efficient manner and road infrastructure is maintained or upgraded as required, it will provide residents with improved living conditions, increase the economic activity and commodity markets, reduce transport prices of goods and services, increase job opportunities, reduce the impact on the surrounding environment and provide a better response to emergency situations. (Sakhapov and Nikolaeva, 2018)

In some parts of the world, the population is increasing daily and this has led to deficiencies in many areas, especially road infrastructure. There is a need for continuous road upgrades to keep up with the growing number of vehicles on the road.

2.2. Urban sprawl

Urban sprawl can be defined as a socio-economic issue that is occurring globally, where an increase in growth within the urban areas has occurred. According to the United Nations, more than half of the world's population is living in urban areas (Magidi and Ahmed, 2018). In developing countries, urban growth is a result of migration and high population growth. In developed countries, the majority of the country is already urbanized. For example, in North America, Latin America and Europe, there are approximately 82%, 80% and 73% of people living in urban areas, respectively. In developing countries such as Africa and Asia, there are 40% and 48% of people living in urban areas, respectively (Magidi and Ahmed, 2018).

For many years, South Africa was a victim of the Apartheid era. The main focus of Apartheid was to produce a spatial divide between the different races, in both rural and urban areas. Townships were developed along the periphery, close to the industrial sectors and a distance from the white areas and the CBD. Residents of the township areas had no access to land and its land-use was controlled by the government (Charman et al., 2017).

Urban sprawl is considered the most challenging issue in many countries. In South Africa, new houses are being built beyond the existing periphery. This periphery comprises development that is separated by major roads or open spaces. Beyond this periphery, there is an increase in the cost of public infrastructure and development costs; there is a decrease in the effectiveness of public transport, increase in energy consumption, less community interaction, poor management of the environment and regression of the inner city (Yusuf and Allopi, 2010).

The apartheid spatial planning impacted negatively on the Cape Town area. Over the last 20 years, Cape Town has grown in a "low density manner", which serves as a threat to the sustainability of Cape Town. The city's developed area has increased by approximately 40% between 1985 to 2005, with an increase in population by 700 000 people. This has had a negative impact on the availability of houses and current infrastructure (Futurecapetown.com, 2019).

According to a summit presentation by Futurecapetown.com (2019), there are a number of contributing factors to urban sprawl and they are discussed below:

- Rapid urbanization

With an increase in population growth, many people often choose to migrate into the city for various push and pull reasons. These reasons often include lack of basic services, limited housing and unemployment that serve as push factors. Pull factors will be anything that will offer people a better quality of life. This increases the demand for infrastructure and resources (Futurecapetown.com, 2019).

- Consumer Demands

With the increase in income and lifestyle consumption, there is a need to have housing close to amenities and infrastructure. This has led to more affordable housing on the outskirts of the city, therefore, leading to lower density areas (Futurecapetown.com, 2019).

- Transportation Demands

With the increase in low density developments taking place on the outskirts of the city, there is an increase in the demand for transportation as well as an increase in mobility within the city. As a result, this has led to an increase in dependency upon the roads and highways to connect the low density to higher density areas (Futurecapetown.com, 2019).

- Other factors

Other factors to consider is the poor planning, limited households available, limited regulation regarding the development along the periphery, limited accessible and affordable housing, as well as an increase in the cost of living with the city (Futurecapetown.com, 2019).

2.3. Sustainable Transport System

In both developed and developing countries, there has been an increase in private vehicle use over the years. In the developed countries, some countries have taken back the streets and reduced the use of private vehicles (i.e. shared space). In developing countries, there have been a number of issues that have developed as a result of private vehicle use which include road accidents, environmental issues, change in climate, increase in traffic congestion, lack of public transport use, depletion of energy and low accessibility especially for the lower income class. (Pojani and Stead, 2015)

A sustainable transport system and sustainable development of the country or city influences one another. In South Africa, the population is on the rise and there is a need for solutions to assist with alleviating traffic related issues and reserving resources for future generations. There is a need for a proper transportation system that is efficient and probable solutions to assist with the challenges that the South African transport system currently faces. (Feikie, Das and Mostafa, 2018)

According to Pujani and Stead (2015), there are a number of options that focus on both the supply and demand of transport that can be implemented to improve the sustainability of transport systems, specifically in smaller cities, and they include the following:

- Improving road infrastructure

The most traditional method was to introduce new roads to alleviate traffic congestion and other transport issues (Pujani and Stead, 2015). Over the years, it's become evident that increasing the road widths won't improve the issues but rather increase the demand of traffic known as induced travel (or generated traffic).

Furthermore, based on research, it is more economical to maintain existing roads rather than constructing new roads. In 85 developing countries, 45 billion dollars was lost, due to inadequate maintenance of roads whereas maintaining the roads would have cost less than 12 billion dollars (Pujani and Stead, 2015).

- Public transport for rail and road

The most central point for the economic growth of a country is an effective public transport system on the road. For the poorer community, public transport is the only form of transport. Some public transport systems do not assist with the needs of the population as they are often unreliable, uncomfortable, inconvenient and often dangerous. Public transport offers on demand mobility for those in need but also carry other costs that include air and noise pollution, traffic congestion, road accidents and sometimes violence (Pujani and Stead, 2015).

- Non-motorised transport

In some developing countries, walking and cycling is considered an important form of transport. Those of the poorer class use this form of transport when travelling to work, school, medical facilities, etc. Even though the travel time is longer, people in developing countries prefer increased time in comparison to higher cost financially for transport. If more people make use of non-motorised transport (NMT), it will make it safer for people to use (Pujani and Stead, 2015).

Even though NMT forms an essential part of people's daily lives, it's still not considered in governmental policies. A politician considers NMT a way of moving backwards and does not identify NMT as a way forward in terms of the goals and aspirations of the government. Therefore, very little expense is spent on improving NMT. (Pujani and Stead, 2015).

- Improved technology

Inventing new technology, such as intelligent transportation systems (ITS), may assist with some of the transport related issues (Pujani and Stead, 2015). This type of technology offers drivers information and communication to assist with scheduling trips and directions. It serves as an important component in the management and control of traffic. This data is presented in the form of queue length, travel time or travel delay. It also includes any road accidents and their locations, construction, better routes, weather conditions that many cause traffic issues. This affects the travel behaviour and may reduce travel time, congestion along the road and fuel emissions. (Ackaah, 2019)

- Campaigns

In the past, campaigns have been used to educate people on a sustainable transport system, but this has not been very successful. One of the main perpetuates of transport problems are social mechanisms. People seek status and private vehicle is seen as a status symbol as it is associated with speed, convenience, comfort, protection, freedom, etc. (Pujani and Stead, 2015).

- Improve pricing mechanisms

With the reduction in parking prices, it increases the use of a private vehicle and on-street parking. If fuel prices are also kept low, oil companies feel the pressure. If fuel prices are increased, it may discourage private vehicle use in the beginning but further on may encourage smaller vehicle use which won't alleviate congestion (Pujani and Stead, 2015).

- Restrictions on vehicle access

The restriction on vehicle access method is preferred above pricing mechanisms. In some developing countries, car rationing is often experimented with. Bangkok prohibited newly registered vehicles from travelling in rush hours. In Guangzhou, motorcycles that are locally registered are only allowed on the road (Pujani and Stead, 2015).

- Land use control

In order for public transport and NMT to remain practical and financially feasible, higher land use densities and mixed land uses are required within close proximity to these facilities, as it will impact the travel behaviour of those making use of these forms of transport (Pujani and Stead, 2015). It is important to note that, due to different cultural and historical trajectories, it is not recommended to use the same solutions in all cities that may experience the same issues. For example, Latin American cities in comparison to African cities have approximately 19% and 5% of people using public transport, respectively. The average distance for non-motorised trips is 1.0km and 2.1km in Latin America and South East Asian cities, respectively.

2.4. Public Transport

Around the world, public transport is widely used as it transports masses of people over longer distances and shorter time frames. The use of public transport reduces the levels of traffic congestion, road accidents and emissions, as well as costs. However, public transport is only effective based on the efficiency of the mode of transport and its availability (Worldatlas.com, 2019).

According to Worldatlas.com (2019), the top 10 countries with the high volumes of public transport users are shown in **Table 1** below. South Africa does not make it to the top and there are no details as to where South Africa ranks compared to the rest of the world.

Table 1: Top 10 countries with the highest public transport users (Worldatlas.com, 2019)

Rank	Country	Public Transit Use (%)
1	Kenya	63
2	Russia	57
3	Venezuela	56
4	Ukraine	56
5	Philippines	56
6	Korea	55
7	Turkey	54
8	Peru	54
9	Colombia	53
10	Chile	53

In some developing countries, the number of public transport users has decreased, due to lack of awareness, miss management of the system resulting in poor quality and the increase in the use of private vehicles. In places such as Indonesia and Bangkok, the use of buses has decreased by 20% and 30%, respectively. For public transport to be a good contender to private vehicle use, the quality and service must constantly be improved (Ngoc, Hung and Tuan, 2017).

Furthermore, other reasons of public transport user decline include people using smartphones to do online shopping, video conferencing, the use of Uber, easy-to-rent bicycles and batteryoperated scooters which are available in some countries. These reasons provided, however, are not suitable for a worldwide decline. (The Economist, 2019)

According to the eNaTis (2019) latest statistics in South Africa, the number of vehicles per province is shown in **Table 2**.

31 May 2019 - Live vehicle population as per the National Traffic Information System - eNaTIS											
Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	3 086 435	1 015 026	1 292 544	464 476	318 435	438 895	325 378	343 255	130 094	7 414 538	65,28%
Minibuses	128 599	55 780	37 303	24 748	12 976	24 969	19 866	24 627	5 626	334 494	2,94%
Buses, bus trains, midibuses	20 571	7 996	7 248	4 473	3 271	8 427	4 231	6 845	1 740	64 802	0,57%
Motorcycles, quadrucycles, tricycles	140 552	31 052	85 685	21 651	18 497	18 444	12 964	8 994	7 984	345 823	3,04%
LDV's, panel vans, other light load veh's GVM <= 3500kg	845 737	368 229	336 625	207 990	131 948	223 809	155 341	235 848	80 442	2 585 969	22,77%
Trucks (Heavy load vehicles GVM > 3500kg)	138 319	49 276	45 355	22 327	21 802	47 926	17 383	26 384	9 095	377 867	3,33%
Other self-propelled vehicles	36 307	31 897	39 501	16 626	35 304	27 553	21 379	17 347	9 403	235 317	2,07%
Total self-propelled vehicles	**4 396 520**	**1 559 256**	**1 844 261**	**762 291**	**542 233**	**790 023**	**556 542**	**663 300**	**244 384**	**11 358 810**	% of total tow vehicles
Provincial % of total	**38,71%**	**13,73%**	**16,24%**	**6,71%**	**4,77%**	**6,96%**	**4,90%**	**5,84%**	**2,15%**	**100,00%**	
Caravans	38 001	7 128	18 215	5 148	7 402	10 064	6 218	5 478	2 741	100 395	8,47%
Light load trailers GVM <= 3500kg	337 529	82 575	149 225	57 949	63 440	65 856	54 063	43 392	29 307	883 336	74,51%
Heavy load trailers GVM > 3500kg	61 703	23 838	23 281	7 251	18 426	40 882	10 961	9 743	5 769	201 854	17,03%
Total trailers	**437 233**	**113 541**	**190 721**	**70 348**	**89 268**	**116 802**	**71 242**	**58 613**	**37 817**	**1 185 585**	
Total provincial % of total	**36,88%**	**9,58%**	**16,09%**	**5,93%**	**7,53%**	**9,85%**	**6,01%**	**4,94%**	**3,19%**	**100,00%**	
All other and unknown vehicles	4 753	2 974	4 408	3 057	3 843	3 709	4 305	2 385	1 335	30 769	
Total number	**4 838 506**	**1 675 771**	**2 039 390**	**835 696**	**635 344**	**910 534**	**632 089**	**724 298**	**283 536**	**12 575 164**	
Provincial % of total	**38,48%**	**13,33%**	**16,22%**	**6,65%**	**5,05%**	**7,24%**	**5,03%**	**5,76%**	**2,25%**	**100,00%**	

Table 2: Vehicle use statistics for South Africa (eNatis, 2019)

In the Western Cape, the total number of motor vehicles is almost four times the amount of minibus taxis. The total number of motorcycles and bicycles is more than the total number of buses, minibus taxis and trains together. This could be a result of high congestion levels on the road, too little investment into our public transport by government or too little people making use of public transport due to its poor quality of service and people feeling unsafe.

Even though public transport is available in South Africa, there are a number of key issues that the public transport system, is facing such as low ridership numbers, low accessibility, imbalanced equity and an increase in traffic congestion (Aropet, 2017). Until these issues are resolved or the impact of these issues is reduced, the number of private vehicles on the road will remain high.

2.5. Transit Oriented Development

Transit Oriented Development (TOD) can be defined as a relationship between the urban development of an area and the transport system. Its main focus is developing housing, job opportunities, activity areas and necessary public services around its public transport system.

These include a train stations, public transport corridors, etc. This strategic approach focuses on densifying and intensifying areas. This strategy has been used internationally in places such as America, Asia and Europe (City of Cape Town, 2016).

TOD comprises a number of methods and they are listed below (Wilkinson, 2006):

- Developing a neighborhood that encourages walking
- Non-motorised transport facilities will be prioritized
- Denser networks will be created
- Development will be nearby an operating public transport facility
- Mixed land use developments
- Transit and density capacity matched
- Regions will be compact with shorter distances to travel
- Mobility will be increased by regulating roads and parking of vehicles

Therefore, the introduction of TOD into certain areas will have a positive impact socially and economically. It will generate fare revenue and increase the number of people making use of public transport. Furthermore, this will reduce the number of private vehicles on the road (Wilkinson, 2006).

3. TRAFFIC CONGESTION

There are two types of traffic congestion, recurrent and non-recurrent congestion. Recurrent congestion is traffic that occurs daily or on weekends as a result of factors that occur regularly or periodically such as people travelling to work daily or weekend trips. This type of congestion is predictable and generally occurs during peak hours. Non-recurrent congestion is as a result of unexpected events such as road construction, accidents or any events that may affect the flow of traffic (Agyaoing and Ojo, 2018).

Traffic congestion is often a result of too many vehicles on the road that cannot accommodate it i.e. demand is larger than its supply (Ackaah, 2019). This has resulted in building new roads or increasing the capacity of the existing roads. Studies have indicated that expanding the road network has only led to the increase in vehicle use known as induced travel demand and this has not assisted with alleviating traffic congestion. With the constraints placed on budgets as well as space, it is not feasible to expand the road infrastructure to assist with the increasing demand within the road network. (Ackaah, 2019).

A traffic survey was undertaken by INRIX (2019), a global company that specialises in transport analysis who analyses large volumes of data from all around the world, to determine how long drivers sit in traffic, annually. The main criteria used in this analysis included time spent in congestion, the intensity in the peak hours and the traffic volume. The latest statistics for South African cities are shown in **Table 3**. The number in the bracket is the 2017 data. In some parts of South Africa, the time spent in congestion increased, such as Bloemfontein who ranked 174 in 2017 and ranked 165 in 2018. The traffic impact in Durban improved, ranking 133 in 2017 and 141 in 2018 (INRIX, 2019).

Table 3: Average travel time of South African cities (INRIX, 2019)

URBAN AREA	2018 IMPACT RANK (2017)	HOURS LOST IN CONGESTION	YEAR OVER YEAR CHANGE
Johannesburg	61 (63)	119 (82)	3%
Pretoria	64 (71)	143 (54)	9%
Port Elizabeth	75 (77)	71 (162)	1%
Cape Town	95 (96)	162 (28)	-4%
Durban	141 (133)	72 (160)	-8%
Bloemfontein	165 (174)	62 (178)	8%

According to Agyaoing and Ojo (2018), there are a number of causes of traffic congestion in developing countries and they are as follows:

- As cities expand, no provision is made for road capacities as the roads are narrow and built quite poorly and this result in bottlenecks.
- In today's society, private vehicle use is seen as wealthy and public transport is seen as low class. Therefore, there has been a surge in the number of private vehicle use. Most cities also have poor public transport facilities, which are also unsafe, forcing people to use private vehicles instead.
- Traffic junctions are independent of any traffic management strategy and therefore often remain unmanned.
- Roads often do not have lane dividers and many vehicles tend to overtake other vehicles, even if it means travelling in the wrong lane. Therefore, lane management is important in ensuring congestion doesn't occur.

- Other causes include traffic control devices and loading and picking of passengers illegally along a portion of road not made for pick-ups or drop offs.

Furthermore, Simdiankin et al. (2018) further states that traffic congestion may also occur because of the volume of traffic, the conditions of the roads, the number of road accidents, the number of drivers changing lanes to save a few minutes as well as a driver's behavior.

A study was undertaken in Accra Central Market in Ghana and the study shows that the main causes of traffic congestion were, due to bad driver behaviour, road accidents and poor road design. The local experts from all over the world has ranked road congestion as one of the most important among the other 9 infrastructural deficiencies, including lack of potable water, poor telephone services, poor internet services, leaking sewers, lack of cooking energy, poor pedestrian facilities, power outages and flooding (Agyaoing and Ojo, 2018).

3.1. Phases of congestion

There are three phase orders in which congestion occurs, which are: the free travel phase, the meta-stability phase and the traffic congestion phase. The phases are shown in **Figure 1.**

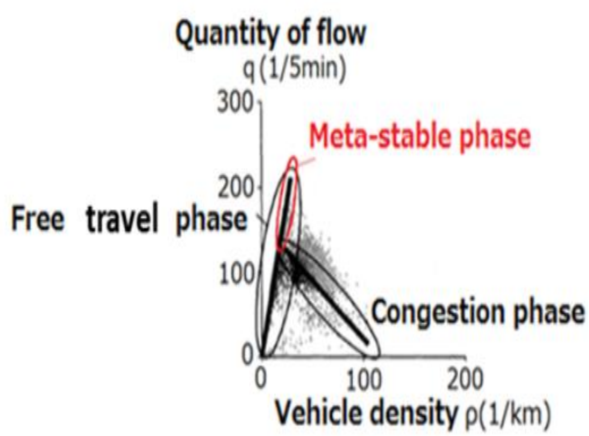

Figure 1: Stages of congestion (Ito and Kaneyasu, 2017)

The free travel phase is the phase where vehicles travel freely, at an appropriate level of service. The meta-stability phase is the second phase and is usually the phase before congestion occurs. During this phase, it is easier to forecast congestion according to Ito and Kaneyasu, (2017). The third and final phase is the congestion phase. As per its name, it is when congestion occurs and vehicles are unable to operate freely (Ito and Kaneyasu, 2017).

3.2. Effects of congestion

To determine the extent, nature and severity of the congestion all depends on the size of the city, the capacity of the roads, the layout of the road, land use distribution, public transport systems and travel patterns, but these differ from city to city (Agyaoing and Ojo, 2018).

Congestion levels affect the amount of fuel consumption and fumes being released. At an intersection, while a vehicle is waiting for its turn to move, the vehicle often remains on and this results in extra fuel consumption and extra fumes being released. It is, therefore, important to measure the delay at an intersection and ensuring an acceptable level of service is provided to vehicle users especially at signalised intersections where the delay may be longer as a result of longer cycle lengths (Sekhar et al., 2013).

According to the National Emissions Inventory, vehicles produce 71% of air pollution. According to the World Health Organization (WHO), 3.2 million have died, due to air pollution worldwide (Agyaoing and Ojo, 2018).

3.3. Effects of human factor on congestion levels

If the capacity of a road has been reached, road accidents and bad driving behavior increases (Federal Highway Administration Research and Technology, 2014). In most cities around the world, congestion levels are experienced during the peak hours of the day (AM and PM).

One fundamental factor related to accidents, congestion and transport processes is psychology. According to Lizbetin and Bartuska (2017), 90% of all accidents are caused by the human factor, with the remaining 10% as a result of other causes that are combined with the human factor (Lizbetin and Bartuska, 2017).

According to Kane and Behrens (2000), drivers change their driving style according to new traffic conditions. In a traffic congestion scenario, where capacity of roads has been reached, the drivers tend to move at a lower speed and close to other vehicles. If a road were to increase in capacity, vehicles from other routes that were quicker but currently slower, will be attracted to this new road. Drivers who often left at a later or earlier time, would then reschedule their trip (return to peak effect). If a road were to decrease in capacity, vehicles would find an alternate route either via neighbouring streets (rat running) or reschedule their departure to avoid increasing congestion.

A study was undertaken by Arai and Sentinuwo (2015) to determine the effects of a driver's behaviour and lane changing maneuvers on traffic. Lane changing can be defined as the movement of a vehicle from one lane to the other laterally, where the lanes are both travelling in the same direction. This often occurs when vehicles want to avoid obstacles, collisions or pass a slow-moving vehicle. In order to undertake lane changing, one must pay high attention and be perceptive (Arai and Sentinuwo, 2015).

According to the study, traffic congestion is influenced not only on the capacity of the road, but also the driver's behaviour. Driver's behaviour has a strong relationship with the number of accidents that occur. The behaviour is dependent upon driver's skills and their driving style (Arai and Sentinuwo, 2015).

Figure 2 shows how changing lanes occur during the different traffic conditions. Lane changing overall affects the traffic condition.

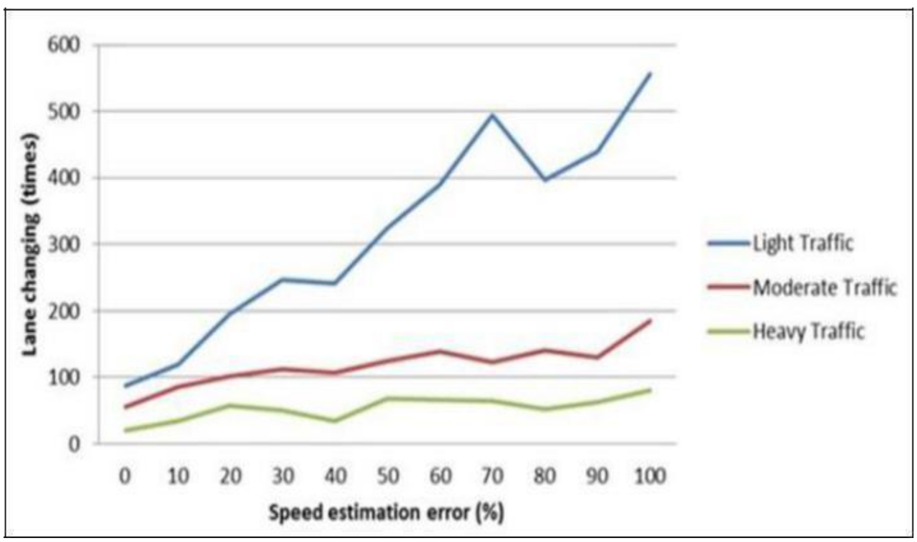

Figure 2: Lane changing during different traffic conditions (Kane and Behrens, 2000)

When a vehicle changes lane, the number of times vehicles make use of spontaneous braking increases. In light traffic conditions, spontaneous braking is higher with lane changing than when traffic is moderate to high. The main reason is that it's easier to change lanes in lighter traffic conditions (Kane and Behrens, 2000).

In summary of the above, any changes in the capacity of a network, increase or decrease, can result in changes of a route, the time of departure, trip origin and destination and trip frequency.

Driver's behavioral responses impact the number of trips undertaken, the distance of the trips or both. This can potentially induce or suppress traffic (Kane and Behrens, 2000).

3.4. Measures to assist with alleviating congestion

Congestion cannot be completely eliminated, but measures can be used to minimize the level of congestion. Some of these measures include (Agyaoing and Ojo, 2018):

- Traffic signal synchronization
- Implement traffic congestion pricing
- Incident management
- Increase the use of public transport
- Using speed controls
- lane management
- Discouragement measures such as financial penalties
- Improve road capacity
- Increasing law enforcement
- Implement lanes for pedestrians and cyclists
- Implement car parks

Litman (2001) states that trying to improve the level of congestion may reduce the cost of driving, but it will encourage higher volumes during the peak periods specifically. Generally, most roads that are congested, have additional trips that are encouraged as a result of the congestion reduction.

Litman (2001) further states, that most people assume that by increasing the width of the roadway, will improve overall congestion. In fact, this tends to attract more traffic from other routes and other modes of transport. This is known as generated traffic.

Research was undertaken by the Federal Highway Administration (FHWA 2004) to determine the effects of additional lanes on capacity of the roadway. The research states that by adding a second lane, 15 years of life is added to the intersection until the capacity of the intersection is reached. Adding a third lane will increase the lifespan by 6 years and a fourth lane by another 6 years. The additional lane eventually increases the demand as drivers will be attracted to this route (Naghawi and Idewu, 2014).

Furthermore, if generated traffic is not considered in the planning process, there will be many future issues to deal with. Traffic can result in incorrect predictions and faulty decisions. This could lead to overstating the capacity and understating the alternative benefit strategies that could provide a more efficient use of the existing road capacity. (Litman, 2001)

4. MEASURING EFFECTIVENESS OF OPERATION

Performance measures also known as Measures of Effectiveness (MOEs), are used to determine the performance of a transport facility in relation to goals, objectives and policies (Oregon.gov, 2019). The performance measures that will be identified in Chapter 3, will focus on mobility and traffic safety. The measures identified will be compared to thresholds, which defines whether the performance is acceptable or not. It should be noted that the measures mentioned in this chapter, is not a complete list, but the most widely used.

4.1. Mobility

The performance of mobility focuses on the supply and demand. The supply includes the transport network such as transport routes, bicycle lanes, pedestrian walkways and all other forms of infrastructure that relates to transport. The demand focuses on the total number of people, motorized vehicles, etc. (Oregon.gov, 2019).

4.2. Capacity

Capacity of a road is defined by the traffic demand / passengers over a period of the day under prevailing weather conditions. The term capacity defines how well a road can operate by the amount of vehicles and passengers making use of it but is not dependent on the amount of vehicles or passengers making use of it. It may vary with time and its position (Mathew, 2014).

Capacity also describes the roadway conditions that are present, such as the number of lanes and its widths, the grades, the allocation of lanes and whether the intersection is signalised or unsignalised (Federal Highway Administration Research and Technology, 2004).

Figure 3 represents the relationship between the concepts that form the basis for a capacity analysis.

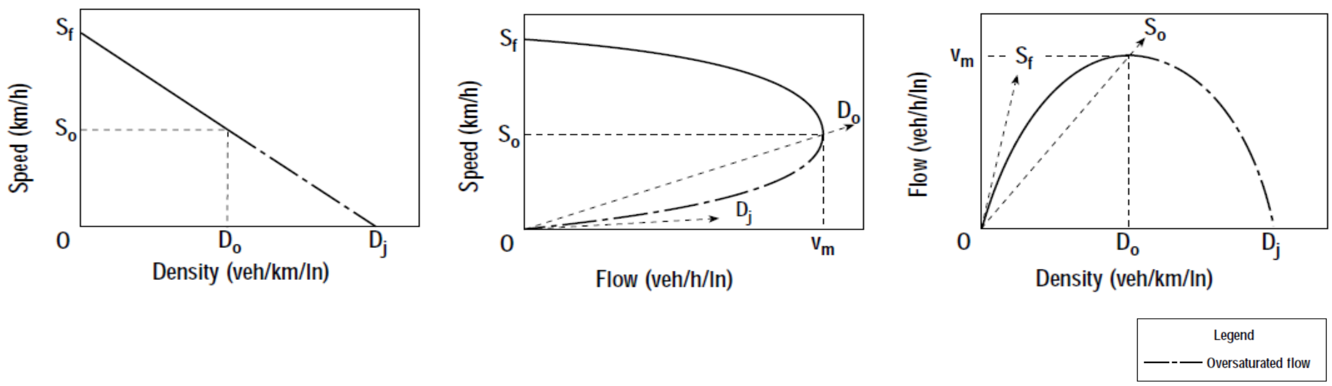

Figure 3: Relationship between the concepts used to measure a signalised intersection

4.3. Volume to Capacity Ratio (v/c)

The V/C ratio determines the traffic status at signalised intersections. The v/c ratios are based on the critical lane groups. The HCM (2000) measures the effectiveness by lane group, which means all movements are included. In countries such as Australia, Canada and Sweden, they have guidelines that assist with estimating the performance measures at an individual lane level. These measures assume that there is equal v/c ratio across all lanes whether shared or not.

4.4. Delay

In the evaluation of the operation of an urban corridor, the average delay and travel time is used to determine the quality of service at a signalised intersection. Based on previous research, the result of the Measures of Effectiveness (MOE) is not so promising. The main reason is due to little concern surrounding unbalance turning movements and its impact on through traffic at an intersection. This results in unbalanced discharge rates of all individual movements and near / oversaturation periods. Saturation Flow Rate (SFR) is the highest number of vehicles that are able to pass through a given lane within a period of time (usually one hour). In a situation where lanes are shared, estimating these volumes are difficult. In countries where vehicles travel on the lefthand side of the road, left turning movements are often shared with through traffic therefore sharing their SFR (Chen, Nakamura and Asano, 2011).

4.5. Queue

A queue is formed when the demand exceeds the capacity at a signalised intersection specifically at the start of green time. This often happens during the period of the red phase where some vehicles have not cleared the intersection during the green time period. Queues can also develop in other instances such as waiting at a service area or waiting to accept a gap in the traffic stream, etc. (Highway Capacity Manual, 2000).

4.6. Level of Service

The level of service of a road is the maximum number of passengers or vehicles that can be accommodated by a facility under certain conditions at a specific level of service. (Mathew, 2014)

LOS is defined based on the standards stated in the Highway Capacity Manual (2000) and AASHTO Geometric Design of Highways and Streets using various letters (A to F):

A - *Free Flow.* Complete mobility with speeds at / above the posted speed limit

B - *Reasonably free flow.* Speeds slightly restricted but maintained

C - *Stable flow.* Maneuvering through lanes is restricted

D - *Approaching Unstable flow*. Speeds have decreased and maneuvering is limited

E - *Unstable flow.* Flow is irregular and speeds vary. Difficult to maneuver

F - *Forced flow.* Frequent slowing required. All vehicles are in lockstep.

4.7. Traffic Safety

Road Accidents are the main cause for the death and disability of many employed citizens, the youth as well as children. The rate of injury affects the safety and activities of the country and the cost implications of road accidents erode the economic well-being of the country. Studies show that those in their productive prime (20 to 40 years old), are the majority age group killed in road accidents. Even though there is an increase in safety control being used and methods implemented to decrease the number of road accidents, the rate is still increasing daily (Sakhapov and Nikolaeva, 2018).

An efficient traffic safety management process requires proper information is required for selection and implementation which will lead to the improvement of the decision-making process. In countries where there is a proper system in place, there is a connection between the government policies and traffic safety (Sakhapov and Nikolaeva, 2018). There are three phases of the development of traffic safety, which are creation, growth and consolidation as shown in **Figure 4**.

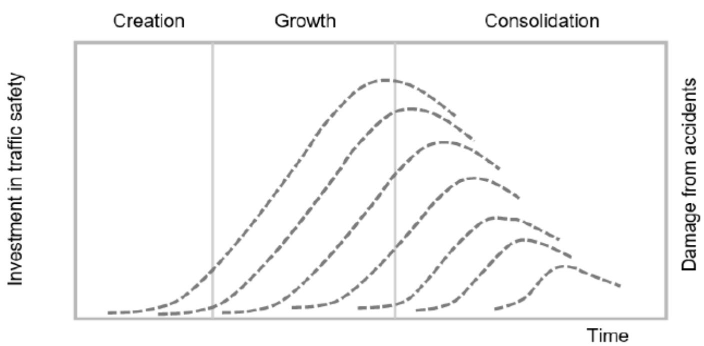

Figure 4: Three phases of development in traffic safety (Sakhapov and Nikolaeva, 2018)

Figure 4 shows the increase in traffic safety issues and the increase in the number of road accidents over time. Once traffic safety policies have been implemented, these numbers decrease and continue on, with the implementation of appropriate measures to improve traffic safety. Furthermore, it is important to identify the problems related to traffic safety and identify which has the biggest and smallest impact on the occurrence of the road accidents. It is also important to reduce risk factors that aggravate the severity of the injury (Sakhapov and Nikolaeva, 2018).

According to the Road Safety Annual Report (2017), South Africa reached its peak in 2006, with the number of road accidents fatalities that occurred. Since then, South Africa has worked towards reducing this rate. The numbers, however, still remain high and have been slowly increasing as shown in **Table 4**.

Table 4: Road accident statistics ((Road Safety Annual Report, 2017)

	1990	2000	2010	2015	2016	2016 % change over			
						2015	*2010*	*2000*	*1990*
Reported safety data									
Fatalities	11 157	8 494	13 967	12 944	14 071	8.7	0.7	65.7	26.1
Fatal crashes	9 174	6 679	10 837	10 613	11 676	10.0	7.7	74.8	27.3
Deaths per 100 000 population	30.3	19.0	27.4	23.6	25.2	7.0	-8.2	32.8	-16.9
Deaths per 10 000 registered vehicles	24.2	14.0	15.3	11.1	9.8	-11.3	-35.9	-29.9	-59.5
Traffic data									
Registered vehicles (thousands)	4 616	6 074	9 134	11 710	11 964	2.2	31.0	97.0	159.2
Registered vehicles per 1 000 population	125	136	179	213	214	0.4	19.2	57.7	70.6

In 2015, fatalities increased by 2% since 2014 and 9% since 2015. In 2016, the fatality rate was approximately 25.2 fatalities per 100 000 inhabitants of which 38% were pedestrians. Furthermore, the data provided also indicates that from 1990 to 2016, the number of registered vehicles increased from 4 616 000 to 11 964 000 (Road Safety Annual Report, 2017). As the total number of registered vehicles increased, so have the number of fatalities. It should also be noted that there are also many unregistered vehicles on the road. This data has not been provided.

5. INTERSECTION DESIGN

Designing an intersection plays an important role as an intersection is the main point where all modes of transport meet. If an intersection design is undertaken correctly, it will ensure proper mobility and safety for all modes of transport. It is therefore important to ensure all factors are taken into consideration when designing an intersection. Chapter 3 will focus on the fundamentals of intersection design.

5.1. What is an intersection?

According to the Connecticut Department of Transportation (2014), an intersection can be defined as intersecting streets that includes the various modes of travel, such as: cycling, motor vehicle, transit and pedestrian movement. In street design, intersections play an important role and the main design features include:

- surrounding land uses,
- movements between various modes of transport that may have conflicting points,
- controlling traffic by means of traffic control devices,
- Determining capacity of the intersecting roadways.

5.2. Types of Intersections

Intersections can be categorized into four types and they are shown in **Figure 5** (Connecticut Department of Transportation, 2014):

- Simple intersections

These types of intersections maintain the same amount of lanes through the intersection along both the minor and major roads and often do not have turning lanes (either because it's not needed, or constraints is located nearby). Crossing distance for pedestrians is minimum and vehicle volume is low.

- Flared intersections

This type of intersection is different from the Simple intersection as it expands across either minor and major (or both) and has auxiliary left turning lanes to improve the capacity of the road. These types of intersections have higher volumes of vehicles and higher speeds of vehicles.

- Channelized intersections

Raised islands or pavement markings are used to indicate the path for the vehicle and it is often used for auxiliary right turning lanes

- Roundabouts

This is a form of channelized intersection with traffic operating in one direction around a central island. Often used in the place of signalised or stop-controlled intersections.

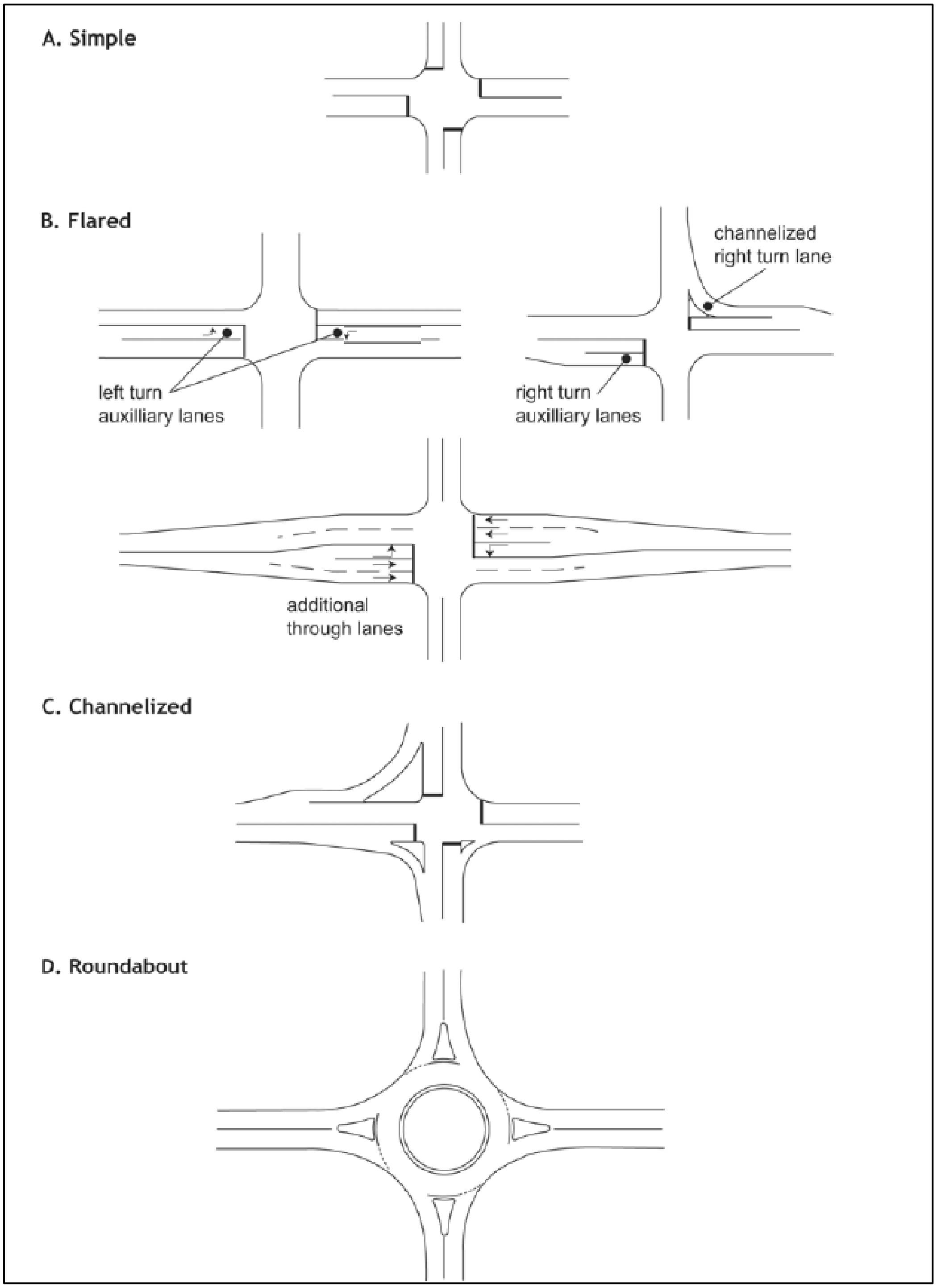

Figure 5: Types of intersections (AASHTO, 2011)

5.3. Types of Intersection Designs

According to the Western Cape's Road Access Guidelines (2002), there are three types of intersection designs and they are as follows:

- Priority control – yield or stop condition;
- Traffic signal;
- Rotary movement control

Furthermore, this section of the report will focus on traffic signals and rotary movement control. Priority control is more suitable where traffic volumes are lower.

5.3.1. Signalised Intersection

A traffic network comprises links and junctions. To determine the most efficient way for a junction area to operate, is to determine the way in which conflicting volumes of traffic will be served. It is not necessary for the junction area to be signalized, but often it is the most preferable, as it can accommodate larger volumes and less undesirable delays (Golias and Porikou, 2004). Signalised intersections are important in urban areas and its capacity and control mechanisms impact the level of service of the networks and the connectivity of the urban roads (Li et al., 2016).

5.3.1.1. Signal Design

It is important for a traffic signal to operate correctly, especially at a major intersection, as it controls the traffic, assists with reducing road crashes and assists road users with using the intersection safely and effectively (Krishna, et al, 2018). If the signal timing at an intersection is incorrect, it can affect the flow of traffic. If the green time of a phase is too long for the queue that has accumulated to dissipate or for new traffic to pass, it often means that the timing on the other phases are either shorter or the overall cycle is long. Shortening the green time, however, won't reduce the accumulated queue of traffic (Eriskin et al., 2017).

If an intersection becomes oversaturated, the flow of traffic becomes unstable. A small instability can result in a number of issues. The oversaturation may appear at one intersection and spread to other adjoining intersections if not optimized correctly (Eriskin et al., 2017). Furthermore, the timing of signal operation affects the price of the trip, which further affects the time of travel, choice of route, the mode of transport and sometimes whether the trip will take place or not (Teply and Fu, 1997).

Retiming of traffic signals is a cost-effective method to improve the flow of traffic. The retiming of signals has improved up to 26% of traffic. However, many Traffic Engineers do not have the budget to conduct a proper program for the signal retiming. The conventional method includes signal timing optimization, current flow of traffic data, knowledge of signal control hardware and knowledge of the field operations (Federal Highway Administration Research and Technology, 2004).

This method is expensive and time consuming. There have, however, been Traffic Engineers that have developed new methods to reduce the cost and the number of tasks associated with it and still produce a proper signal timing plan. This is known as "near-optimum" plans. It should be noted that this few step is suitable in smaller situations. The practitioners can expect to save 70 – 80 % of the budget on this evaluation (Federal Highway Administration Research and Technology, 2004).

5.3.1.2. Signal controls

Fixed timing is often used, especially in urban areas to ensure regularity, organization of the network, predictability and mostly, to reduce unnecessary delays. The benefits of this type of signal control include routine gaps in traffic, which allows pedestrians to cross at consistent intervals and more regularly, making them part of the traffic. It requires low initial and continuous maintenance costs. This type of signal control is suitable in CBD areas and urban areas where pedestrians are visible and speeds of vehicles are low (National Association of City Transportation Officials, 2019).

Fully actuated signals detect vehicles before the stop line, known as the dilemma zone, which is used in areas where vehicles are travelling at high speeds and protection is required. Detection is placed along the minor roads and the phasing along the mainline varies. If the phasing along the non-coordinated can be completed in less time, the time is then allocated to the mainline phase. If vehicles along the non-coordinated phase arrive late, these vehicles will be given the opportunity to move during the permissive period without impeding the mainline phase (Yarger, n.d.).

Semi actuated signals have detection signals along the minor routes, to detect when there is movement. The cycle lengths are imposed and may vary based on traffic flows. The non-coordinated phases have maximum green time for coordination. The main phase has minimum green time that must be completed. Once completed, the non-coordinated phases can be completed in conjunction with clear time, to ensure no conflicting traffic movements. Once the maximum green time along the main phase has been completed and no traffic is along the non-coordinated phases, these phases may be skipped and the main phase continued (Yarger, n.d.).

It should be noted that signalization is not always the best option especially in lower volume areas, specifically residential or local intersecting streets. Yield and stop controls are the better options (National Association of City Transportation Officials, 2019).

5.3.1.3. Right turn signal phasing (left side of the road)

According to the Highway Capacity Manual (2000), there are a few factors that must be considered first before any adjustments are made to the right turning lane and they include:

- o Is the lane exclusive or shared?
- o What type of phasing should be implemented?
- o What is the distribution of right turn movements in shared lane?
- o What is the volume of opposing traffic volumes when left turns are made?

Austin, et al., (2017) have listed a few criteria that must be used to determine when a right turn phase is needed, and they are listed below:

- There should be a high number of right turning accidents.
- If sufficient sight distance is available, permissive phase can be used. If sight distance is poor, then protected phase must be used to reduce potential conflicting points.
- Does the geometry of the road allow for a right turning movement?
- What are the speeds of vehicles?
- What are the intersection volumes and its operation?

To implement a right turning phase, there are approximately five options that could be implemented, and they are summarized below. (Signal Timing Manual, 2015)

- Permitted right turn phase
    - o Vehicle is required to yield to oncoming vehicle traffic;
    - o It is displayed using both the right turn and opposing through movements;

    - This is often used on light to moderate traffic conditions and where sight distance is adequate;
    - It provides the most efficient green time allocation, but the efficiency of this phase is based on the number of gaps available for vehicles to take;
    - The disadvantage is if gaps are not visible and vehicles view is obstructed. This may lead to a road accident.

- *Protected right turn phase*
    - Vehicle users are assigned rights of way;
    - Turns are only allowed once the green arrow is visible on display;
    - The advantage of this is that it provides an efficient turning service and is often recognized as the safest option for this operation;
    - The disadvantage is that it increases cycle length, and this may delay other movements at the intersection.

- *Protected-Permitted right turn phase*
    - This is a combination of both the permitted and protected phases. Vehicles can complete the turning movement once gaps have opened up in oncoming traffic. These vehicles will continue to turn once the green arrow goes on display in the next phase;
    - The advantage of this phase is that it provides an efficient right turning phase without heavy delays. It is also safe if sufficient sight distance is available;
    - The disadvantage is there is a possibility of delays. It is also difficult to implement at coordinated corridors as there will be fewer opportunities for vehicles travelling straight ahead.

- *Split phasing*
    - This type of phasing assigns right of way to all the movements on a certain approach, followed by the next approach;
    - This type of phasing is necessary when more than one right turn lane needs to be accommodated but space is limited, and vehicles may conflict with opposing traffic;
    - The advantage of this phase is that it prevents conflicts between the opposing right turn movements;

- The disadvantage of this phase is that it is considered less efficient and may increase the cycle length or reduce the timing on some of the approaches.

- *Prohibited Right turn phase*
    - This occurs generally when right turn is prohibited during the day or portions of the day;
    - The advantage of this is that right turn can assist an intersection with maintaining mobility;
    - The disadvantage is that some vehicles may be required to find an alternative route.

5.3.1.4. Left turn signal phasing (left side of the road)

The majority of the guidelines focus on the turning movements that may conflict with the opposing traffic. No specific guidelines have been provided to implement a left turning phase. However, according to the Highway Capacity Manual (2000), there are certain factors that must be considered when adjusting the left turning lane and they include:

- Left turn lane is exclusive or shared lane
- Distribution of left turning movements in shared lane

According to Naghawi and Idewu (2014), if an additional phase is implemented, the cycle length of the signal will increase and green time along the major routes will be reduced, thereby increasing the queue length. However, reducing the number of phases in a cycle will improve the overall operation, safety of the intersection and reduce the delay time.

5.3.2. Roundabouts

The construction of roundabouts over the years has been on the increase, whether it is to build a new at-grade intersection or rebuilding an existing intersection. Currently, no geometric guidelines of roundabouts exist, as the guidelines may differ from country to country. What may be safe in one country may not be safe in another.

Research undertaken by Yin and Qiu (2012) indicates that roundabouts are much safer than other forms of at-grade intersections. The number of fatalities and crashes that occur at roundabouts, in comparison to signalised intersections, are much lower. The main reason is its configuration, as all vehicles are travelling in the same direction, thereby eliminating some types of crashes, which include head on collisions, right angle crashes and a few others (Yin and Qiu, 2012).

Furthermore, the design of a roundabout controls the speed of vehicles. It provides a limited curve that forces vehicles to slow down naturally; it has a reduced gap length for vehicles entering the roundabout and has a deflection at the roundabout entry point (Yin and Qiu, 2012).

The lower speeds experienced at a roundabout in conjunction with its geometric features, has resulted in the following (Yin and Qiu, 2012):

- Drivers have more time to judge before entering the roundabout and adjust the speed of the vehicle, which results in safer merging;
- Sufficient time is given to drivers to correct mistakes being done by the driver or other drivers;
- The severity of a collision is reduced, due to lower speeds;
- There are fewer conflicting points within a roundabout for all users;
- Pedestrians have a higher chance of vehicles providing them right of way than at an intersection;
- The distance for pedestrians to cross is shorter and the disruption of traffic to allow pedestrians to cross is only in one direction;
- Medians separating the direction of moving vehicles, provides refuge for crossing pedestrians.

Furthermore, a study was undertaken by Persand et al (2000) of 24 intersections in the United States that were converted to roundabouts. The intersections were either signalised or stop-controlled. As a result, the total number of collisions was reduced by 39%. Injury collisions were reduced by 76% and fatal and incapacitating injury collisions were reduced by 90%.

It should further be noted that the collision reduction varies between a single-lane and multi-lane roundabout. For a multi-lane roundabout, the injury collision is lower, but for all collision type, the single-lane roundabout has a better reduction rate (Yin and Qiu, 2012).

5.3.3. Unsignalised Intersection

Unsignalised intersections are generally the type of intersection where accidents occur especially in developing countries, as the rules of the road are not strictly followed. There are many types of vehicles that travel at various speeds and have various dimensions. This affects the flow of traffic, as well as the capacity of the road. The flow may not be affected if the volumes at the intersection are low. In the case where volumes are high, the flow will be difficult to maintain and there is a greater chance that traffic congestion may occur. Therefore, it is important to determine the capacity of an intersection, which is very difficult to do at an unsignalised intersection, as the speeds of vehicles will vary. Furthermore, vehicles travelling along the minor roads may find it difficult to enter the major roads as speeds along the major roads are generally higher, therefore, increasing the waiting time of vehicles along the minor roads (Paul and Pitale, 2017).

5.4. Lane Design

A lane forms part of a roadway which is used by drivers daily. The lane guides the driver and assist with reducing traffic conflicts that may occur. Designing a lane is, therefore, important in ensuring proper operation of a roadway.

5.4.1. Lane Grouping

According to the Highway Capacity Manual (2000), lane grouping is used to identify each approach. It is used to determine the geometry of the intersection and the distribution of the traffic along each approach. It should be noted that during the process, the smallest number is generally used to describe the operation of the intersection. The following guidelines may be used:

- Exclusive right turn lane/s should remain separate lane group unless this lane is shared with through traffic. The distribution between the right turning movements and through traffic will determine the lane grouping.
- At the approach, exclusive right/left turn lanes or both will be included as a single lane group.
- In a shared lane situation, the distribution must be determined to establish whether equilibrium conditions exist. If the right/left turn volumes are high that it acts as an exclusive right/left lane. This is also known as de-facto right / left turn lane.

Furthermore, critical lane groups could also occur. They refer to the lane group that has the highest flow ratio or in other words, highest traffic intensity. In this group, the necessary green time is often allocated.

5.4.2. Turning Lane

DeBaie (2004) states that turning lanes at intersections, could assist with reducing the number of road accidents that occur. Guidelines and warrants have not been properly established to provide guidance on this. Most transport departments use volumes and road accident statistics to determine whether turning lanes are required (DeBaie, 2004).

Three components that determine the length of the turn lanes are the taper, deceleration length and the storage length and it is shown in **Figure 6**. To begin the design, the taper is determined, which is based on the location and traffic characteristics (Traffic Engineering Handbook, 1999).5

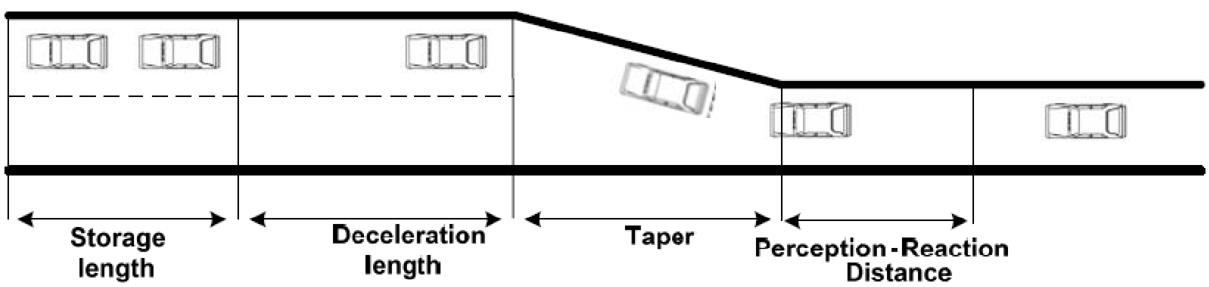

Figure 6: Components of a turning lane (Traffic Engineering Handbook, 1999)

The length for deceleration for right turning traffic is shown in **Table 5** (Traffic Engineering Handbook, 1999).

Table 5: Deceleration distance according to design speeds (AASHTO)

Design Speed (mph)	Deceleration Distance (ft)	
	Traffic Engineering Handbook	AASHTO
30	170	170
40	275	275
45	340	340
50	410	410
55	485	485

When determining the storage length, it is important to determine the overflow or backlog of traffic that could occur from the turning lane. According to the HCM 2000 and Traffic Engineering Handbook (1999), 95% of all turning vehicles must be considered to be stored. This means that there is a probability that only 5% of the total queue length will be exceeded (Traffic Engineering Handbook, 1999).

6. CASE STUDY

6.1. Research Problem

Milner and Klipfontein Road signalised intersection, located off the M5 highway in Mowbray is used daily as it provides access to many surrounding residential areas. High volumes of congestion are experienced at this intersection specifically during the PM peak period, with majority of the congestion operating along the southbound approach.

The layout of the southbound approach consists of three lanes: a shared (left turning and straight ahead) lane, a straight-ahead lane and a short right turn lane. Majority of the traffic entering the southbound approach, often choose to travel west on Klipftontein Road, as this provides access to many surrounding areas and is often used as a rat run route (not investigated in this report). The signalized intersection does not have a permitted left turn phase, and this has resulted in high volumes of congestion within the shared lane.

Furthermore, the congestion within the shared lane has resulted in spilling of traffic onto nearby roads, vehicles are unable to enter the shared lane (if entering from M5 highway) due to limited gaps available, travel time from Raapenberg Road is longer than usual and its resulted in number of crashes.

The aim of this investigation is to determine suitable solutions to alleviate some or all of the issues experienced along the southbound approach.

6.2. The Study Area

The M5 highway is an expressway that serves as an important route as it connects the northern suburbs to the southern suburbs via N1 and N2 highways. Along the M5 highway, there are various points where congestion levels are higher, as a result of merging vehicles (on ramps onto M5 highway). This has resulted in slower traffic along the M5 highway, which in turn results in vehicles using alternative routes, including that of the southbound approach of Milner and Klipfontein Road intersection, specifically during the peak periods of the day.

Milner and Klipfontein Road intersection is located with the Mowbray area as shown in **Figure 7** and provides access to areas, such as Claremont, Sybrand Park, Rondebosch and many more surrounding areas.

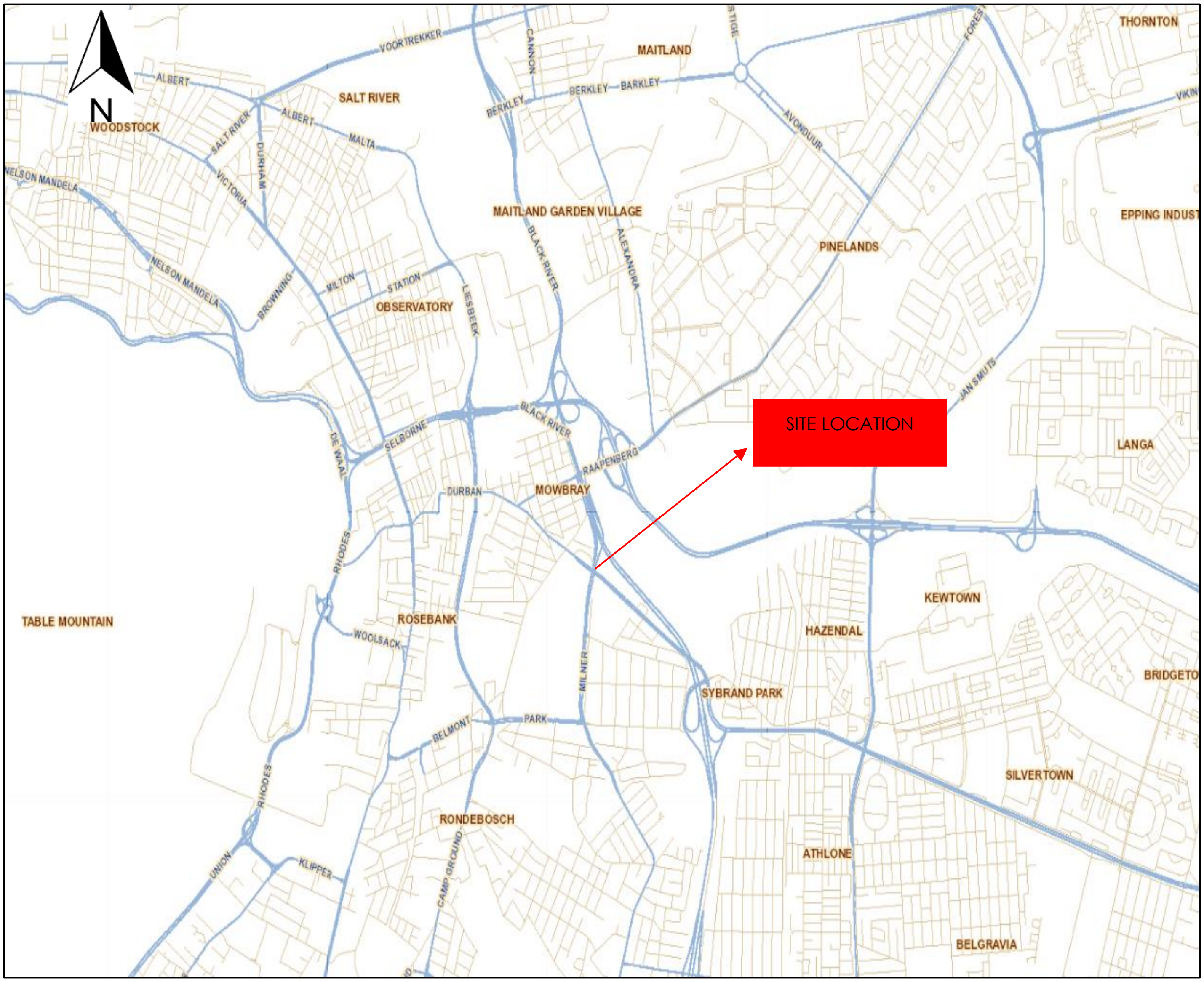

Figure 7: Locality Plan of Milner and Klipfontein Road intersection (City of Cape Town City Map Viewer, 2019)

Milner and Klipfontein Road southbound approach is often used as a rat running route to avoid traffic on the M5 highway during the PM peak hour. Vehicles are observed exiting left onto Klipfontein Road and often re-enter the M5 at the M5 on-ramp turn off that is located 1.4kms away.

Please note that rat running will not be assessed during this investigation. Please refer to *Scope and Limitations* in *Chapter 1.* An aerial view of the approach is shown in **Figures 8**.

Figure 8: Aerial View of Milner and Klipfontein Road intersection (Google Maps, 2019)

6.3. Road Network

There are a number of road-based routes that access this portion of the study area of Milner and Klipfontein southbound approach. These roads are described according to Transport for Cape Town's *Public Right of Way: Road Network Map* (August 2013) and shown in **Figure 9**:

- Klipfontein Road is a two-lane divided road and is classified as a Class 3 Secondary Arterial with a speed limit of 60km/hr. in the vicinity of Milner and Klipfontein Road intersection.
- Blackriver Parkway is a one lane undivided road and is classified as a Class 3 Secondary arterial with a speed limit of 60 km/hr.
- Raapenberg Road is a two-lane divided road and is classified as a Class 3 Secondary arterial with a speed limit of 60 km/hr. in the vicinity of Alexandra and Raapenberg Road intersection.
- Milner Road is a two-lane undivided road and is classified as a Class 5 Access Road with a speed limit of 60km/hr.

Milner and Klipfontein Road is located on the outskirts of the CBD. It is surrounded by residential as well as shopping malls, schools, hospitals, recreational facilities, etc. It can, therefore, be described as an Intermediate Development area.

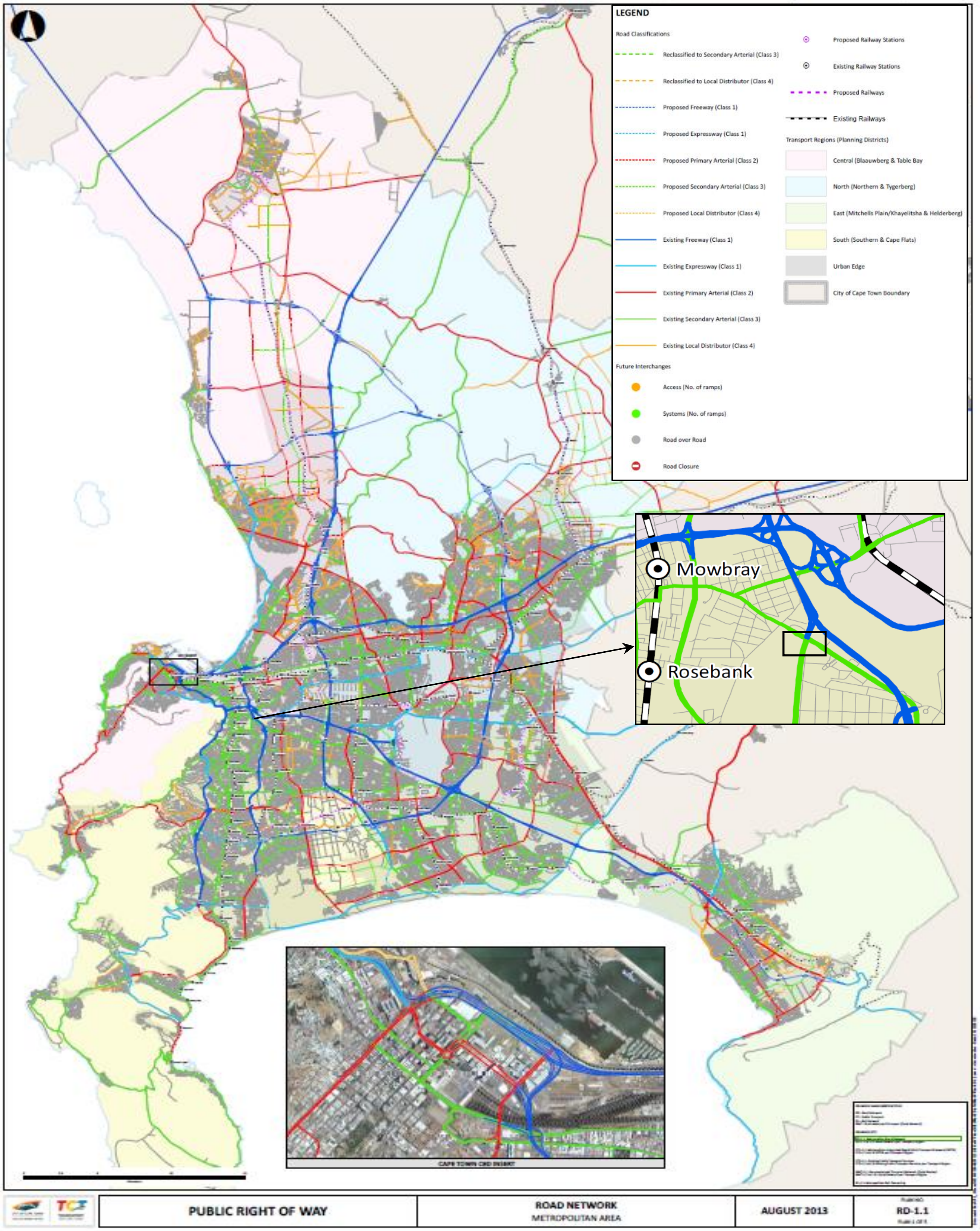

Figure 9: Road Network Map (Transport for Cape Town, August 2013)

7. METHODOLOGY

A process chart was drawn up and is shown in **Figure 10**. The chart explains the process that was undertaken to complete the dissertation.

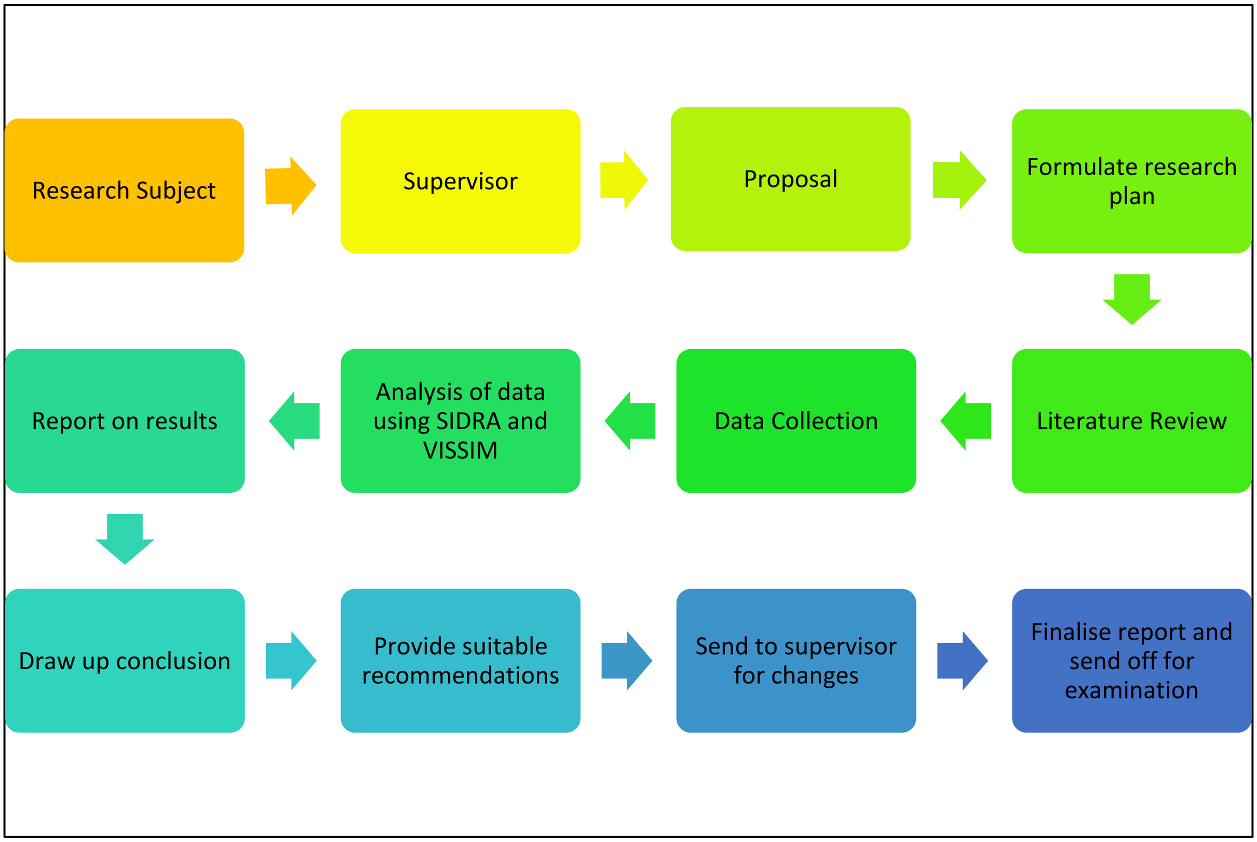

Figure 10: Research Project Process

7.1. Project Initiation

The project initiation began with finding a suitable research subject that would allow for suitable research. The topic that was chosen was based on personal experience of living close to the area for many years. Research was completed to determine whether this topic had been done previously and if there was suitable literature relating to this topic.

A supervisor at the University of Cape Town was contacted to discuss the research subject. The discussion focused on the selection of the topic, what limitations the topic, the method that would be undertaken to complete the research and timeframe for the work to be completed.

A proposal was drawn up discussing the research topic and what the project was trying to achieve. This was sent off to the supervisor for approval. On approval, the research could commence.

A research plan was developed that determined the type of data that needed to be collected, when these surveys would be undertaken, the method that would be followed to assess the data, how the report would be drawn up, etc.

Literature regarding the issues relating to the research project was collected. A proposal was drawn up and given to the supervisor for approval. The literature focused mainly on the type of traffic experienced in Cape Town and other parts of the world, traffic congestion, mitigating measures and more.

7.2. Conceptual Framework

This section provides an overview of the conceptual framework for the investigation. It is based on the literature provided in the Literature Review as well as details from the site assessment. The key objective of the framework is to understand what is being assessed and what outcomes are to be expected.

The vision

Milner and Klipfontein Road serves as main transport route for many vehicles daily. The aim of this investigation is providing a suitable solution to reduce the high levels of congestion that is currently being experienced along the southbound approach of Milner and Klipfontein Road intersection. This high level of congestion has further resulted in a number of issues that include spilling of traffic onto nearby roads, vehicles experiencing a difficulty with changing lanes, increase in crashes and longer travel times.

What we want to achieve

- To reduce the high levels of congestion along the southbound approach
- To alleviate some of spilling as a result of congestion onto nearby roads such as Raapenberg Road and M5 highway
- To allow vehicle to change lanes without difficulty
- To reduce the number of crashes along this section of the road
- To reduce the time, it takes to travel this section of road and for vehicles to reach their destination faster

Objectives

- A site assessment will be completed to determine the existing traffic conditions at Milner and Klipfontein Road intersection. The site assessment will provide further details of the layout of the intersection, the type of intersection and how vehicles operate at this intersection.
- The site assessment will also determine the levels of traffic congestion and what its possible causes are.
- To assess how the signalized intersection operates in terms of its phasing, if there are permitted signal phasing, signal timing and how this affects the operation of the intersection. The data obtained will be assessed against the literature in the Literature Review.
- To assess the layout of the lanes along the southbound approach to determine the effects of the shared lane and the short turn right turn lane has on the congestion levels. The data obtained will be assessed against the literature in the Literature Review.
- There are existing traffic counts of this intersection and therefore a traffic count survey does not need to be completed. However, it is important to compare the existing counts to the current condition of the road and operation of vehicles to ensure that they are still suitable and accurate.
- Two additional surveys will be completed. A travel time survey to determine how long it takes to undertake the complete distance of the southbound approach during the PM peak period. A directional survey will also be completed to determine the direction in which vehicles are travelling from and travelling to.
- Two analysis software tools will be used to determine the overall operation of the intersection and the southbound approach. The results from both software tools will then be compared to determine if the results obtained are accurate.
- A report will be written up that includes literature for the components investigated as well as the results and findings of the data collected.
- Suitable recommendations will be provided based off of the results and findings and the literature review.

Focus areas

- Traffic congestion

  Congestion negatively impacts the road network. Congestion can be caused by many things, including the layout of the road, the type of intersection (signalized or unsignalized), the number of lanes, etc. Basically, congestion can be a result of the geometric layout.

- Signalised and unsignalized intersections

  For major intersection, signalized is most suitable as its able to deal with large volumes of traffic. However, in this case the layout of the southbound approach does not operate efficiently. Majority of the traffic operating along the southbound approach can be found within the left lane (shared lane). This left lane does not have a permitted left turn phase.
- Lane design

  The signalized southbound approach is made up of three lanes – a short turn right lane, a straight-ahead lane and a shared left lane (both straight ahead and left turning movements only).
- Type of suitable upgrades

  There are various ways in which an intersection can be upgraded. Those include changing the signal timing, additional or reduction in phases, changing the layout and number of lanes, or changing the signalised intersection to a roundabout.

Actions / Recommendations

- To identify suitable recommendations.
- To improve the operation of the southbound approach and alleviate some or all of the issues that have been caused by traffic congestion.

8. RESULTS AND FINDINGS

The data that was collected from the surveys that were undertaken, will be processed and analysed in this portion of the report. The data analysis process will include the use of Sidra, Junction and Microsoft Excel.

8.1. Site Assessment

Milner and Klipfontein Road intersection is located within Mowbray, Cape Town. The intersection is used daily with large volumes of traffic operating through the intersection during both peak periods of the day. A site assessment was undertaken on 20 February 2019 between the AM peak (6:00 and 8:30) and the PM peak (16:00 and 18:30) as the issues are expected to worsen during peak periods.

Milner and Klipfontein Road intersection is a large intersection with large volumes of traffic operating through the intersection daily. Milner Road has four lanes travelling northbound to cater for traffic from nearby areas, such as Rondebosch and Claremont. Blackriver Parkway has three lanes travelling southbound which transports vehicles from Raapenberg and the M5 highway. Klipfontein Road has three lanes operating in both directions. The approach transports vehicles travelling to and from areas such as Sybrand Park, Rondebosch, Observatory and Mowbray area.

For the purpose of this investigation, the entire intersection will be assessed with a lot of focus on the southbound approach. The southbound approach of Milner and Klipfontein Road comprises a shared left lane for left turning and straight-ahead movements, a middle lane for straight ahead movements and a short right turning lane. The layout of the entire intersection is shown in **Figure 11**.

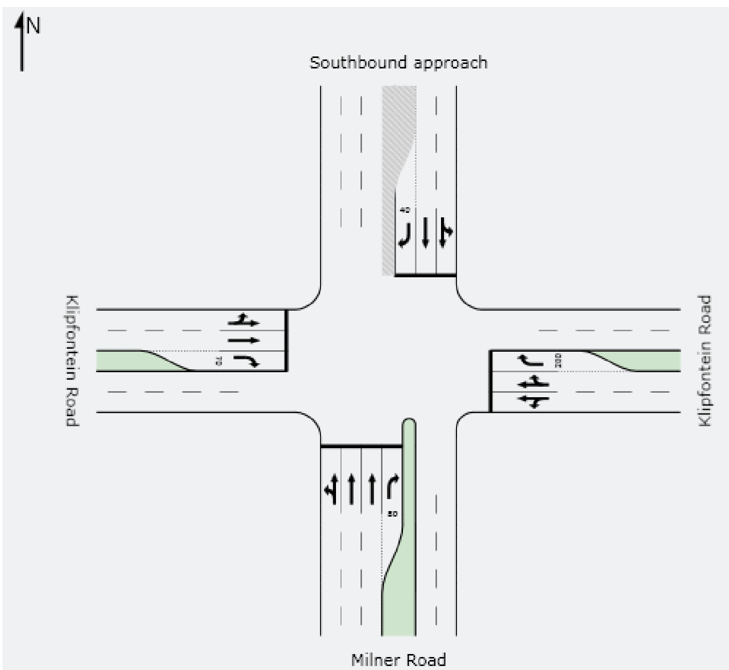

Figure 11: Layout of the southbound approach

A site assessment was undertaken on 20 February 2019 between the AM peak (6:00 and 8:30) and the PM peak (16:00 and 18:30). During the site assessment, it was observed that congestion occurred along the southbound approach during the PM peak was higher than during the AM peak. The site assessment corresponds to the data that was obtained from the City of Cape Town through a traffic count that was completed at Milner and Klipfontein Road intersection in 2017. The traffic count results in shown in **Figures 12** and **13.**

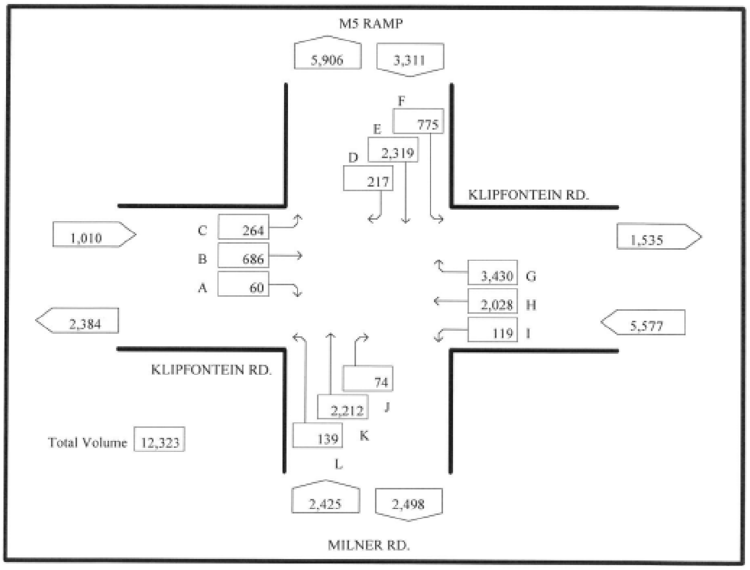

Figure 12: City of Cape Town traffic count survey results for the AM peak (2017)

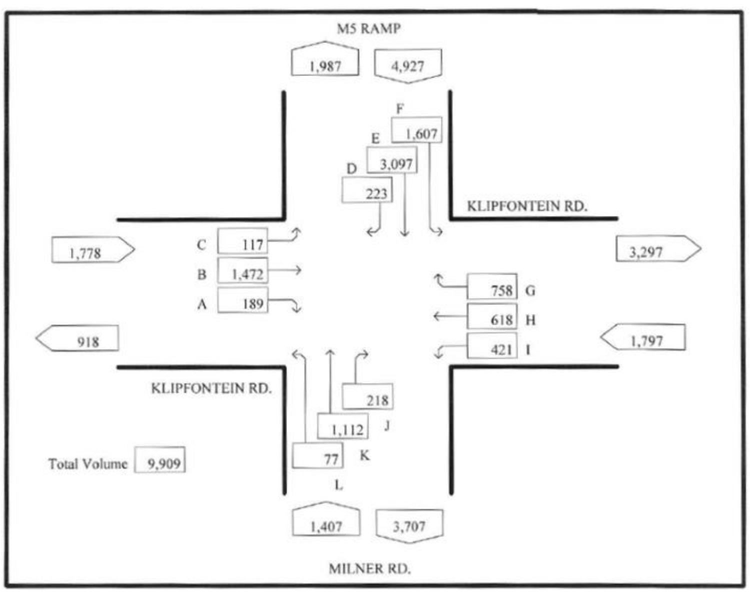

Figure 13: City of Cape Town traffic count survey results for the PM peak (2017)

During the AM peak a total of 3 311 vehicles enter the southbound approach. During the PM peak, the total vehicles entering the southbound approach is 4 927. It is also observed that 23% of the AM peak and 33% of the PM peak total vehicles entering the approach, exits eastbound onto Klipfontein Road

The site assessment further revealed a number of other issues that are currently being experienced along the southbound approach. High volumes of traffic enter from both the M5 highway and

Raapenberg Road. During the assessment, a large majority of the traffic entering the approach, entered or wanted to enter the left lane as to travel eastbound along Klipfontein Road. This direction can only be accessed from the left turning lane which is a shared lane. With no priority given to the large volume of left turning vehicles, this resulted in a backlog of traffic onto Raapenberg Road, vehicles struggling to enter the left turning lane due to limited gap length, obstruction to vehicles travelling in other directions and vehicles undertaking illegal moves (crossing a solid line). Therefore, there is a need to re-evaluate the intersection and provide a suitable mitigating measure/s.

8.2. Background Traffic

A traffic count survey is necessary as it determines the volumes of vehicles along each approach. It also provides insight into the level of congestion that is currently being experienced. However, an intersection survey was not undertaken as data was obtained from past records at the City of Cape Town. A traffic count survey was undertaken on Thursday, 30 March 2017 during the AM (6:30 to 8:30) and PM (16:00 to 18:00) periods. This data is still considered suitable for this research project. The total volumes of the traffic count are shown in **Figure 13** and the full traffic count data is shown in **Appendix A.**

The data was modeled using SIDRA 5.0 and Junctions to measure the effectiveness of operation. The data will investigate the queue length along each approach and the level of service of the intersection.

8.2.1. SIDRA

The background traffic was captured in Sidra 5.0 to determine the LOS and queue length of the Milner and Klipfontein Road intersection in its current state during the PM peak hour only. This is shown below in **Figure 14.**

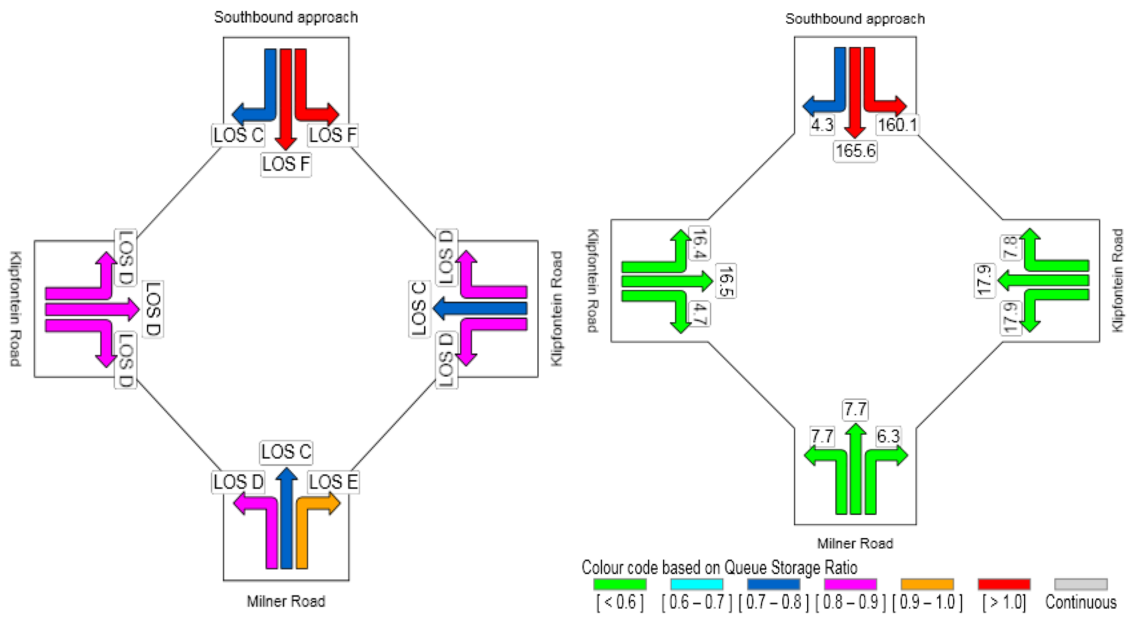

Figure 14: Level of service for background traffic of Milner and Klipfontein Road intersection

The output data from Sidra 5.0 shows that Klipfontein Road operates at an acceptable LOS D during the PM peak hour. However, Milner Road northbound approach operates at an acceptable LOS with the exception of the right turning lane, which operates at LOS E. Furthermore, the right turning and straight-ahead lanes along the southbound approach operate poorly at LOS F.

The queue length data provided shows that the length of the queue along Klipfontein Road is high with the longest length of 18 vehicles. Based on the queue storage ratio, this is considered acceptable. The queue length along the southbound approach is, however, very long. For the straight ahead and left turning movements, the queues reach approximately 166 and 160 vehicles, respectively.

8.2.2. JUNCTIONS 9

The layout of Milner and Klipfontein Road intersection in Junction is shown in **Figure 15**. The letters represent the signal phasing of the intersection.

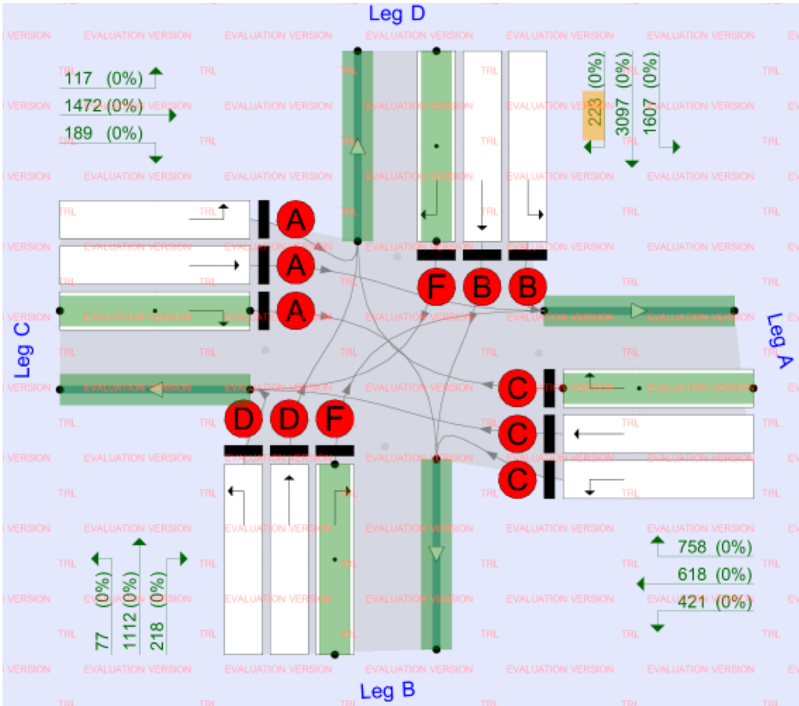

Figure 15: Future traffic volumes

The background traffic volumes of the AM and PM peak hour was captured to calculate the level of service of the intersection. A summary of the results is shown in **Figure 16**.

	AM					PM				
	Delay (s)	DOS	LOS	Intersection Delay (s)	Intersection LOS	Delay (s)	DOS	LOS	Intersection Delay (s)	Intersection LOS
	2019									
Leg A	18.91	0.49	B	46.37	D	18.08	0.44	B	189.51	F
Leg B	30.06	0.35	C			416.83	1.37	F		
Leg C	38.73	0.73	D			42.38	0.77	D		
Leg D	81.86	0.98	F			29.31	0.08	C		

Figure 16: Future traffic volumes

The figure above shows that during the AM peak hour, the Milner and Klipfontein Road intersection operates at LOS D. During the PM peak hour, the operation of the intersection deteriorates to operate at LOS F with an intersection delay of 189.51.

8.2.3. COMPARISON OF SOFTWARE RESULTS

The results in SIDRA and Junctions 9 were compared to the results obtained from the site investigation as well as the traffic count that was undertaken by the City of Cape Town in 2017.

The results obtained from both software programs both indicate that the overall operation of the intersection is poor and does require an upgrade. However, based on the results, SIDRA has provided worse results for the southbound approach. According to Junctions 9, the southbound approach operates at LOS C. SIDRA, however, indicates that two of the three lanes operate at LOS F except the right turning lane, that operates at LOS C. Junctions 9 has provided the overall operation of each approach, whereas, SIDRA has provided results of each individual lane. Queue length values were not available in the Junction software, as a demo version was used to complete the modelling

8.3. Future Traffic

The future traffic volumes were calculated using the existing South Africa census data for 2011, as no recent and relevant traffic growth data was available. The future traffic volumes are shown in **Figure 17.** The census data was used to calculate the population growth rate and the full calculation is shown in **Appendix B**.

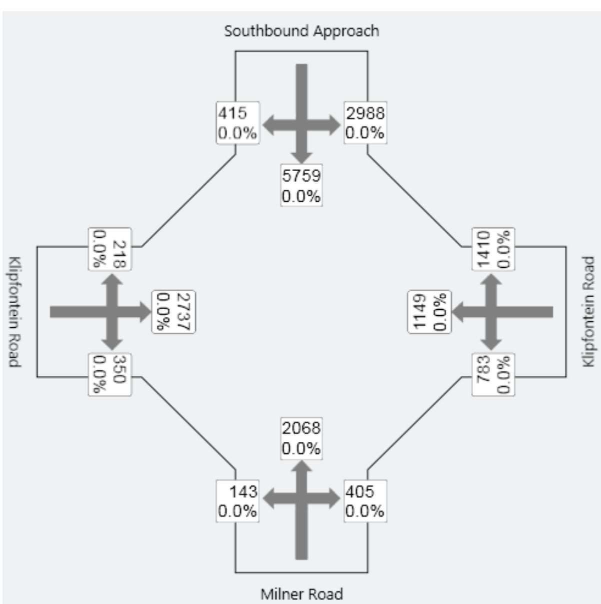

Figure 17: Future traffic volumes at Milner and Klipfontein Intersection for 2039

It should be noted that the future traffic volumes (2039) is not accurate representation but will provide an idea as to how an increase in traffic volumes will affect the existing southbound approach, that is currently operating at a poor level of service. Pedestrian volumes were not included in the analysis, as the very limited number of pedestrians was observed travelling through the intersection.

8.3.1. SIDRA

The future traffic volumes were captured in Sidra 5.0 to determine the LOS and queue length of the Milner and Klipfontein Road intersection in its future state and this is shown below in **Figure 18.**

As stated previously, only the PM peak was used to determine the future traffic results, as the PM peak hour was considered the worst-case scenario.

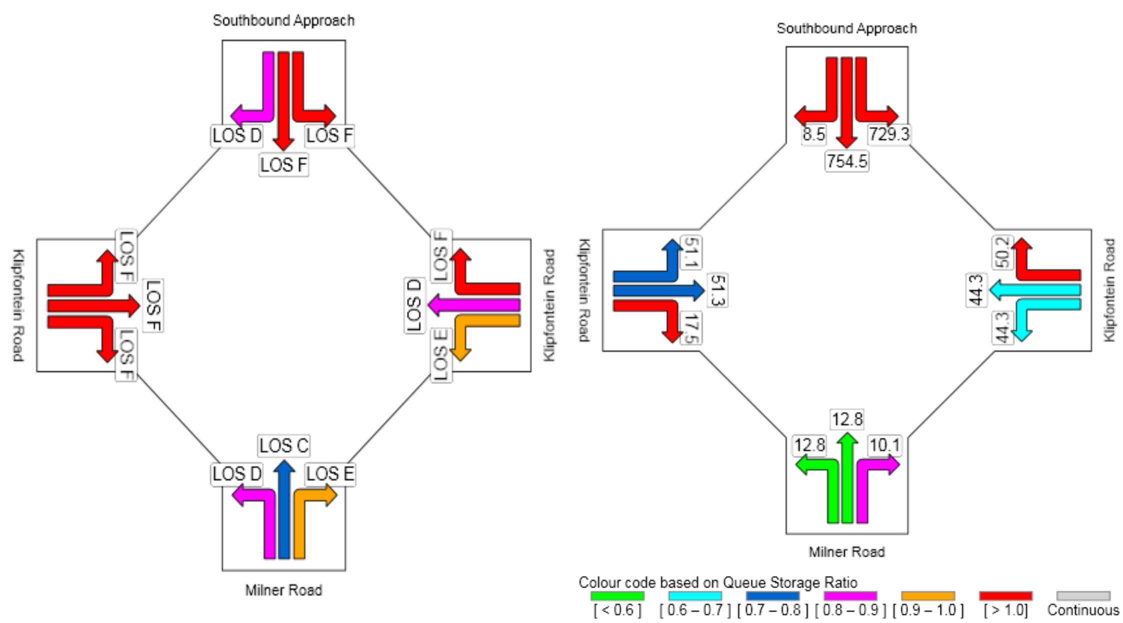

Figure 18: LOS and queue length for the Future Traffic (2039)

The future traffic data for Milner and Klipfontein Road intersection shows that the increase in traffic will cause the intersection to deteriorate and operate at a very poor level. The increase in traffic volumes has a negative effect on all approaches.

The queue length along each approach will worsen over the years and the intersection will operate very poorly as a result of the increase in traffic volumes. The southbound approach of

Milner and Klipfontein Road intersection will operate very poorly with queue length reaching over 700 vehicles. This is excessive and the roadway will not be able to cater for such a queue nor will drivers be able to reach their destination within a decent time frame.

8.3.2. JUNCTIONS 9

The future traffic volumes for the AM and PM peak period was captured in Junctions 9 to determine the overall operation of the intersection and the results are shown in **Figure 19**.

	AM					PM				
	Delay (s)	DOS	LOS	Intersection Delay (s)	Intersection LOS	Delay (s)	DOS	LOS	Intersection Delay (s)	Intersection LOS
	2019									
Leg A	19.06	0.49	B	30.25	C	15.53	0.22	B	217.80	F
Leg B	39.91	0.71	D			439.66	1.40	F		
Leg C	27.24	0.15	C			163.32	1.07	F		
Leg D	37.20	0.60	D			43.45	0.75	D		

Figure 19: Future traffic volumes

The results indicate the overall operation of the intersection improves slightly, to operate at LOS C during the AM peak hour. The PM peak hour, however, continues to operate poorly at LOS F, with intersection delay of 217.80.

8.3.3. COMPARISON OF SOFTWARE RESULTS

Based on the results obtained in both SIDRA and Junctions 9, the intersection of Milner and Klipfontein Road intersection, will continue to operate acceptably during the AM peak hour and poorly during the PM peak hour.

SIDRA provides worse results, indicating a very long queue length, especially along the southbound approach. Queue length values were not available in the Junction software, as a demo version was used to complete the modelling. Junctions 9 results, however, indicates that the southbound approach operates at LOS D. This is still considered acceptable but approaching poor operation.

8.4. Travel Time Survey Results

A travel time survey was undertaken on Wednesday, 24 July 2019 between 16:00 and 18:00. It should be noted that the PM was only assessed. The PM peak is considered "the worst case" as per the traffic counts and majority of traffic will be travelling home i.e. along the southbound approach, during the PM peak of the day. Three vehicles, operating at 10-minute intervals, as shown below in **Table 6** were used to determine how long it took for vehicles travelling from Alexandra and Raapenberg Road intersection to reach Milner and Klipfontein Road intersection during the PM peak. This provided insight into the level of congestion experienced along the southbound approach.

The total stretch of road is measured at 1.2km. If a driver, driving at an average speed of 60 km/hr. is travelling along the southbound approach, it should take a vehicle 1 minute and 20 to reach Milner and Klipfontein Road intersection without delay. This was calculated using basic calculation of distance = speed x time.

Table 6: Travel Time survey results

	Travel Time survey at 10 min intervals
16:00	2 min 27 secs
16:10	2 min 28 secs
16:20	4 min 33 secs
16:30	3 min 27 secs
16:40	4 min 49 secs
16:50	7 min 42 secs
17:00	3 min 26 secs
17:10	6 min 56 secs
17:20	7 min 44 secs
17:30	4 min 18 secs
17:40	4 min 58 secs
17:50	4 min 42 secs
18:00	3 min 2 secs
18:10	2 min 24 secs
18:20	3 min 55 secs
18:30	1 min 23 secs

Based on the travel time survey results, it took a vehicle an average time of 4 minutes 15 seconds to travel the complete distance. The top three longest runs were 7 mins 44 secs, 7 mins 42 secs and 6 mins 56 secs. These travel times are very high even if the cycle time of 2 minutes (120 seconds), is included.

If the travel time survey results are compared to the results obtained in the traffic count surveys for the PM peak, it is evident that high levels of congestion are being experienced along the southbound approach of Milner and Klipfontein Road. These high congestion levels could be a result of a number of issues, which include signal phasing, geometry of the roadway (shared lanes) and high volumes of traffic entering from both the M5 highway and Raapenberg Road.

8.5. Travel Direction Survey

To understand the extent of the congestion levels that are being experienced at Milner and Klipfontein Road intersection, it was necessary to determine where the vehicles were entering the southbound approach from and which lane they opted to use.

A traffic count was undertaken on Thursday 25 July 2019 between 16:00 and 18:00. This survey was different to the normal traffic count as it focused mainly on the number of vehicles changing lanes. This information would provide insight into the origin and destination of vehicles along the southbound approach during the PM peak only.

It should be noted that southbound approach comprises three lanes: shared lane which is for both left turning and straight ahead, a straight-ahead lane and a short turn right turning lane. The assessment, therefore, only included the two lanes before the start of the short turn right lane. Vehicles would only be required to change lanes, if they want to travel either eastbound or westbound onto Klipfontein Road as Milner Road can be accessed from both lanes.

The survey was undertaken on Thursday, 25 July 2019 between 16:00 and 18:00 at 15-minute intervals. The data was captured in excel and presented in graph form as shown in **Figure 20**.

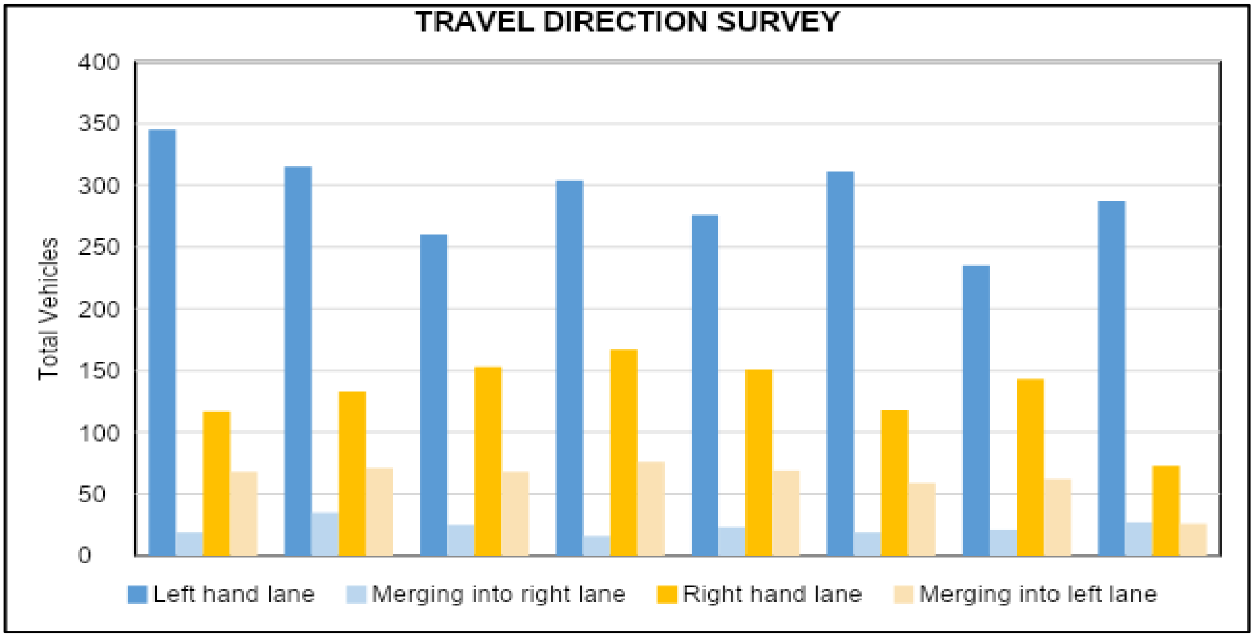

Figure 20: Travel direction survey results

Figure 20 provides a detailed view of the number of vehicles that were assessed during this survey. The "blue" represents the vehicles travelling along Blackriver Parkway from Raapenberg Road and the "orange" represents the vehicles travelling from the M5 highway.

A total of 2 333 vehicles was observed entering the southbound approach from Raapenberg Road. Of the 2 333 vehicles, 185 vehicles (8%) were observed merging into the right-hand lane. These vehicles were opting to either travel straight onto Milner Road or west onto Klipfontein Road.

Approximately 1 055 vehicles were observed exiting the M5 highway onto the southbound approach. Of the 1 055 vehicles, 499 vehicles (47%) were observed merging into the left lane. It can, therefore, be assumed that these vehicles wanted to travel eastbound onto Klipfontein Road, as Milner Road can be accessed from the right lane.

Furthermore, a separate analysis was undertaken to determine how many of the vehicles merging into the left lane, were doing them legally i.e. by not crossing the white solid line that separates the left and right lanes. The white solid line is located along the bend of the southbound approach, to prevent vehicles from merging when unsafe to do so and this is shown in **Figure 21.** The orange line represents the area where the solid line no longer exists, and vehicles are able to legally change lanes.

Figure 21: Location of solid line

The solid line continues up until approximately 200m before the signalised intersection, therefore, only offering a short distance for vehicles to merge. However, with high volumes of traffic experienced along the southbound approach, finding a suitable gap to switch lanes is limited. During the site assessment, it was noted that when vehicles attempted to switch lanes, it resulted in vehicles standing stationary between two lanes, causing obstruction and blockage to other vehicles wanting to make use of the other lanes along the southbound approach.

The data obtained during the survey is shown in **Figure 22.** It is evident from the graph that majority of merging into the left lane along the southbound approach, is undertaken legally.

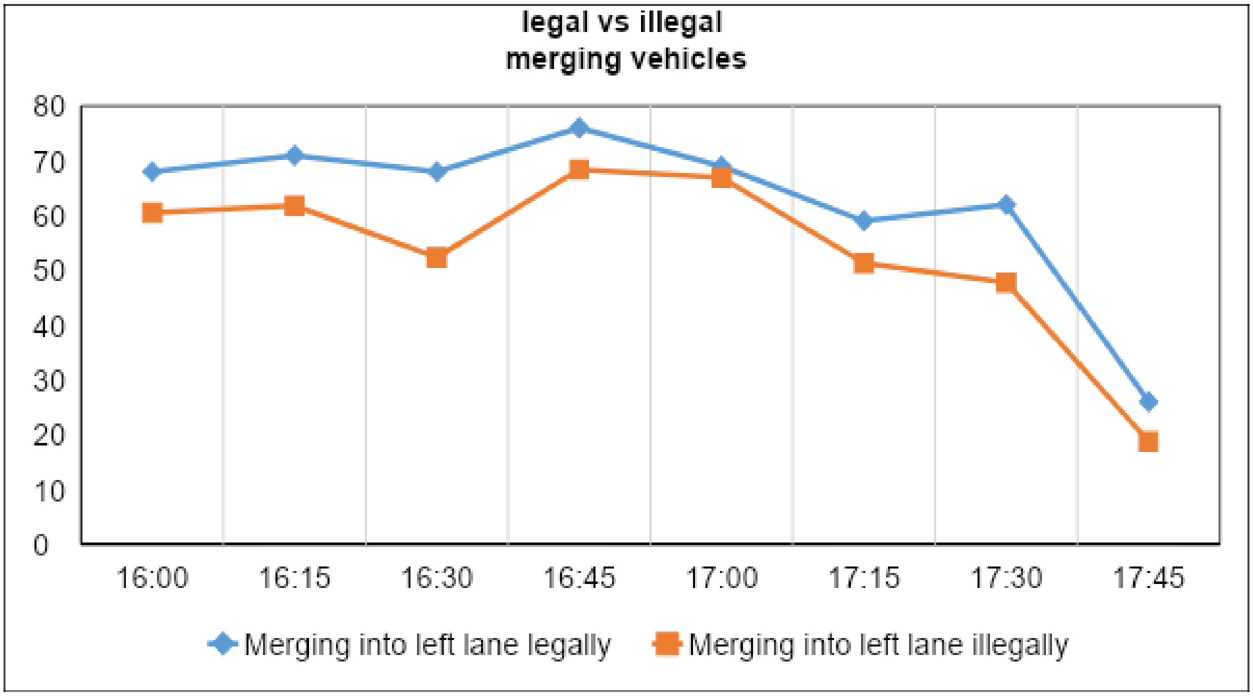

Figure 22: Graph of the number of vehicles merging legally vs. illegally

8.6. Road Accident Statistics

Road accident statistics were obtained from the City of Cape Town records, for Milner and Klipfontein Road southbound approach and is shown in **Table 7** below. The accident statistics were collected over a five-year period from 2012 to 2017.

Table 7: Accident statistics for Milner and Klipfontein intersection southbound approach

Type of accident	% Accidents
Insufficient following distance	34.07%
Driver Error / Other	11.85%
Ignored red robot	11.85%
Change lane while unsafe	10.37%
Turn in face of on-coming traffic	7.41%
Swerving	6.67%
Entered traffic while unsafe	5.19%
Did not yield	2.96%
Failing to keep left	1.48%
Failing to stay in lane	1.48%
Making a U-turn when unsafe	1.48%
Mechanical problems	1.48%
Pedestrian	1.48%
Sudden stop	1.48%
Lost control	0.74%

The total accidents that occurred at Milner and Klipfontein Road intersection over the five-year period, was 256 accidents. Of the 256 accidents that have occurred, 53% of the accidents took place along the southbound approach. This is an estimated 27 accidents per year along the southbound approach. This is considered quite high and necessary adjustments must be undertaken to reduce these numbers.

Based on the data obtained, the accident that occurred frequently was "insufficient following distance", followed by "driver error" and "ignoring the red robot". This could be a result of high congestion levels or drivers becoming impatient in traffic. It could also be a result of vehicles trying to merge, where limited gap length is available.

8.7. Signal Phasing and Timing

Signal timing and phasing data was obtained from City of Cape Town records. The data was published in July 2017 and is still considered suitable for this study. Additional signal timing and phasing data was collected during the site assessment that was undertaken on 20 February 2019 between the AM peak (6:00 and 8:30) and the PM peak (16:00 and 18:30). This was undertaken to ensure that the records obtained from the City of Cape Town was still accurate.

Milner and Klipfontein Road intersection comprises four stage signal phasing and this is shown below in **Table 8** and **Figure 23**.

Table 8: Signal phases for Milner and Klipfontein Road intersection

Stream Number	Stream	Stage	Stage Description	Phases
1	Milner - Klipfontein	1	Klipfontein	A B E
		2	Milner	D F
		3	Milner Double RHT	G H
		4	Klipfontein RHT	B C

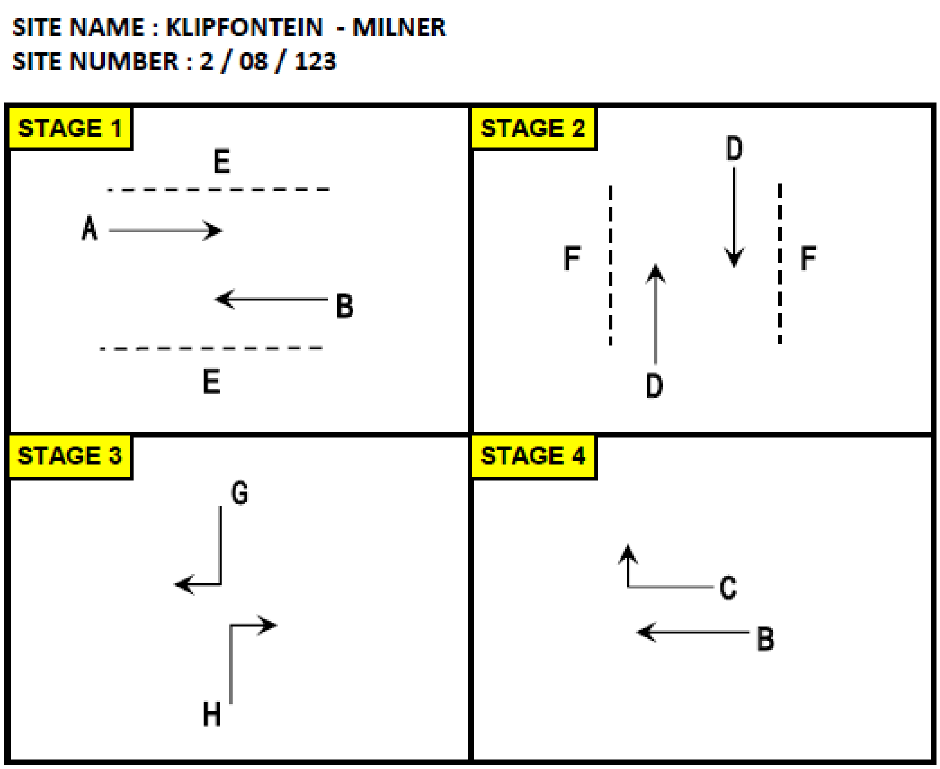

Figure 23: Milner and Klipfontein Road intersection signal phasing

The signal phasing begins with the assignment of all right of way along Klipfontein Road, followed by all right of way movements along Milner Road. The next phases to follow include a protected right turn phase along both the northbound and southbound approaches, followed by all right of way along Klipfontein Road westbound approach.

The signal timing data was also obtained from City records and is shown in **Figure 24**. The total cycle time at Milner and Klipfontein Road intersection is 120 seconds and is semi actuated control. This type of setting prioritizes movements along the major roads. It is not suitable in areas where there are high volumes of pedestrians on the minor roads (National Association of City Transportation Officials, 2019). The signal system also has imposed cycle lengths with minimum green time allocated to the main phase (Milner Road) along both approaches (all right of way). Once the minimum green time is completed, the detection signals along the minor road indicate whether there is traffic. If no traffic is evident, the phase will be skipped and returned to major route (Yarger, n.d). However, at Milner and Klipfontein Road intersection, high volumes of traffic are experienced along all approaches during both peak periods.

Plan Data for Stream 1	
Plan Number	3
Type	Semi-VA Plan
Description	Pm Peak
Phase Profile Mapping	A B C D E F G H
Semi-VA Plan Data	
Cycle Time	120
Max Cycle Decrease	----
Max Cycle Increase	----
Stage Requests	

Stage	**Stage Max**	**Stage Min**	**Window Start**	**Window End**	**Can Start Early**	**Always Run**	**Assigned Free Time**
1	33	11	0	38	Yes	Yes	Yes
2	48	11	38	38	----	----	----
3	8	5	92	92	----	Yes	----
4	9	5	106	106	----	----	----

Figure 24: Milner and Klipfontein Road intersection signal timing plan

8.8. Proposed Mitigating Measures

Based on the results of the surveys undertaken, high volumes of traffic are currently being experienced at Milner and Klipfontein Road intersection. The high congestion levels are mainly being experienced along the southbound approach and this has affected the manner in which these drivers operate causing high number of accidents and undertaking illegal movements. Therefore, there is a need to implement mitigating measures.

There are a number of mitigating measures that can be implemented to assist with alleviating some of the issues that are currently being experienced. However, this report will investigate the implementation of a roundabout. Based on the results obtained, it is necessary to upgrade the entire intersection, as the level of service of the entire intersection operates at LOS F. The background and future traffic data will be captured in both SIDRA and Junction to determine the effects of the measures.

8.8.1. Roundabout

The mitigating measure that was considered was a roundabout. Roundabouts, as stated previously, allow for a reduction in conflicting movements and can handle large volumes of traffic. The proposed layout of the roundabout is shown in **Figure 25**.

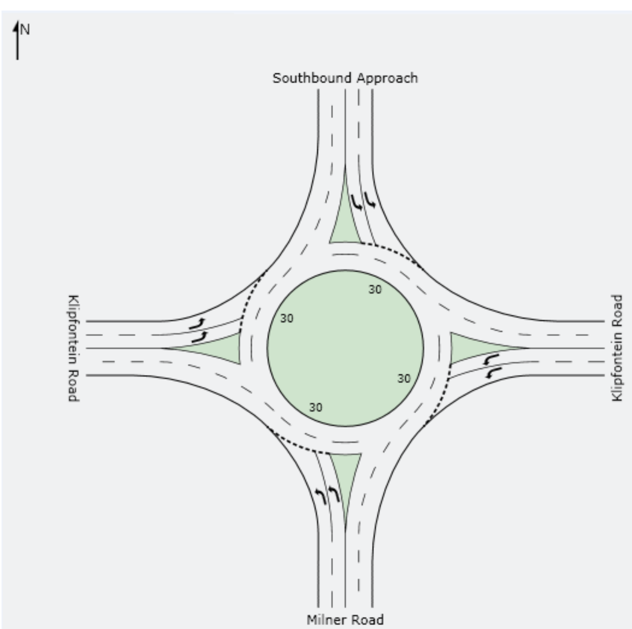

Figure 25: LOS for the proposed roundabout

Majority of the intersections at Milner and Klipfontein Road intersection have more than 2 lanes. However, the proposed layout of the roundabout will comprise a maximum of two lanes entering and exiting with a 30-degree radius.

8.8.1.1. SIDRA

The future traffic volumes were captured in both SIDRA to determine the queue lengths and level of service, if a roundabout is implemented at Milner and Klipfontein Road intersection. The results are shown in **Figure 26.**

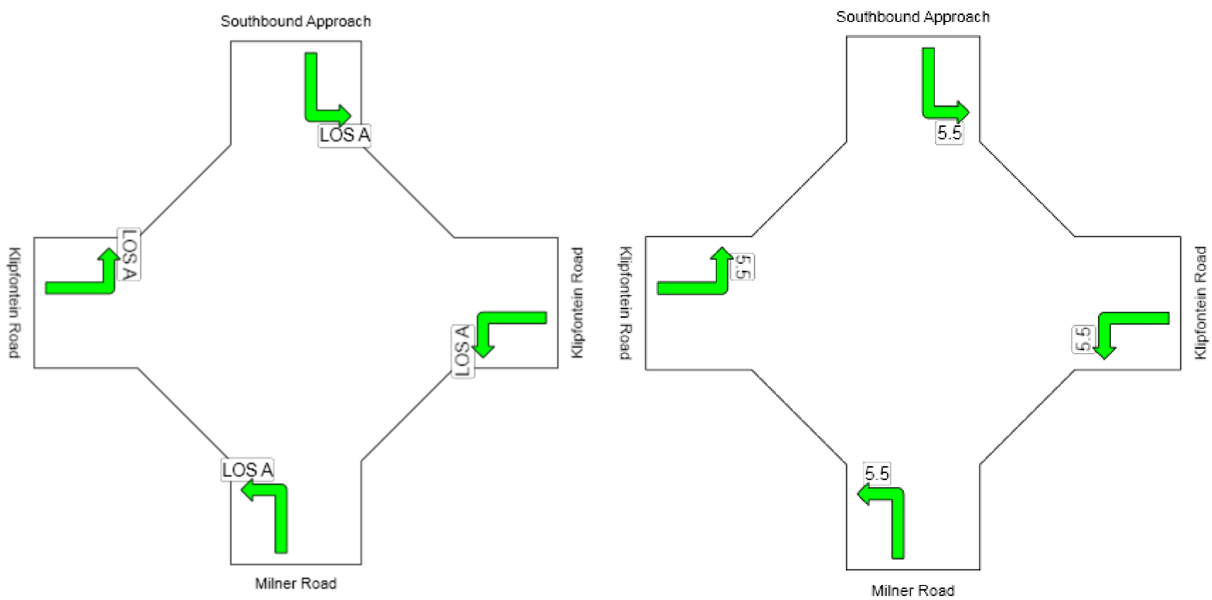

Figure 26: LOS for the proposed

With the implementation of the roundabout, the LOS at Milner and Klipfontein Road intersection has improved to LOS A for all approaches. The queue length has also been reduced along each operate, with no more than 6 vehicles queueing.

8.8.1.2. JUNCTIONS

The future traffic volumes were captured in Junction to determine the queue lengths and level of service, if a roundabout is implemented at Milner and Klipfontein Road intersection. The results are

	PM						
	Queue (Veh)	95% Queue (Veh)	Delay (s)	V/C Ratio	LOS	Intersection Delay (s)	Intersection LOS
	2019						
Leg 1		7.4	12.84	0.58	B	12.14	B
Leg 2		8.8	15.31	0.63	C		
Leg 3		2.0	11.32	0.27	B		
Leg 4		4.6	8.46	0.45	A		

summarised in **Figure 27.**

Figure 27: LOS for the proposed

The results obtained indicate that the level of service of the entire intersection will improve and operate at LOS B. The queue length along each approach does not exceed 9 vehicles. This is considered acceptable. Klipfontein Road will operate at LOS B, while Milner will operate at LOS C and the southbound approach will operate at LOS A,

8.8.1.3. COMPARISON OF SOFTWARE RESULTS

The results of both SIDRA and Junctions 9 indicate that by constructing a roundabout at Milner and Klipfontein Road, this will improve the operation of the intersection. With the time delay improving as a result of installing a roundabout, it can be assumed that this improvement will have a positive effect on nearby intersections.

8.8.2. Geometric Guidelines

The geometric layout was assessed to determine what the spatial implications of a roundabout would be as there are existing large commercial properties located nearby.

According to Guidelines for Roundabouts on Provincial Roads in Gauteng (2005), modern roundabouts have an outer diameter of minimum 28m to 30m with lane widths of 3.6m. The total diagonal distance between the shoulder of the intersection is approximately 81m. This is considered sufficient to install a modern roundabout at Milner and Klipfontein Road intersection with approximately 2 to 3 lanes along each approach.

Furthermore, there is open land on the southern portion of the intersection. If more land would be required, Government would be able to discuss this will the owners of the properties located to the south of the intersection. However, this would most likely not be required.

8.8.3. Cost Benefit Analysis

A basic cost-benefit analysis was undertaken to determine whether the installation of the roundabout to replace the existing signalised intersection would be suitable.

Operational Cost of a roundabout

There are two costs involved that include the construction cost and the ongoing operation and maintenance cost of the roundabout. In comparison to signalized intersection, roundabouts are cheaper to maintain as it does not require any power and any electrical equipment.

Cost of delay

The cost of delay of the proposal was calculated and it discussed below. The below cost of delay was taken from a template used by Beaty, Ellis and Glover (2016).

Estimated Cost of Project Delay

Project related variables

	Roundabout
Total Cost of Project (Zar)	R5,000,000.00
Total number of months project was delayed	2.1
Change in Intersection Cost Index (Delay period)	3%

Travel Related Variables

Total Length of Project	5.6
Daily Traffic (average) - Before Improvement	49959
Daily Traffic (average) - After Improvement	69942.6
Vehicle Travel Speed - Before Improvement	30 km/hr
Vehicle Travel Speed - After Improvement	40 km/hr
% Trucks - Before Improvement	2.20%
% Trucks - After Improvement	3.10%

Assumptions that are commonly used

Total person per vehicle	1.25

Value of time (cars)	R16.28
Value of time (trucks)	R107.42
Total cost of Fuel (cars)	R15.32
Total cost of Fuel (trucks)	R15.49
Return on Investment associated with Economic Impacts	8%

Monthly Cost of Project Delay

Personal Time wasted from Project Delay	R10,300.00
Personal Fuel wasted from Project Delay	R2,020.00
Commercial Time wasted from Project Delay	R5,030.00
Commercial Fuel wasted from Project Delay	R1,690.00
Total Direct Cost to Travelers	R17,350.00
Construction cost increase per month based on HCI	R356,000.00
Subtotal, Direct Costs	R373,350.00
Economic Impact of Project Delay	R135,000.00
Total cost of Project Delay per month	R508,350.00
Total cost of Project Delay	R1,067,535.00

To summarize the above, the total cost of delay was over R1m as a result of a 2.1-month delay. Majority of the cost involved was a result of construction price increases over the delay period. Please note that the majority of the values provided above are based off of assumptions made as a result of previous project knowledge and general assumptions.

Benefit of a roundabout

Further to the above, there are many benefits of installing a roundabout as mentioned by (Sampson, 2013) and some of them include:

- Improves the safety overall, reducing the likelihood and severity of crashes due to the type of crashes that would occur
- Reduces the congestion levels
- Reduces air pollution
- Saves money as no additional money is required to install and maintain the roundabout
- Provides better functionality and it is aesthetically pleasing
- It requires special consideration for other road users such as pedestrians, cyclists and those who are visually impaired
- There are fewer queue backups

9. RECOMMENDATIONS

Based on the results obtained from the traffic counts, the time travel survey, accident statistics, it was necessary to provide mitigating measures. The results prove that high levels of congestion are currently being experienced at Milner and Klipfontein Road, especially along the southbound approach.

However, the future traffic was calculated, and the results prove that if no mitigating measures are implemented, the results will be excessive. Using SIDRA and Junctions 9, it was evident that constructing a roundabout is the acceptable mitigating measure, as the level of service of the intersection improved. Roundabouts reduce conflicting points, resulting in less accidents as well as manages the large volumes of traffic better than a signalised intersection.

10. CONCLUSION

The results obtained from the traffic count that was completed by the City of Cape Town and the site assessment, indicates that Milner and Klipfontein Road intersection is very congested. Majority of the volume throughout the day, operates along the southbound approach, as a result of traffic travelling from both Raapenberg Road and the M5 highway. These roads are higher order roads, with high volumes of traffic operating along them daily.

During the AM and PM peak hour, the congestions levels along the southbound approach are high. The PM peak hour, however, operates at a worse level. The surveys that were undertaken were therefore, only assessed during the PM peak period, as this is considered the "worst case scenario".

The travel time survey identified that majority of the vehicles travelling from Alexandra and Raapenberg to Milner and Klipfontein Road, took approximately 4 minutes and 15 seconds. It should, however, take a driver driving at an average speed of 60 km/hr., 3 minutes and 20 seconds to travel the complete 1.2km distance. Some of the runs took over 7 minutes to complete. This indicates that the congestion levels along the southbound approach, during the PM peak hour, is quite high.

The travel direction survey also indicated that majority of the traffic entering the southbound approach, wanted to travel onto the left turning lane and east onto Klipfontein Road. As mentioned, Klipfontein Road is often used as a rat running route to avoid high levels of congestion along the M5 highway. However, this was not assessed as part of the research. This further confirmed that many of the vehicles were opting to change lanes, thereby, impacting the congestion levels.

Furthermore, the latest accident statistics also prove that a high number of accidents have taken place at Milner and Klipfontein Road intersection, with the majority of the accidents taking place along the southbound approach.

The results of the surveys were captured in both Sidra and Junctions 9 to determine the delay and level of service of the intersection and the southbound approach. The results indicated that there was a need for mitigating measures, as the intersection operated poorly at LOS F (during the PM peak hour), using both the background traffic and future traffic data.

It was, therefore, necessary to provide mitigating measures to alleviate all or some of the issues experienced at this intersection. The proposed mitigating measure was upgrading the intersection from a signalised intersection to a roundabout. Roundabouts are considered safer, more efficient to deal with large volumes of traffic and reduce conflicting movements, thereby reducing accident statistics.

The future traffic data was placed in Sidra and Junctions to determine the delay and level of service. Both modeling programs produced positive results, with the intersection operating at a level of service B and A using Junction and Sidra, respectively. The queue lengths and delay at the intersection was reduced.

From this, it can be assumed that the installation of a roundabout at this intersection will have a positive effect on the nearby intersection. If congestion is reduced and overall operation of Milner and Klipfontein Road significantly improved, the operation of other nearby intersection will also be improved especially along the southbound approach, as more vehicles would be able to enter the approach at a faster rate. Less spilling of traffic would occur and travel time to reach destinations will be shortened.

It is recommended that further investigation be undertaken to determine the impact of the proposed mitigating measures has on the AM peak period as well as the surrounding road network. It is further recommended that the analysis be completed using more substantial micro simulation models, as the Junctions 9 model is not considered user friendly and errors may have been made.

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APPENDIX A

KLIPFONTEIN RD./M5 RAMP/MILNER RD.

Suburb : RONDEBOSCH

Time : 6:30 – 8:30

Date : 2017/03/30 THURSDAY

Control : SIGNALS

Geometry : 4-Leg Intersection

Peak Hour Start : 6:30

2017-03A13

Peak Hour Factor : 0.93

City of Cape Town

	A	B	C	D	E	F	G	H	I	J	K	L
6:30	6	28	9	25	276	80	401	229	36	16	305	25
6:45	2	68	37	19	307	58	418	300	7	13	357	15
7:00	7	60	68	22	304	107	451	303	10	7	306	28
7:15	2	60	25	41	260	100	455	328	7	8	205	26
7:30	11	92	33	29	290	102	339	200	9	11	232	28
7:45	12	82	30	22	285	131	437	256	15	5	266	7
8:00	11	50	33	25	294	22	500	162	14	9	286	3
8:15	9	118	29	22	271	151	405	149	18	2	245	7
Light	60	558	264	205	2,287	751	3,406	1,927	116	71	2,202	139
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	1	0	0	1	1	2	0	0	0	1	0
6:45	0	1	0	1	2	2	1	0	0	0	2	0
7:00	0	2	0	1	0	1	0	0	0	0	0	0
7:15	0	0	0	0	3	2	0	0	1	0	0	0
7:30	0	2	0	0	2	0	0	2	0	0	1	0
7:45	0	1	0	0	2	2	2	1	0	1	1	0
8:00	0	1	0	0	3	1	3	1	2	0	1	0
8:15	0	3	0	0	2	0	1	3	0	1	2	0
Heavy	0	11	0	2	15	9	9	7	3	2	8	0
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	10	0	3	1	1	4	9	0	0	0	0
6:45	0	8	0	1	3	1	0	7	0	0	0	0
7:00	0	26	0	0	4	1	3	3	0	1	0	0
7:15	0	9	0	0	1	2	0	3	0	0	0	0
7:30	0	10	0	1	2	1	0	1	0	0	1	0
7:45	0	9	0	2	2	3	1	2	0	0	0	0
8:00	0	5	0	2	2	4	3	3	0	0	1	0
8:15	0	4	0	1	1	2	1	9	0	0	0	0
Taxis	0	81	0	10	16	15	12	37	0	1	2	0
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	3	0	0	0	0	0	10	0	0	0	0
6:45	0	4	0	0	0	0	0	3	0	0	0	0
7:00	0	0	0	0	0	0	0	1	0	0	0	0

KLIPFONTEIN RD./M5 RAMP/MILNER RD.

Suburb : RONDEBOSCH

Time : 6:30 ‒ 8:30

Date : 2017/03/30 THURSDAY

Control : SIGNALS

Geometry : 4-Leg Intersection

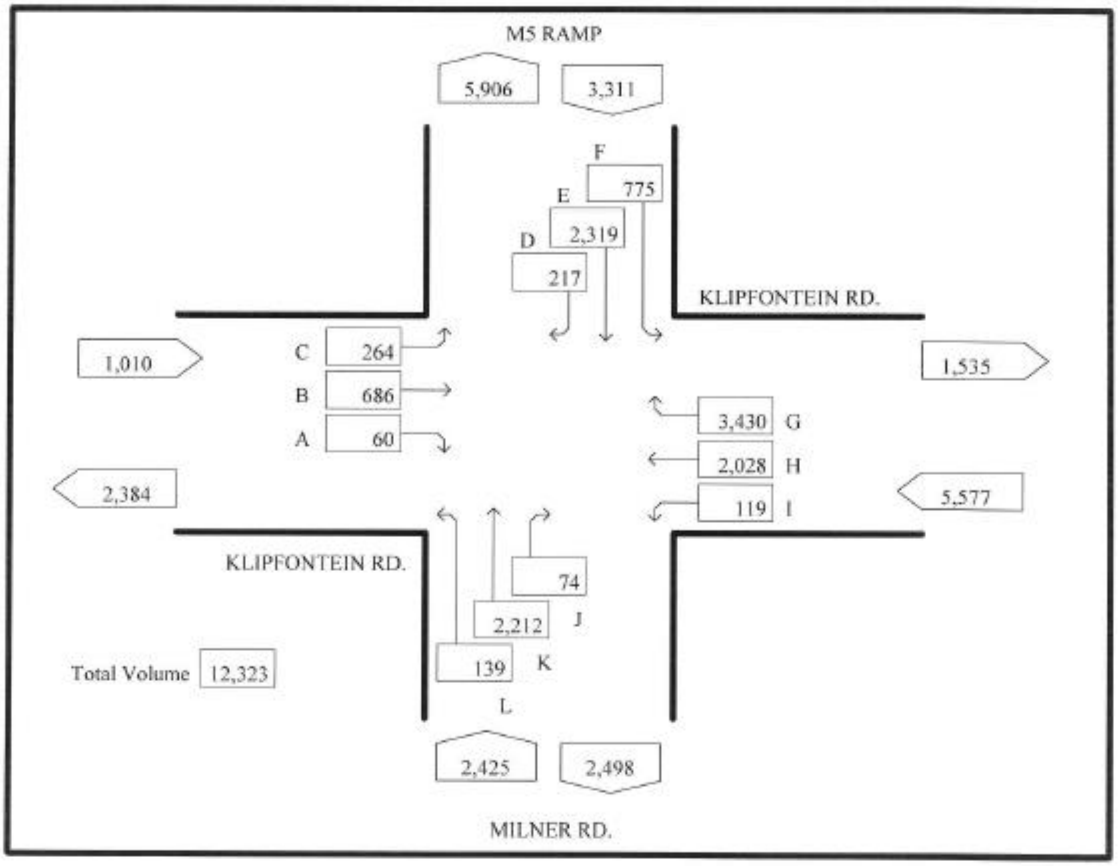
Peak Hour Start : 6:30

Peak Hour Factor : 0.93

2017-03A13

City of Cape Town

7:15	0	3	0	0	0	0	0	5	0	0	0	0
7:30	0	9	0	0	1	0	1	3	0	0	0	0
7:45	0	3	0	0	0	0	0	8	0	0	0	0
8:00	0	9	0	0	0	0	2	11	0	0	0	0
8:15	0	5	0	0	0	0	0	16	0	0	0	0
Busses	0	36	0	0	1	0	3	57	0	0	0	0



KLIPFONTEIN RD./M5 RAMP/MILNER RD.

Suburb : RONDEBOSCH

Time : 16:00 – 18:00

Date : 2017/03/30 THURSDAY

Control : SIGNALS

Geometry : 4-Leg Intersection

Peak Hour Start : 16:00

Peak Hour Factor : 0.81

2017-03P13

City of Cape Town

	A	B	C	D	E	F	G	H	I	J	K	L
16:00	76	249	21	36	424	226	110	45	70	46	221	22
16:15	17	187	16	35	350	168	82	58	43	36	154	9
16:30	14	167	7	35	428	256	93	95	66	38	164	5
16:45	22	157	21	25	298	138	96	55	46	19	104	13
17:00	26	210	20	15	416	160	99	47	54	33	141	11
17:15	7	103	5	33	461	220	109	53	41	13	99	7
17:30	18	99	10	22	353	237	72	91	54	10	101	7
17:45	8	161	10	21	354	178	71	62	46	21	107	2
Light	188	1,333	110	222	3,084	1,583	732	506	420	216	1,091	76
	A	B	C	D	E	F	G	H	I	J	K	L
16:00	1	4	2	0	2	1	1	0	1	0	3	1
16:15	0	3	0	0	1	0	0	0	0	1	6	0
16:30	0	2	0	0	0	1	0	0	0	0	2	0
16:45	0	5	0	0	1	0	1	0	0	0	3	0
17:00	0	1	4	1	0	2	2	0	0	0	1	0
17:15	0	3	0	0	0	0	0	0	0	1	3	0
17:30	0	2	0	0	0	1	0	0	0	1	3	0
17:45	0	1	1	0	0	1	1	0	0	0	1	0
Heavy	1	21	7	1	4	6	5	0	1	2	21	1
	A	B	C	D	E	F	G	H	I	J	K	L
16:00	0	24	0	0	0	2	0	13	0	0	0	0
16:15	0	6	0	0	0	0	1	13	0	0	0	0
16:30	0	15	0	0	0	5	1	10	0	0	0	0
16:45	0	4	0	0	0	2	2	7	0	0	0	0
17:00	0	7	0	0	1	4	0	14	0	0	0	0
17:15	0	2	0	0	1	2	6	13	0	0	0	0
17:30	0	7	0	0	1	1	3	7	0	0	0	0
17:45	0	7	0	0	1	2	5	9	0	0	0	0
Taxis	0	72	0	0	4	18	18	86	0	0	0	0
	A	B	C	D	E	F	G	H	I	J	K	L
16:00	0	11	0	0	0	0	0	4	0	0	0	0
16:15	0	5	0	0	0	0	0	4	0	0	0	0
16:30	0	13	0	0	1	0	2	5	0	0	0	0

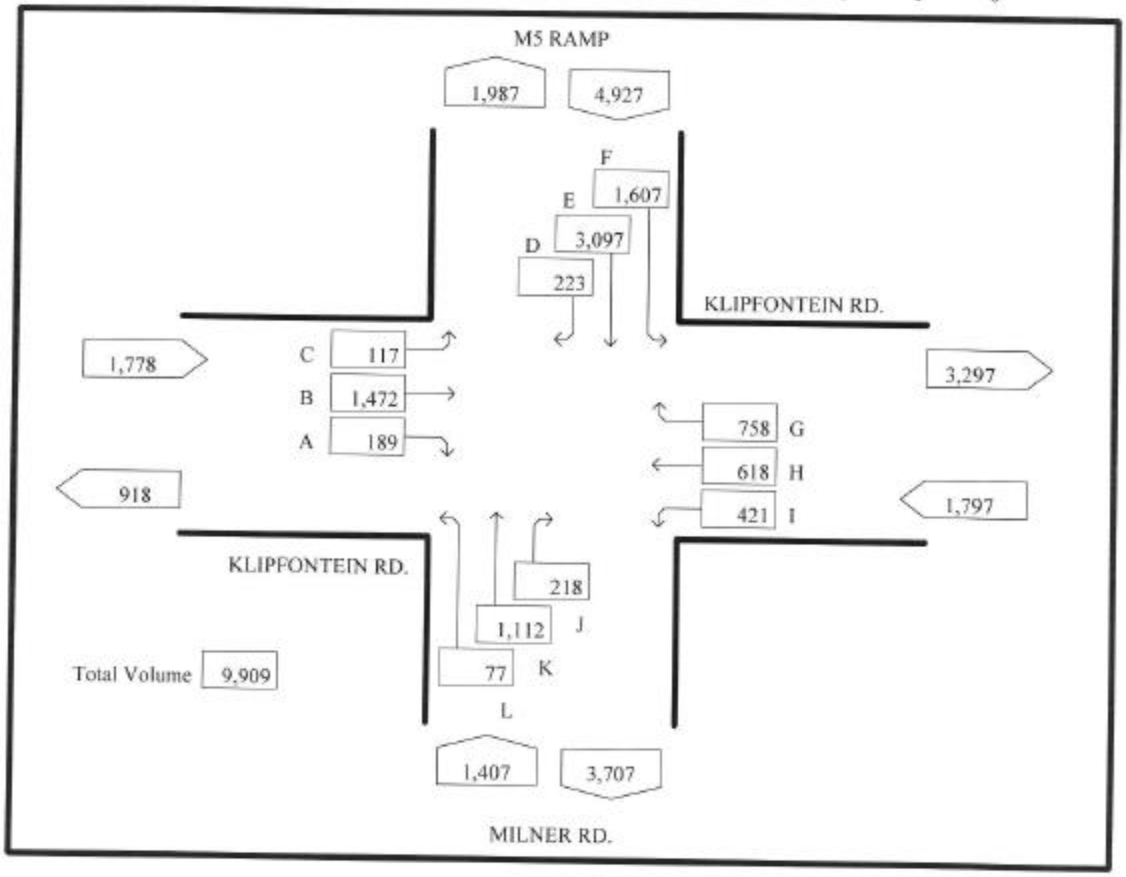
KLIPFONTEIN RD./M5 RAMP/MILNER RD.

Suburb :	RONDEBOSCH
Time :	16:00 ~ 18:00
Date :	2017/03/30 THURSDAY
Control :	SIGNALS
Geometry :	4-Leg Intersection
Peak Hour Start :	16:00
Peak Hour Factor :	0.81

2017-03P13

City of Cape Town

16:45	0	2	0	0	4	0	0	3	0	0	0	0
17:00	0	5	0	0	0	0	1	3	0	0	0	0
17:15	0	4	0	0	0	0	0	2	0	0	0	0
17:30	0	4	0	0	0	0	0	1	0	0	0	0
17:45	0	2	0	0	0	0	0	4	0	0	0	0
Busses	0	46	0	0	5	0	3	26	0	0	0	0



APPENDIX B

A detailed calculation as to how the peak hour was calculated, using the existing background traffic data from 2017, that was recorded by the City of Cape Town in conjunction with the South African census data for 2011.

Peak hour for the background traffic (2017)

The peak hour volumes are calculated as the total peak hour volume in the maximum hour volume (total of four consecutive 15-minute period). According to **Table 9**, it is evident that the peak hour took place between 16:00 and 17:00.

Table 9: Background traffic data (2017)

	A	B	C	D	E	F	G	H	I	J	K	L	Total Volume
16:00	76	288	23	36	426	229	111	62	71	46	224	23	*1615*
16:15	17	201	16	35	351	168	83	75	43	37	160	9	*1195*
16:30	14	197	7	35	429	262	96	110	66	38	166	5	*1425*
16:45	22	168	21	25	303	140	99	65	46	19	107	13	*1028*
17:00	26	223	24	16	417	166	102	64	54	33	142	11	*1278*
17:15	7	112	5	33	462	222	115	68	41	14	102	7	*1188*
17:30	18	112	10	22	354	239	75	99	54	10	102	7	*1102*
17:45	8	171	11	21	355	181	77	75	46	21	109	2	*1077*
Total Volume	**188**	**1472**	**117**	**223**	**3097**	**1607**	**758**	**618**	**421**	**218**	**1112**	**77**	

Using the values above, the peak hour factor was determined using the following equation:

Peak Hour Factor = Total volume of the peak hour / (4 x peak 15-minute period)

PHF = (1615+1195+1425+1028) / (4*1615)

PHF= 0.815

Peak hour for the background traffic (2019)

The data used previously was obtained in 2017. It is, therefore, necessary to calculate the new PHF based on the background traffic of 2019. In order to determine the population growth rate over the past 2 years, the Census data obtained in 2001 and 2011 (latest) will be used and this is shown in **Table 10**. (Census 2011, 2012)

Table 10: Census data for South Africa for 2001 and 2011

Province	Census 2001	Census 2011
Western Cape	4524335	5822734
Eastern Cape	6278651	6562053
Northern Cape	991919	1145861
Free State	2706775	2745590
KwaZulu Natal	9584129	10267300
North West	2984098	3509953
Gauteng	9388854	12272263
Mpumalanga	3365554	4039939
Limpopo	4995462	5404868
Total	**44819777**	**51770561**

To determine the growth rate, the following calculation was used:

$$GR = (((V_{PRESENT} – V_{PAST}) \ / \ V_{PAST}) * 100)$$

The data used was Census 2001 and Census 2011 data for the Western Cape.

$$GR = (((5822734 – 4524335) \ / \ 4524335) * 100)$$

$$GR = 28.7\% \text{ (10-year period)}$$

Therefore, the GR is 2.869% per year.

To determine the new population values for the year 2019, the following calculation was used:

$$(1 + GR\ (\%/100))^{\ YEAR\ (N)}$$

Therefore, if the average growth rate per a year is 2.86%, the growth rate from 2017 to 2019 is as follows:

$$\text{New GR} = (1 + (2.869/100))^2$$

$$\text{New GR} = 1.058\%$$

Using this new growth rate, the new background traffic volumes for 2019 is shown in **Table 11.**

Table 11: Background traffic data (2019)

2019	A	B	C	D	E	F	G	H	I	J	K	L	Total Volume
16:00	80	305	24	38	451	242	117	66	75	49	237	24	*1709*
16:15	18	213	17	37	371	178	88	79	45	39	169	10	*1264*
16:30	15	208	7	37	454	277	102	116	70	40	176	5	*1508*
16:45	23	178	22	26	321	148	105	69	49	20	113	14	*1088*
17:00	28	236	25	17	441	176	108	68	57	35	150	12	*1352*
17:15	7	118	5	35	489	235	122	72	43	15	108	7	*1257*
17:30	19	118	11	23	375	253	79	105	57	11	108	7	*1166*
17:45	8	181	12	22	376	192	81	79	49	22	115	2	*1139*
Total Volume	**199**	**1557**	**124**	**236**	**3277**	**1700**	**802**	**654**	**445**	**231**	**1177**	**81**	

Table 11 above shows that the volumes per each lane have increased slightly over the 2-year period. The peak hour also remains the same from 16:00 to 17:00.

Peak hour for the future traffic (2039)

To determine the volume of vehicles for the future traffic (2039), the growth rate of 2.86% per year was used and the new growth rate for a 20-year period is as follows:

$$\text{New GR} = (1 + (2.869/100))^{20}$$

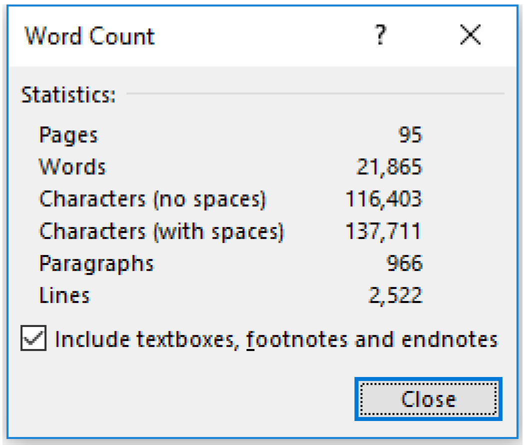
$$\text{New GR} = 1.758\%$$

Therefore, the future traffic volumes for 2039 are shown in **Table 12.**

Table 12: Future Traffic data (2039)

2039	A	B	C	D	E	F	G	H	I	J	K	L	Total Volume
16:00	141	536	43	67	792	426	206	115	132	86	417	43	*3003*
16:15	32	374	30	65	653	312	154	139	80	69	298	17	*2222*
16:30	26	366	13	65	798	487	179	205	123	71	309	9	*2650*
16:45	41	312	39	46	563	260	184	121	86	35	199	24	*1912*
17:00	48	415	45	30	775	309	190	119	100	61	264	20	*2377*
17:15	13	208	9	61	859	413	214	126	76	26	190	13	*2209*
17:30	33	208	19	41	658	444	139	184	100	19	190	13	*2049*
17:45	15	318	20	39	660	337	143	139	86	39	203	4	*2003*
Total Volume	**350**	**2737**	**218**	**415**	**5759**	**2988**	**1410**	**1149**	**783**	**405**	**2068**	**143**	

Word count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