ESTABLISHING AND APPLYING ROAD CLASSIFICATION AND ACCESS MANAGEMENT TECHNIQUES ON BIRD STREET IN STELLENBOSCH, SOUTH AFRICA

by

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DECLARATION

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ABSTRACT

Bird Street is one of the roads in Stellenbosch with the slowest movement of traffic and the highest level of congestion during peak hour periods (06:00 to 09:00 and 16:00 to 19:00). The optimum functioning of the transport network cannot be achieved, due to outdated transport systems and changes that have occurred over the past few decades. The purpose of this study is to investigate the traffic operation along the road, with the intention of establishing whether there is a discrepancy between the actual and intended road classification and access management of Bird Street, and to determine the impact of this potential discrepancy on traffic parameters.

Vehicle movement and traffic volume data were analysed for further use in other components of the study. From the analysed data, Bird Street was classified according to the functional classification system techniques. These techniques were used to classify Bird Street under two conditions, namely the current designed condition and the current operating condition. Thereafter, different scenarios were developed based on the classification of the two conditions and by representing different techniques identified for each of them within the context of the literature.

A microscopic traffic modelling software package from PTV Group was used to construct a traffic model (static) for the simulation of different scenarios and to obtain results for further analysis. From the results, the impact of jaywalking activities within the network, current signal plans vs optimised signal plans, functional classification and functional classification vs without jaywalking were determined. Ultimately, the economic impact and the change in emissions for the best-case scenario category were compared to the base scenario.

From the results, it was concluded that jaywalking activities and the optimisation of the current implemented signal plans had a minor impact on the current traffic conditions. It was also concluded that by redesigning outdated road networks within a realistic context and according to the standards identified by the literature, the same outcome can be achieved as within a utopian context. For the realistic design condition, an average percentage speed and volume increase of 66% and 100%, respectively, was determined. The total cost saving was determined as R11 951 548.76 per year and the improved design proved to be more environmentally friendly by reducing the carbon footprint.

Overall, it was concluded that the main cause of the current traffic conditions along Bird Street was the outdated functional classification and access management thereof.

OPSOMMING

Bird Straat is een van die paaie in Stellenbosch met die stadigste verkeer en die hoogste vlak van opeenhoping gedurende die piek ure van die dag (06:00 tot 09:00 en 16:00 tot 19:00). Die optimale werking van die vervoer netwerk kan nie bereik word nie, weens verouderde vervoerstelsels en veranderinge wat die afgelope paar dekades plaasgevind het. Die doel van hierdie studie is om die verkeer operasie langs Bird Straat in Stellenbosch te ondersoek, met die doel om vas te stel of daar 'n verskil tussen die werklike en beoogde pad klassifikasie en toegang bestuur van Bird Straat is, en om die impak daarvan op verkeer parameters te bepaal.

Data oor voertuig beweging en verkeersvolume was geanaliseer vir verdere gebruik in ander komponente van die studie. Uit die geanaliseerde data was Bird Straat geklassifiseer volgens die funksionele klassifikasiestelsel tegnieke vir twee toestande, naamlik die huidige ontwerp of uitleg toestand en die huidige werkings toestand. Daarna was verskillende konsepte (scenario's) ontwikkel, gebaseer op die klassifikasie van die twee toestande en deur verskillende tegnieke voor te stel wat vir elkeen geïdentifiseer was, binne die konteks van die literatuur.

'n Mikroskopiese verkeer modellering sagteware pakket van die PTV Groep, was gebruik om 'n verkeer model (staties) te konstrueer vir die simulasie van verskillende scenario's en om resultate te verkry vir verdere ontleding. Uit die resultate was die impak van “jaywalking” - aktiwiteite binne die netwerk, huidige sein planne teenoor geoptimiseerde sein planne, funksionele klassifikasie, en funksionele klassifikasie teenoor sonder “jaywalking” bepaal. Vir die beste scenario kategorie was die ekonomiese impak sowel as die impak op die hoeveelheid uitlaatgasse bepaal.

Uit die resultate was daar tot die gevolgtrekking gekom dat “jaywalking” - aktiwiteite en die optimisering van die huidige geïmplementeerde sein planne 'n geringe invloed op die huidige verkeer omstandighede het. Daar was ook tot die gevolgtrekking gekom dat deur die herontwerp van verouderde padnetwerke, binne 'n realistiese konteks en volgens die standaarde wat deur die literatuur geïdentifiseer was, dieselfde uitwerking sal hê as binne 'n onrealistiese konteks. Vir die realistiese ontwerp toestand was 'n gemiddelde persentasie snelheid- en volume-verhoging van onderskeidelik 66% en 100% bepaal. Die totale kostebesparing was bereken as R11 951 548.76 per jaar en die uitwerking op emissies was bevind om meer omgewingsvriendelik te wees deur die koolstof voetspoor te verlaag.

In die algemeen was daar tot die gevolgtrekking gekom dat die hoofoorsaak van die huidige verkeer omstandighede langs Bird Straat was die verouderde funksionele klassifikasie en toegang bestuur daarvan.

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- Students of the SSML
- TomTom

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LIST OF ACRONYMS

ACRONYMS

AADT	-	Annual Average Daily Traffic
AASHO	-	American Association of State Highway Officials
AASHTO	-	American Association of State Highway and Transportation Officials
CAGR	-	Compound Annual Growth Rate
CBD	-	Central Business District
COTO	-	Committee of Transport Officials
CPAF	-	Conducting Period Adjustment Factor
CSRA	-	Committee of State Road Authorities
CUTA	-	Committee of Urban Transport Authorities
CV	-	Connected Vehicles
DCD	-	Department of Community Development
DCMG	-	Data Collection Measurement Groups
DOH	-	Department of Housing
DOS	-	Degree of Saturation
DOT	-	Department of Transport
FCD	-	Floating Car Data
FHWA	-	Federal Highway Administration
HCM	-	Highway Capacity Manual
ITS	-	Innovative Transport Solutions
LOS	-	Level of Service
NHB	-	The National Housing Board
NMT	-	Non-Motorised Transport
OSM	-	OpenStreetMap
PGWC	-	Provincial Government of the Western Cape
PHF	-	Peak Hour Factor
PTPPHP	-	Parking Turnover Per Peak Hour Period
PTPSO	-	Parking Turnover Per Single Observation
RCAM	-	Road Classification and Access Management Manual
RISFSA	-	Road Infrastructure Strategic Framework for South Africa
SAICE	-	South African Institution of Civil Engineering
SSML	-	Stellenbosch Smart Mobility Lab

TDM	-	Travel Demand Management
TRB	-	Transportation Research Board
TRH	-	Technical Recommendations for Highways
UTG	-	Urban transport guidelines
WSDOT	-	Washington State Department of Transportation

CHAPTER 1 : INTRODUCTION

1.1 Background

An effective transportation system enables cities and communities to reach their full potential to meet daily human needs and accomplish activities without wasting valuable travel time. Additionally, the effectiveness of a community's transportation system has a direct influence on their economy.

1.1.1 Population Growth

An increase in the global population over the past few decades has had a significant impact on the effectiveness of traffic systems all around the world. Traffic systems are designed to accommodate a certain maximum number of vehicles on the road network, and future population growth and city changes have exceeded the planned levels, resulting in higher traffic demand than what can be managed.

According to estimated statistics provided by the World Population Prospects (Unidas, 2017), the global population has increased by 197.7% from 1950 to 2017. It has been estimated that the global population will increase by 13.26% from 2017 to 2030 and by 14.28% from 2030 to 2050. It has also been estimated that, for the African continent, the population will increase by 35.67% from 2017 to 2030 and 48.36% from 2030 to 2050. According to the Worldometer (2018), the population of South Africa has grown from 1960 to 2018 by 228.80% and it has been estimated that the population of South Africa will grow further with 26.75% from 2018 to 2050. The Western Cape province in South Africa has the second highest net migration ("in" minus "out" migration) in South Africa, according to Statistics South Africa (2017). Statistics South Africa made the estimation that the net migration of the Western Cape will increase by 13.84% from 2011 to 2021.

An increase in population will directly affect the number of vehicles and will have a negative effect on the road network. The change in traffic volumes in certain areas due to population growth will increase congestion and delays on the road network. As the level of congestion increases, some travellers will start to reconsider their route choice with the option of changing it to avoid congestion. Changing the route choice to avoid congestion transfers the problem to other routes. Thereby, more and more roads become congested due to the impact of the change in traffic volumes.

1.1.2 Classification of Roads

From 1964, roads were classified in the USA according to a three road-category system (AASHO, 1964). Roads were classified according to their primary function, as either an arterial, collector or local road. Arterial roads were defined as high vehicle usage roads with mobility as the primary function, collector roads as low-to-moderate vehicle usage roads and local roads as low vehicle usage roads where access was the main function. From 1983, roads were categorised in South Africa according to a five-class numbering system (DCD, 1983; NHB, 1995). A sixth class was added to the five-class numbering system in 1996 (COTO, 2012b). According to the Technical Recommendations for Highways (TRH) 26 Manual (2012b), from 2010, Class 1 to 3 were classified as arterial roads, Class 4 as collector roads, Class 5 as local roads and Class 6 as pedestrian routes.

From 1964 to 2010, the standard road classification system changed significantly by becoming more specific in terms of the requirements and features of the road classes, such as intersection spacing, access to property, parking, operating speed, intersection control and road reserve width. Roads constructed prior to 1964 were either not designed according to a classification specification or were classified according to dated systems and therefore often do not function optimally.

1.1.3 Design Guidelines

From 1976, South African authorities adopted certain versions of the road classification system and added it to their guidelines (COTO, 2012b). The *Guidelines on the Planning and Design of Township Roads* from the South African Institution of Civil Engineering (SAICE), published during 1976, was the base version of the guidelines used in South Africa (COTO, 2012b). Many similar guidelines from different authorities were published from 1976, as seen in **Table 1.1** below, with different versions of the road classification system.

Table 1.1: Guidelines published by different authorities (COTO, 2012b)

Name	Authority	Year
Guidelines on the Planning and Design of Township roads	SAICE	1976
Urban transport guidelines (UTG)	Committee of Urban Transport Authorities (CUTA)	1986
Pavement management systems TRH 22	Committee of State Road Authorities (CSRA)	1994
Road access policy	Provincial Administration Western Cape	1996
Typical SA and international access standards	Jeffares & Green	1999
Road access policy	Provincial Administration Western Cape	2000
Guidelines for Human Settlement	Department of Housing (DOH)	2000
Road Infrastructure Strategic Framework for South Africa (RISFSA)	Department of Transport (DOT)	2002
National guidelines for road access management	Committee of Transport Officials (COTO)	2005
RISFSA	DOT	2006
Road Classification and Access Management Manual (RCAM) TRH 26	COTO	2010

1.1.4 Road Network in Stellenbosch

Stellenbosch is located in the Western Cape of South Africa. The road network of Stellenbosch consists of arterial, collector and local roads. Three arterial roads merge on the northern side of town (R304, R44 and R310) as do the two arterials on the southern side of town (R44 and R310), as seen in **Figure 1.1**, forming Adam Tas Road. This one arterial accommodates traffic between the northern and the southern arterial roads, as seen in **Figure 1.1**, and is located along the western urban boundary of the town of Stellenbosch.

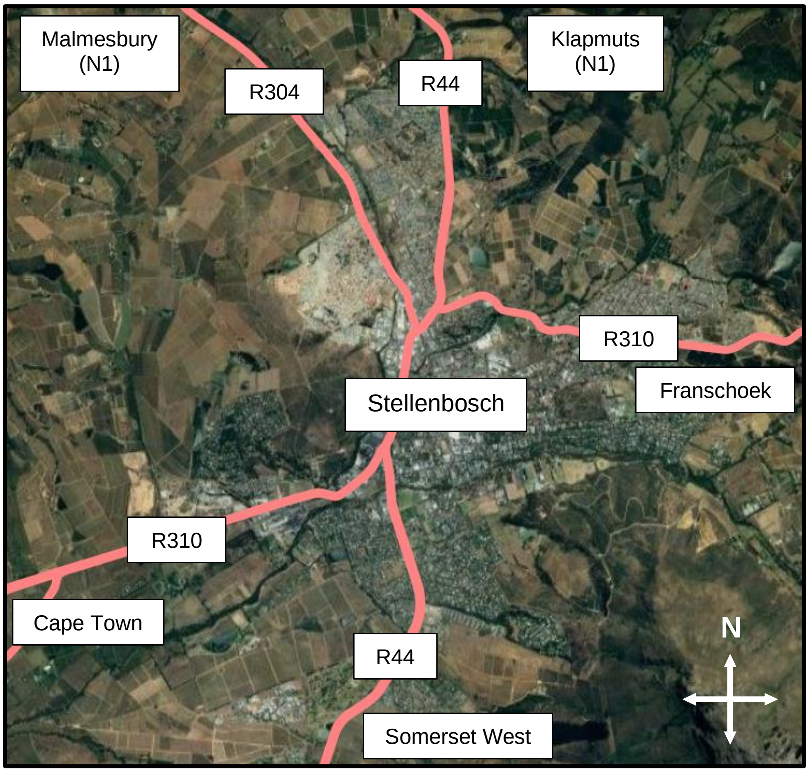

Figure 1.1: Roads entering and exit Stellenbosch

1.1.5 Congestion in Stellenbosch

High levels of population growth and migration to the Western Cape puts the transportation system under pressure. According to a study done by Sinclair et al. (2012), the annual average daily traffic (AADT) on the R44, just outside Stellenbosch at the Blaauwklippen Road, increased by 6.2% per year from 2000 to 2009. This AADT growth rate was 2.5% higher per year than the average traffic growth rate of the Western Cape during the same period. By 2030, if the average traffic growth rate of the Western Cape is maintained, the traffic volumes of four of the main arterials around Stellenbosch will double.

With the current public transport system in South Africa not conforming to international standards, it is a difficult task to convince communities with access to private vehicles to use public transport to accomplish their daily traveling needs. According to an article written by Petersen (2018), the number of active trains transporting commuters in Cape Town has decreased from 33 to 8 trains in 2018. Vandalism of trains in the City of Cape Town area has escalated during the past year. The Minister of Transport made the following comment on the current situation in Cape Town: "the city's rail transport situation is the worst in the country" (Petersen, 2018). Taxi violence has also become a regular occurrence during the past few years. According to Sinclair et al. (2012), one of the primary reasons for the high private vehicle usage rate in Stellenbosch is the lack of a safe and reliable public transport system in the area.

Stellenbosch is well known for Stellenbosch University (SU) which accommodated 31 765 students during 2018, according to the official SU census in June 2018 (Stellenbosch University, 2018). The SU campus forms part of Stellenbosch and is not separated from the rest of the town. Many students stay off-campus and use private transport to attend class and other university activities. With an increase in the number of registered students at the university and limited space in residences and on-campus accommodation, more students will be forced to live off-campus which will result in even more vehicles on the road network.

According to Sinclair et al. (2012), the transportation network of Stellenbosch caters for a large number of people travelling through, from or to Stellenbosch from other towns. Since there is only one existing arterial that caters for the heavy amount of traffic passing through Stellenbosch, other surrounding roads are also affected by traffic choosing to avoid the congested arterial.

1.1.6 Study Area

Bird Street is one of the roads in Stellenbosch with the slowest traffic movement and the highest level of congestion during peak periods of the day (06:00 to 09:00 and 16:00 to 19:00) and was therefore selected as the study area for the research. Bird Street provides access from the northern arterials to the central business district (CBD) of Stellenbosch. The study area along Bird Street is indicated in **Figure 1.2** and starts at Masitandane Road on the northern side of Stellenbosch and ends at Dorp Street on the southern side of Stellenbosch. The study area is 2.4 km long.

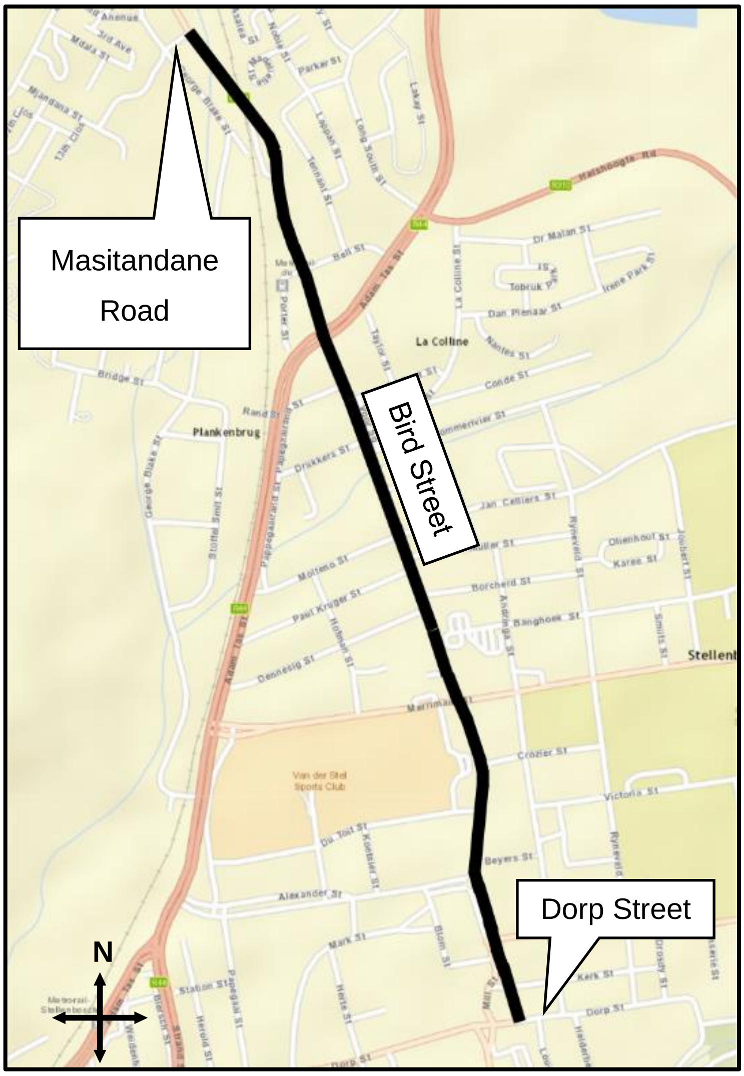

Figure 1.2: Study Area: Bird Street (USGS LandsatLook, 2019)

1.2 Problem Statement

A road network cannot function optimally if the road classification system with which it was designed is not according to current standards. It has been found that travel along Bird Street is often delayed. To understand and solve the problem of poor traffic progression along Bird Street, multiple aspects including the functional classification of the road and travel demand need to be investigated and taken into consideration.

The purpose of this study is to investigate traffic operation along Bird Street in Stellenbosch, with the intention of establishing whether there is a discrepancy between the actual and intended road classification and access management of Bird Street, and to determine the impact of this potential discrepancy on traffic flow. For example, a road may be designed according to one function, for example local access, however the road might be used for mobility purposes (long distance travel). The purpose of the study is also to identify the issues leading to poor traffic progression in the study area, which can be generalised to other similar situations, and to make recommendations for improvement in the road classification and access management system.

1.3 Aim and Research Objectives

The aim of this study is to investigate the design and management of roads as well as the movement patterns of drivers, in order to improve the understanding of the current traffic conditions along Bird Street. The objectives of the study are as follows:

1. Investigate road classification and access management techniques for different road types.
2. Investigate different types of intersections, intersection control techniques and their impact on specific road networks.
3. Quantify traffic patterns along Bird Street through collected traffic data.
4. Analyse data to determine the functional classification of the road according to design and according to operation and compare the two.
5. Develop a traffic model of the Bird Street Corridor to test different scenarios with the purpose to identify the main cause of poor traffic operation and identify whether there is a discrepancy between the actual and intended road classification of Bird Street.
6. Recommend any improvements to the current situation in terms of the findings of the different scenarios.

1.4 Outline of the Thesis

For the study, the outline of the thesis can be seen in **Table 1.2** below.

Table 1.2: Thesis outline

Chapter 1: Introduction
Chapter 2: Literature Review
Chapter 3: Methodology
Chapter 4: Data Collection
Chapter 5: Vehicle Movement Data Analysis
Chapter 6: Traffic Volumes Analysis
Chapter 7: Functional Classification
Chapter 8: Scenario Development
Chapter 9: Microscopic Traffic Modelling
Chapter 10: Traffic Modelling Results
Chapter 11: Conclusions and Recommendations
References
Appendixes

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

In **Chapter 2**, a detailed review of the literature, covering different components of the study, is discussed. The literature will serve as the basis of establishing and applying road classification and access management techniques to Bird Street. Firstly, the current functional classification and access management system, as per the TRH 26 manual (COTO, 2012b), is discussed by examining different components thereof, such as: mobility and access, the road classification system, road classification criteria and the road access management system. Secondly, different types of intersections and intersection control techniques are discussed. Thirdly, different factors affecting travel patterns and traffic volumes are examined and finally, information is provided on the application and integration of non-motorised facilities within a vehicular network.

2.2 Basic Traffic Operations Terminology

2.2.1 Relationship Between Flow, Density and Speed

Traffic operation on a section of a road network can be defined by primary measures, such as the average speed (U), density (K) and flow (Q) of the traffic stream on the road section. These three primary measures give a good indication of the state of the traffic. The average speed of the traffic stream is the distance travelled per unit of time and is measured in kilometres per hour (km/h). The density of the traffic stream is an indication of the number of vehicles found on one kilometre of a specific road and is measured in vehicles per kilometre (veh/km). The flow of the traffic stream is an indication of the number of vehicles that pass a certain point in one hour and is measured in vehicles per hour (veh/h). There is a relationship between the three characteristics, as seen in **Equation 2-1**. According to Garber and Hoel (2009), the relationship between these three primary measures assists traffic engineers with the planning, designing and evaluating of the effectiveness of alterations to a road system.

$$Q = UK \qquad \text{Equation 2-1}$$

Greenshield provided a model for the relationships between speed, density and flow, which assumes a linear relationship between speed and density, as seen in **Figure 2.1**. According to Garber and Hoel (2009), the relationships for flow and speed, and for flow and density, can further be developed from Greenshield's assumption. The parabolic relationship between flow and speed, and between flow and density, can be seen in **Figure 2.1**.

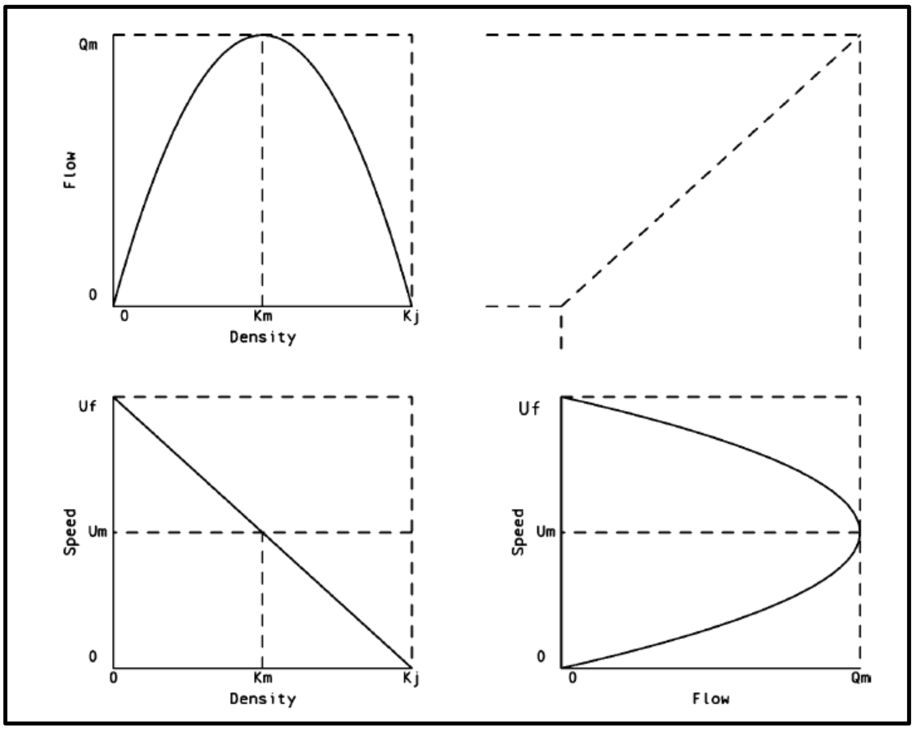

Figure 2.1: Greenshield Model (van As and Joubert, 2002, fig. 2.5.1)

Where:	Km	=	Optimal Density
	Kj	=	Jam Density
	Um	=	Optimal Speed
	Uf	=	Free Flow Speed
	Qm	=	Capacity

As seen from **Figure 2.1**, the density of traffic has a significant impact on the speed and flow of the traffic. As the density of the traffic stream increases, the flow will decrease and as the flow decreases, the speed will also decrease.

The operating speed on a certain road section has a direct impact on the travel time between two points and therefore if congested flow occurs, improvements need to be made to minimise the travel time by improving speed. The Greenshield model gives a good indication of the impact of the three characteristics on each other. The operating speed is the speed at which a vehicle operates on a specific road, whereas according to van As and Joubert (2002), the optimum speed is the speed at which a vehicle can operate at maximum flow.

2.2.2 Level of Service

The operational conditions of a certain traffic stream can be described by a quality measure, such as the Level of Service (LOS) (TRB, 2000). According to the Highway Capacity Manual (HCM) (2000), the LOS describes operational conditions in terms of service measures, inter alia speed and travel time. The levels of the LOS are categorised in six categories, from A to F. LOS A represents the best condition for operation, whereas LOS F represents the worst condition for operation.

2.2.3 Degree of Saturation

When traffic signals are oversaturated, overflow occurs at intersections at the end of the green phase. The overflow is called spillback traffic and will be discussed in **Section 2.9**. To determine whether the signal is oversaturated or not, the Degree of saturation (DOS) needs to be determined. According to van As and Joubert (2002), the DOS can be defined as the ratio of traffic demand to the maximum flow, as seen in **Equation 2-2**.

$$X = \frac{Q \times C}{G \times S}$$ Equation 2-2

Where:	X	=	Degree of saturation
	Q	=	Average arrival rate (vehicles/second)
	C	=	Cycle length (seconds)
	G	=	Effective green (seconds)
	S	=	Saturation flow (vehicles/second)

The DOS for a certain approach can be one of three degrees (van As and Joubert, 2002). It can either be X < 1 (undersaturated), X = 1 (saturated) or X > 1 (oversaturated). The traffic demand exceeds the capacity in case of oversaturation.

2.2.4 Peak Hour Factor

According to the HCM, the Peak Hour Factor (PHF) describes the relationship between the highest 15-min flow rate in the peak hour and the full peak hourly volume, as seen in **Equation 2-3**. According to the HCM, the PHF range for urban areas generally lies between 0.80 and 0.98. High traffic volumes can often be identified if the PHF of a certain road section is over 0.95 (TRB, 2000).

$$PHF = \frac{Hourly\ volume}{4\ \times Peak\ 15\ minutes\ flow}$$ Equation 2-3

2.3 Mobility and Access

Mobility could be described as the ease at which traffic can travel at the design speed with minimum delay or interruptions. Design speed can be defined as the maximum safe speed which is appropriate to maintain on a road, for a certain design purpose. Therefore, mobility roads can be identified as a vehicle-priority road due to their higher speed through movements, which puts limitations on the number of traffic interruptions on the road segment. Traffic interruptions on mobility roads will cause traffic congestion. These interruptions can be defined as road accesses, intersections or pedestrian crossings.

The broad definition of the term access can be defined as the connection which allows traffic to cross or to enter a public road (COTO, 2012b), at either an access or intersection (also refered to as an interruption). A private road that provides access to a private property and the driveway or access street belongs to the owner, it is called access. An intersection is the crossing point of two public roads.

Access/activity streets can be defined as streets which provide access to properties or any other related activities (COTO, 2012b). These type of streets need to accommodate both pedestrians and vehicles and their movement activities become the predominant function, therefore, safety becomes a priority. Since safety is a priority, the speed of the traffic needs to be kept low to ensure a safe and liveable environment for both vehicles and pedestrians. The main focus of access/activity streets remains land access, but other activities need to be kept in mind and need to be taken into consideration. Other activities include pedestrian movement, cyclists, non-motorised transport and any type of social activity (for example walking, running and children playing in the street).

Relationship Between Mobility and Access

Both mobility and access play an important role in the function of a road. According to previous studies done from 1962 until the present date on the impact of the number of accesses versus travel time, it was found that increasing the number of accesses on a road section, reducing the spacing between the access points, will cause a reduction in the capacity and an increase in delays on the road section (Gluck *et al.*, 2000).

According to previous studies done by Reilly et al. (1989) and McShane (1995) on the impact of the number of accesses on the travel speed of the traffic stream, similar outcomes were observed. According to Reilly et al. and McShane's studies, the operating speed on a certain road will reduce when the number of accesses are increased. The studies were performed using two separate techniques; namely a field study, done by Reilly et al. (1989), and traffic simulations, done by McShane (1995). For a traffic volume of 373 vehicles per hour per km, Reilly et al. and McShane's studies' results indicate a speed loss range of 1.61 to 2.74 km/h and 1.61 to 3.22 km/h per access respectively. Therefore, there can be deduced that, due to interruptions by the turning movements of vehicles entering or exiting the major road from other minor roads and due to pedestrian crossings, the speed of the traffic stream will reduce. Interruptions also create spaces for collisions to happen and therefore creates an unsafe area for other drivers and pedestrians.

On mobility roads, the operating speed of vehicles are much higher and therefore when any collisions happen, especially with pedestrians, it could be more serious and sometimes fatal. Interruptions will have a direct impact on the functionality of the mobility of a road and therefore need to be limited to a certain level, depending on the road function. On access/activity streets, the operation speed and volumes are much less than on mobility roads. Therefore, by operating roads at the same level of mobility and access, creates an unsafe and inefficient road network. Thus, mobility and access cannot be allowed to operate at high levels on the same road section (COTO, 2012b).

Although roads must be classified as having either a mobility or an access/activity function, all roads still consist out of a certain level of mobility and access. Mobility roads still have some level of access and access/activity streets must have some level of mobility. Thus, there is an important and sensitive relationship between mobility and access, as seen in **Figure 2.2**.

Figure 2.2 indicates that the number of access points on mobility roads affect the level of mobility. The level of mobility on roads will decrease as the number of access points increase; therefore, roads with a high level of access can accommodate a low level of mobility. The figure explains that, as the level of mobility increases, the level of access needs to be decreased to obtain the level of mobility and vice versa. The figure also explains that arterial roads contain a high level of mobility with a low level of access, collector roads a low-to-moderate level of mobility and access, and local roads a high level of access and a low level of mobility.

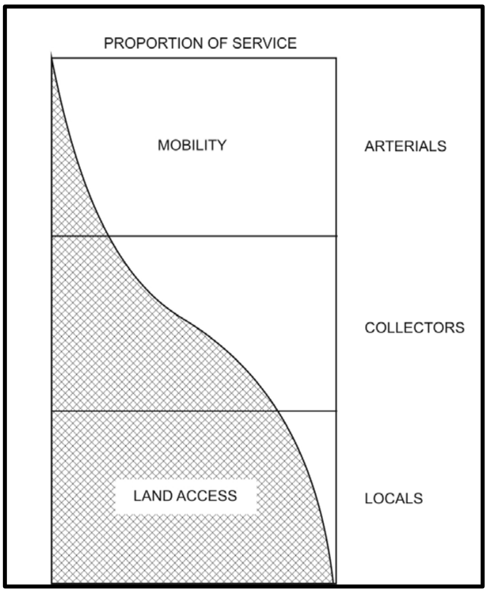

Figure 2.2: Relationship between Mobility and Access (AASHO, 1964)

2.4 Road Classification System

Roads are classified according to their primary function, based on a balance of mobility and access. By classifying roads according to a road classification system, roads can function optimally. Roads can be subdivided into six classes, depending on their function, as seen in **Table 2.1**. The first three classes are associated with mobility roads and the second three classes with access/activity streets. The level of mobility increases from Class 6 to Class 1 (with higher levels of mobility for Class 1 to 3) and the amount of allowable access increases from Class 1 to Class 6 (with higher levels of access for Class 4 to 6).

Table 2.1: Six class classification system (COTO, 2012b)

Class number	Function	Description
1	Mobility	Principal arterial
2		Major arterial
3		Minor arterial
4	Access/Activity	Collector street
5		Local street
6		Walkways

2.5 Road Classification Criteria

The road classification criteria provide different principles' on how to classify a road segment as one of the six road classes.

2.5.1 Functional Road Classification Criteria

According to the TRH 26 Manual (COTO, 2012b), the functional classification criteria consists out of three parts, which are used to divide roads into six classes. The three parts are as follows:

a) Size and strategic importance of the trip generator

According to the TRH 26 Manual, large or important trip generators and centres of development are linked by mobility roads, whereas access to individual properties are provided by way of access streets. Access streets also provide the function of collecting and distributing traffic between mobility roads and/or properties.

b) Reach of connectivity (travel distance)

The travel distance for mobility roads are significantly longer than the travel distance for access roads. According to the TRH 26 Manual, the travel distance should not be very long for access roads, therefore speeding can be avoided by limiting the length of access streets to less than one kilometre before reaching a mobility road.

c) Travel stage

According to the TRH 26 Manual, traveling is undertaken in three stages, from a local travel at the origin, a through stage and then local travel at the destination. Traveling is "local" where a vehicle specifically departs from an origin or arrives at a destination. Local traveling should be served by access roads. Away from the origin or destination, travelling becomes "through" in nature. Mobility roads should serve through traffic.

According to the TRH 26 Manual, traffic volume and travel speed should not be used as criteria to classify roads. Various situations have proven that the variance in the volume and speed is too big and is overall not consistent, therefore they cannot be used as reliable criteria.

2.5.2 Rural and Urban Roads

Before a certain road can be classified as either rural or urban, the area needs to be classified as either a rural or an urban area. Although both rural and urban roads use the same numbering system, there are still differences between the urban and rural road classes (COTO, 2012b). According to the TRH 26 Manual, an urban area can be defined as an area which consists out of subdivided plots of one hectare or less. Rural areas consist of the remaining areas.

2.5.3 Multiple Road Functions

When roads are classified according to the functional classification system, situations may occur where multiple functions appear. According to the TRH 26 Manual, there are three ways to address multiple functions during the road classification process of a road segment (COTO, 2012b). These three ways are as follows:

a) Mixture of mobility classes

According to the TRH 26 Manual, the highest level of mobility classification should be maintained on a specific road segment if a mixture of mobility classes occurs. The highest mobility classification level refers to Class 1 and the lowest to Class 3.

b) Mixture of access classes

According to the TRH 26 Manual, the lowest level of access classification should be maintained on a specific road segment if a mixture of access classes occurs. The highest access classification level refers to Class 4 and the lowest to Class 6.

c) Mixture of mobility and access

The TRH 26 Manual provides three choices on how to address situations where conflicting functions between mobility and access occur. These three choices can be described as the following:

- The two functions can be separated by constructing a bypass (for mobility traffic) or a service road (for access traffic).
- The two functions could be separated by classifying the road as a mobility road and thereby applying an access management process on the road segment by modifying the accesses.
- The least favourable choice would be to classify the road as a Class 4a major collector road with a few restrictions on the road section in terms of the design and speed, in order to create a safe environment for access traffic.

2.6 Road Access Management System

After classifying a road according to a certain degree of mobility and access, it is important to apply access management to ensure the compatibility of its function. In other words, it is important to control the relationship between mobility and access on a road. On mobility roads, it is important to control access and on access streets it is important to control mobility.

The purpose of access management on mobility roads would be to ensure traffic flow with minimal interruptions. Controlling accesses includes various requirements in terms of the provision of access to properties, intersection spacing and parking. A lack of access control on mobility roads will directly affect the mobility thereof. As previously mentioned, the outcomes of a study done by Reilly et al. (1989) and McShane (1995) identified the negative impact per access on the speed of the traffic stream on a road section. Therefore, the statement could be made that as the number of access points on a certain road increase, the effects on the mobility (flow of traffic and the travel time) on a road section will also increase.

Access/activity streets are not designed to accommodate through traffic and therefore if the street carries through traffic, due to avoidance of congested arterials, an unsafe environment will be created. Many years of research on the impact of access management on roadways highlighted the safety benefits thereof (TRB, 2003). According to AASHTO (2004), the accident rate is directly related to the number of accesses along a roadway, thus, the accident rate will increase as the number of accesses on the road segment increase. Roadways without proper access control appear to have 25% to 50% more accidents than roadways with proper access control (AASHTO, 2004).

During the road classification proses, access management cannot be used to define the function of a certain road segment or assist with the classification proses, since access is only properly managed after the functional category of a road has been determined (COTO, 2012b). By applying a successful program to a road network, the safety and mobility on the network will be improved (Fitzpatrick et al., 2005).

As previously mentioned, intersections provide access to one or more public roads or streets (at-grade intersections) and access provides access to private properties by way of driveways. Both at-grade intersection and access/driveways will be discussed in more detail in **Section 2.6.1**. The variety of different types and the spacing measurement criteria thereof will be discussed.

2.6.1 Intersection vs Access

At-grade intersections

At-grade intersections can be described according to the number of approaches or legs, as seen in **Table 2.2**.

Table 2.2: Types of at-grade intersections (PGWC, 2002)

Type of intersection	Number of approaches or legs
T-type junctions	3
Cross-type intersection	4
Staggered intersection	4 (with left or right staggers)
Multi-leg intersection	> 4

During the design process of an intersection, spacing and access separation measurements between two intersections are important to take into consideration for determining the ideal location of the intersection. The spacing between two intersections needs to be a certain distance apart from each, depending on the road class. A spacing criterion for different road classes was developed by the Committee Of Transport Officials (2012b). According to a study done by Gluck *et al.* (2000), based on the standard of Colorado, New Jersey and AASHTO, the access (intersection) separation distance depends on the percentage spillback allowance, speed limit and the turning volume per access (intersection). As the separation distance increases, the speed limit will increase (to a certain degree), and the percentage spillback allowance will decrease.

The distance of access spacing between two intersections is measured from the centres of two intersections, as seen in **Figure 2.3** (indicated in red). However, access separation between two intersections are measured from the inside of the road reserve or from the edge of the roadway (in case of no road reserve), as seen in **Figure 2.3** (indicated in blue).

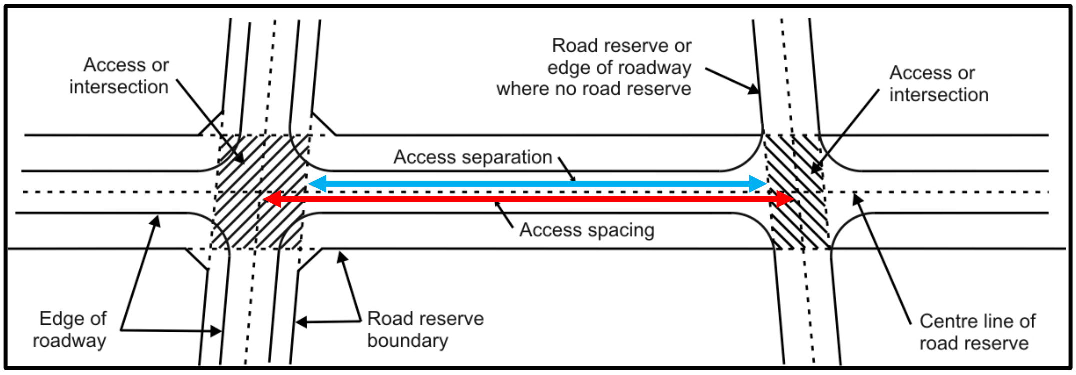

Figure 2.3: Access Separation and Spacing (COTO, 2012b)

A small roundabout should be interpreted as a cross-type intersection, whereas large diameter roundabouts should be measured from where the circular lane intersects with the approaching road (PGWC, 2002).

Property access and driveways

As previously mentioned, access to an individual property can be provided by way of a driveway. The Road Access Guideline (2002) provides driveway criteria which depend on the road functional category and the roadside development environment. The criteria have been categorised from low generator to equivalent district distributor. For each category, a vehicle per peak hour range is set and linked to a certain functionality. A variety of different spacing values, which depends on the type of development, environment and the type of road, are set out in the Road Access Guideline (2002). These measurements are primarily based on safety considerations due to lower operating speed on the road (Gluck *et al.*, 2000), but certain other aspects also need to be taken into consideration when determining the spacing distance. These considerations are as follows (COTO, 2012b):

- The safety of traffic, pedestrians and cyclists
- To follow the access and mobility requirements
- To allow appropriate reaction and decision time
- To take queueing and stopping in consideration at an intersection

Measuring access spacing (intersection and driveway) for three scenarios can be seen in **Figure 2.4** to **Figure 2.6**. These three scenarios are as follows: normal conditions (intersection and driveway), with a slip road (intersections) and with a roundabout. For Scenario 1, the spacing between an intersection and driveway access needs to be measured as seen in **Figure 2.4**.

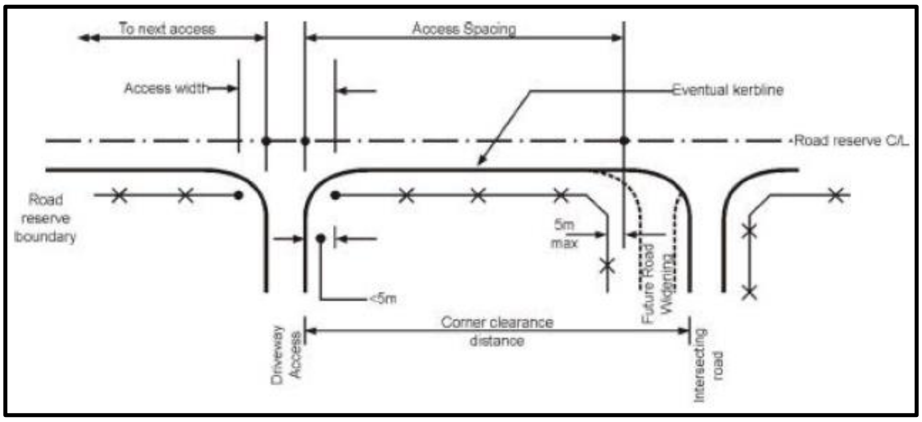

Figure 2.4: Normal conditions (PGWC, 2002)

In Scenario 2, where a slip road is present, the spacing needs to be measured from where the slip road intersects with the approaching road to the edge of the nearest access road.

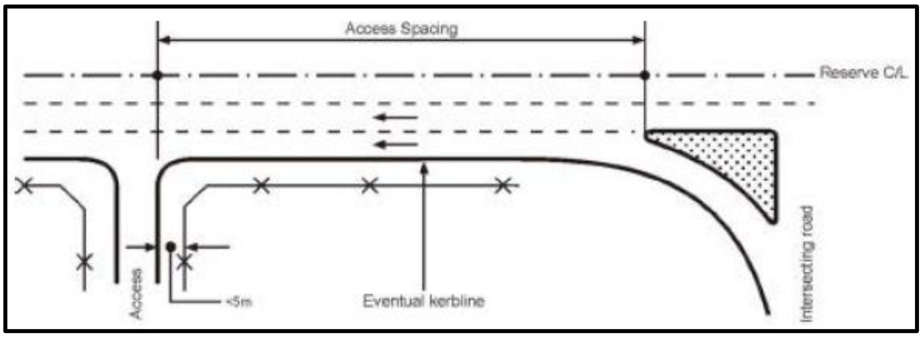

Figure 2.5: When Slip Road present *(*PGWC*,* 2002*)*

In Scenario 3, where a roundabout is present, the spacing needs to be measured from where the exit road of the roundabout intersects with the approaching road to the edge of the nearest access road.

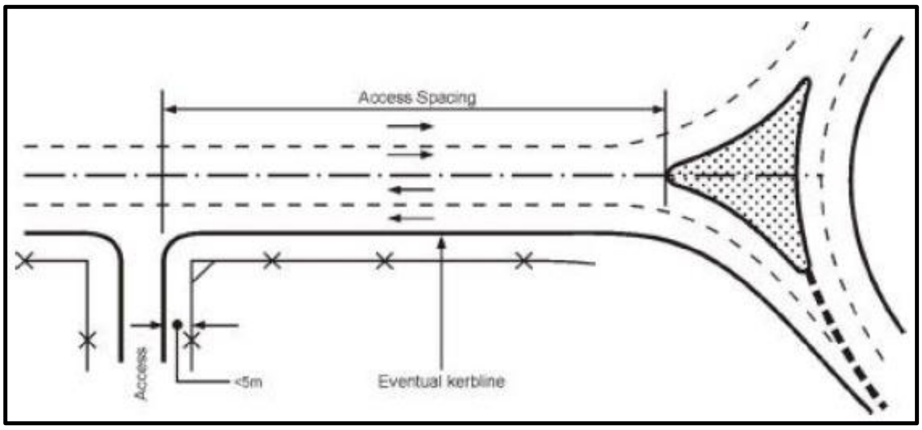

Figure 2.6: When roundabout present *(*PGWC, 2002*)*

2.6.2 Connections between Different Road Classes

According to the TRH 26 Manual, the connection between different road classes is an important principle and therefore a strategy needs to be followed as far as possible to classify such situations. The connection between a low and much higher road class should be avoided in order to avoid any disruptions in how they operate related to their function. The preferred and allowable connections between different road classes can be seen in **Table 2.3**.

Table 2.3: Connections between different road classes (COTO, 2012b)

Higher class	Preferable connection classes	Allowable in exceptional cases
Class 1	Class 1 and 2	Class 3
Class 2	Class 2 and 3	Class 4
Class 3	Class 3 and 4	Class 5 and 6
Class 4	Class 4, 5 and 6	

2.6.3 Types of Intersection Control

Roundabouts

A roundabout is a circular intersection, which makes use of a controlled system where the approaching traffic yields to other users of the roundabout and reflectively enters it when a safe and appropriate gap opens. Roundabouts are normally safer than other intersection types due to the fewer number of conflict points and the decrease in approaching speeds at the intersection. Roundabouts are ideal for accommodating high turning movements and are also appropriate for enabling U-turn movements, especially in combination with access management (WSDOT, 2018). Two most common types of roundabouts are discussed below:

- Mini Roundabout

  According to Tracz (2004), a mini roundabout with a 26 m external diameter is useful to implement as a straight-through calming measure and is also ideal for low traffic volumes. Mini-roundabouts are ideal for a capacity of 1500 veh/h.

- Small Roundabout

  According to Tracz (2004), a small roundabout (one-lane roundabout) with single entry lanes and a 26 to 40 m external diameter is much safer than other control types. Small roundabouts are ideal for a capacity of 2500 to 2800 veh/h.

Priority controlled intersection

Priority controlled intersections can either be a multi-way or a two-way stop-controlled intersection. At multi-way intersections, all traffic needs to stop before proceeding through the intersection. The right of way in a multi-way stop control intersection allows the first road user approaching the intersection to enter the intersection. Multi-way stop control intersections are suitable for low entering volumes, where volumes should not exceed 1400 vehicles per hour (WSDOT, 2018).

At two-way stop control intersections, traffic from minor roadways needs to stop before they can enter the roadway while major roadways are given priority. Road users can access the major road when there is a safe and acceptable gap to the nearest oncoming vehicle.

Signal controlled intersection

A signal-controlled intersection is an intersection where the traffic is controlled by way of traffic signals. This type of intersections can accommodate a higher capacity of traffic than other control types. Signal controllers can be used for various functions, such as to accommodate and manage different modes of travel at the intersection, provide priority to certain services and to create a signal control network by coordinating traffic signals along a certain roadway. Signal control networks will be discussed in more detail in **Section 2.8**.

Discussion

According to a study done by Abdelfatah and Minhans (2014) on guidelines for the selection of a certain intersection control type, recommendations were made in terms of certain traffic volumes. For low traffic volumes (3000 veh/h or less), a roundabout is recommended and for high traffic volumes (4000 veh/h), a traffic signal is recommended. Abdelfatah and Minhans (2014) findings on the high traffic volumes correspond to previous results from research studies done by Sisiopiku and Oh (2001). The overall LOS during peak hour periods for intersections should not be lower than level C, individual major movements should not have a lower LOS than LOS D and individual minor movements should not have a lower LOS than LOS E. More specifically, the DOS for signalised intersections should not exceed 0.9 and for individual movement roundabouts, it should not exceed 0.85 (WA, 2015).

The TRH 26 Manual recommends specific intersection control types for each of the six road classes, which are appropriate to accommodate the capacity of the specific road class. The recommendations of the TRH 26 manual correspond to the findings and recommendations previously mentioned. The intersection control types for the four relevant road classes which are in the scope of the study area can be seen in **Table 2.4**.

Table 2.4: Intersection control types per road class (COTO, 2012b)

Road class	Intersection control
2	Co-ordinated traffic signal
3	Co-ordinated traffic signal, roundabout
4a	Traffic signal, roundabout or priority
4b	Roundabout, mini-circle or priority
5a	Priority
5b	Mini-circle, priority or none

2.7 Functional Classification and Management System

2.7.1 History of the Functional Classification System

In 1963, Buchanan made a statement in Traffic in Towns (Buchanan, 1963) about two kinds of roads; distributors and access roads, which are respectively designed for movement and access. Buchanan's statement plays an important part in the development of the functional classification system. There was found that during the development phase of the functional classification system, the distinction between mobility and access was unclear. Around 1964,

Figure 2.2 was developed and published in “A Guide for Functional Highway Classification” (AASHO, 1964) to represent the relationship between access and mobility.

A clear interaction between mobility and access can be seen in **Figure 2.2**, but there was a lack of guidelines to determine which should be given priority between mobility and access, since there is a mixture between mobility and access. Therefore, according to the Technical Recommendations for Highways (TRH) 26 Manual (COTO, 2012b), modifications were made on **Figure 2.2** until current date to improve on the clarity and understanding of **Figure 2.2**.

According to the Guidelines of the Provision of Engineering Services for Residential Townships (DCD, 1983), the relationship between access and mobility are inconsistent. Therefore, they suggest that the level of access and mobility between access streets and mobility roads needs to be separated according to a certain degree. These certain degrees were categorised into a five-class numbering system and were launched in South Africa for the first time during 1983 (DCD, 1983; NHB, 1995).

During 1987, research was done by Austroads (Brindle, 1987) on the relationship between Traffic Mobility and Land Access. The results of their work indicate two options in terms of the following: 1) when access and mobility are mixed together and 2) when the two functions are completely separated from each other. **Figure 2.7** refers to Option 1, where the traffic (mobility) function and land service (access) function are plotted on the same figure. The figure is subdivided into different sections, which represent different road types. From the figure, the main function of the road types can clearly be identified. In other words, it can clearly be seen that arterial roads serve traffic movement (high traffic function percentage and low land service percentage) and local streets serve the adjacent land (low traffic function percentage and high land service percentage). **Figure 2.8** refers to Option 2 where the complete separation between the two functions are plotted on the same figure. From the figure, it can be seen that arterial and distributor roads only serve a network (mobility) function with no access, and access streets serve no network function, with exits only for land services.

Nine years later, the same author proposed a new option, Separation Functional Model, by combining the previous two options (Brindle, 1996), shown in **Figure 2.9**. The Separation Functional Model represent the relationship between movement (mobility) and access, as described for **Figure 2.2**, as well as the function which should be given priority for different types of roads. According to Page (2004) **Figure 2.2** is, in terms of the functionality of a certain road segment, a more realistic portrayal than **Figure 2.9**.

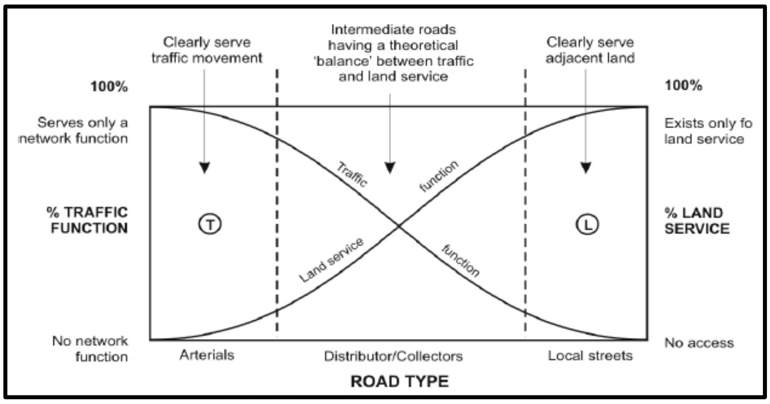

Figure 2.7: Mixture of mobility and access (Brindle, 1987)

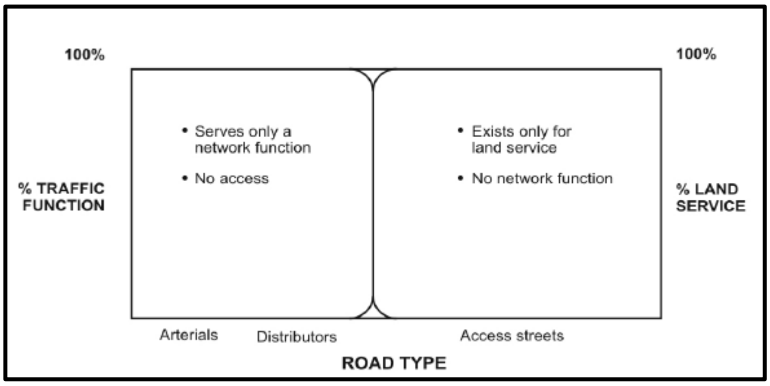

Figure 2.8: Separation of the two functions (Brindle, 1987)

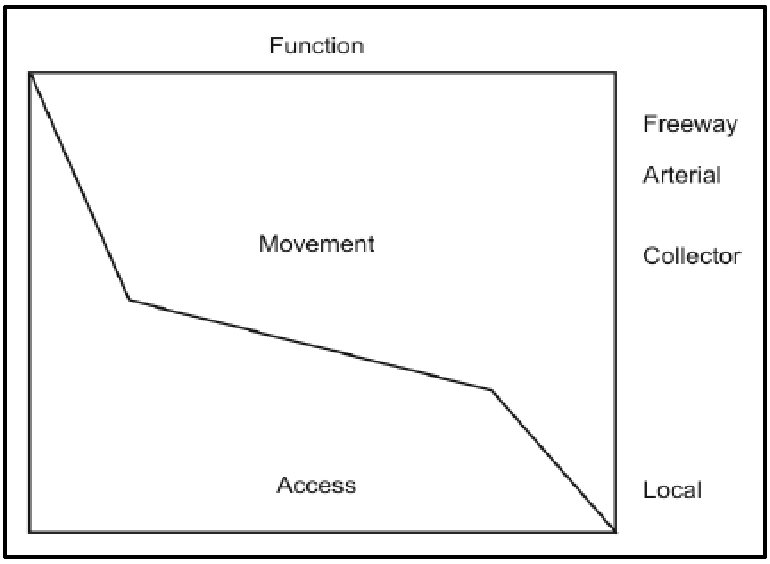

Figure 2.9: Separation Functional Model (Brindle, 1996)

The five-class numbering system was changed to a six-class numbering system by adding an extra class for pedestrians (COTO, 2012b). The extra class was added to the previous five classes during 1996, according to the National Guidelines for Road Access Management (COTO, 2005) and the Road Infrastructure Strategic Framework for South Africa (DOT, 2006).

According to the TRH 26 manual (COTO, 2012b), the five classes describe the road types for vehicles and the sixth class could be referred to as a walkway, which is also a type of road, but for pedestrians.

The six-class numbering system is currently being used by the TRH26 manual and is considered by COTO (2012b) as one of the best available systems. The system is based on information from the RISFSA (DOT, 2006). The system is almost the same as a few other systems previously used by different manuals and guidelines, such as the COTO Road Access Management Guidelines, FHWA, AASHTO and the USA Transportation Research Board Access Management Manual (COTO, 2012b). The TRH 26 manual is currently being used by the Municipality of Stellenbosch as a guideline for road classification and access management.

2.7.2 Benefits of Road Classification and Access Management

Applying Road Classification and Access Management techniques is beneficial. Some of these benefits are:

- **Capacity and traffic flow benefits**
  One of the aspects that will give a good indication if a road segment reaches its maximum utility under the current traffic conditions, is the capacity (vehicles/hour/lane) and flow (vehicles/hour) of the traffic. As previously mentioned from the Greenshield model, traffic flow will decrease as congestion starts to increase. Thus, applying good access management to road segments will have a positive impact on the capacity and the flow of traffic. These positive impacts will lead to a reduction in travel time, which relate directly to travel cost (COTO, 2012b). Proper management of access spacing will increase the utility of a road by reducing the traffic congestion and thereby enable traffic signals to synchronise with each other. Synchronisation of traffic signals will increase the flow of traffic with a reduction in traffic delays. According to the TRH 26 manual, proper access management with synchronised traffic signals has a 50% to 75% reduction in delay and congestion.
- **Safer road environment**
  Road Classification and Access Management play an important role in the operating speed of traffic on certain road segments. As the number of accesses increase, the speed needs to decrease according to the management system. At activity streets, with higher pedestrian volumes compared to mobility roads, a lower speed would preferably be enforced to create a safer environment for non-motorists. Thus, more closely spaced accesses would be acceptable and should be encouraged to reduce speed and to increase safety.

- **Social and economic benefits**

  By applying Road Classification and Access Management techniques, economic and social needs could be met by finding the perfect balance between mobility and access (COTO, 2012b). The Road Classification and Access Management techniques will have the following benefits on the economy of a certain area:

  - Higher productivity in distributing goods or services
  - Reduction in transport cost from home to work
  - Increase in land value due to its accessibility

2.8 Signal Controlled Networks

2.8.1 Reason for Implementation

According to the South African Road Traffic Signs Manual (COTO, 2012a), the timing and phasing of traffic signals plays a fundamental part in proper operations thereof. Incorrect timing and phasing at signalised intersections can cause major delays. Therefore, by managing the signal timing and phasing of signalised intersections efficiently, travel time and delays will reduce and throughput will increase. By increasing the throughput of traffic, the possibility of spillback traffic will be decreased.

2.8.2 Signal Timing and Phasing

At a signalised intersection, the controller controls the right-of-way of traffic by displaying different colour lights which change according to a certain plan, depending on the type of traffic-control technique. Important parameters of traffic signals are discussed below:

Cycle

The cycle length is the time in seconds from start of green to the start of green again of the same signal group/phase. Signal group/phase will be discussed later in this section.

Intergreen

The intergreen (or interstage) period is a safety period separating two conflicting traffic streams when allocated right of way. This safety period is the yellow interval plus the all-red interval. The yellow interval allows drivers, which are in the position where they cannot stop when the green time ends to safely cross the intersection. The all-red interval is when all traffic signals show red after the end of a phase allowing the intersection to clear.

Offset

The offset between the signal timing of two intersections is the difference in time from the start of green for the first signal (intersection) to the start of green for the following signal (intersection), as seen in **Figure 2.10**.

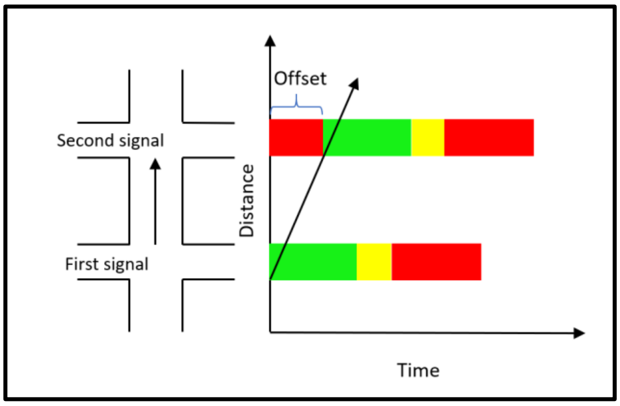

Figure 2.10: Intersection offset coordination

Signal group or Phase

A signal group is a group of traffic streams which may be given green during the same period of the signal plan. In the context of this document, signal group and phases have the same definition.

Stage

A stage is a series of phases in the signal cycle, which can run together as a combination without conflicting each other. The stage starts at the beginning of the first phase, turning green in this stage, and ends as soon as the first one of the signals, which are in the stage, are terminated. **Figure 2.11**, an example of "signal intervals for a three-stage traffic signal with six signal groups" (COTO, 2012a), illustrates the different parameters of traffic signals.

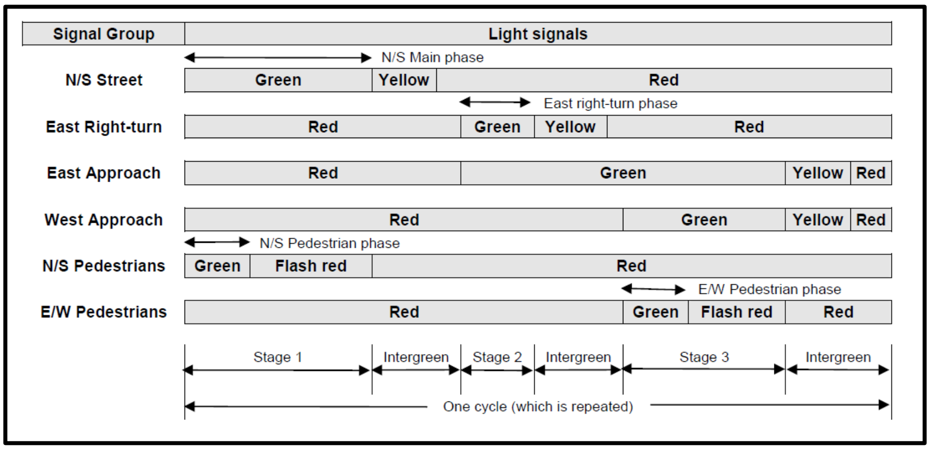

Figure 2.11: Example of different signal groups and intervals (COTO, 2012a, fig. 6.1)

2.8.3 Area Traffic Control Techniques

Three traffic control technique systems, such as fixed time, vehicle actuated, and traffic adaptive and responsive systems, are discussed below:

2.8.3.1 Fixed time systems

According to van As and Joubert (2002), the basic form of linking traffic signals is the fixed time system. The traffic signals timing plan needs to be developed for a specific time of day and is based on the traffic condition, information and/or previous knowledge of the traffic condition. Assistance and guidance from an appropriate manual also needs to be added to the process of developing the timing plan. The timing of signal plans is normally different for different times of the day, due to the change in traffic conditions (demand). The signal plans need to be calculated and set up, before being implemented and managed by off-line programs. As the state of traffic constantly changes, due to new developments in the area or other similar activities, the timing of signal plans needs to be updated on a regular basis to keep track of any changes in traffic patterns and volumes.

2.8.3.2 Vehicle-actuated systems

According to van As and Joubert (2002), vehicle-actuated systems operate more or less the same as isolated control systems with an exception; changes can be made by the central controller on the signal timings.

Similar to fixed time systems, the cycle length (controlled by the controller) is divided into intervals with all the linked phases guaranteed to be given green (van As and Joubert, 2002). All the phases will commence during the cycle length in the same sequence, but the duration of the phases may change depending on the demand. Vehicle detectors are used to detect the demand and thereby changes can be made to the duration of the phases.

The adjacent stream has a minimum green time and can be extended if the demand increases. On a road network with high demand on the main stream and low demand on the adjacent stream, a minimum green time is set for the adjacent stream and maximum green time for the main stream. The green time of the intersections will readjust, within certain limits, as the demand of the two directions change.

2.8.3.3 Traffic adaptive and responsive systems

While fixed time and vehicle-actuated systems work completely offline, adaptive systems can control different scenarios for signal control plans from historical data created offline, but in real time. All the signal control plans are put together in a “library” of plans. These plans need to be up to date in order to keep track with the possibility of any traffic changes.

The central controller adjusts the signal plan at regular intervals according to the overall traffic conditions. Information about the real-time traffic conditions can be provided by using Connected Vehicles (CV), cameras, detectors, floating car data etcetera. CV is a real-time data source which can provide real-time information, such as the speed, position, direction of motion and acceleration of a specific vehicle, to a certain infrastructure (controller) (Argote-Cabañero et al., 2015).

The controller goes through the library of signal plans on-line and selects the best and most appropriate plan for the specific traffic conditions. According to van As and Joubert (2002), the selection procedure operates on a pattern recognition basis. The selection procedure needs to be updated and readjusted at regular intervals to keep track with the change in traffic conditions over the time of the day.

2.9 Congestion and Spillback

Traffic congestion is one of the biggest nightmares in the transportation sector and appears when traffic becomes oversaturated, i.e. when the demand exceeds the capacity on a certain road section (van As and Joubert, 2002). The capacity of a certain road segment is a function of the design of the road according to its specific class.

When traffic congestion occurs on a signalised road section, due to oversaturated conditions, queues will grow in the upstream direction. When there is more than one signalised intersection on a road segment and the queue starts to grow and passes the upstream intersections, then it is called spillback. By implication, spillbacks can cause extreme delays and gridlock (Argote et al., 2012). Different types of blockage may occur due to spillback traffic when intersections become congested. Two of the different types of blockage are lane and link blockage (Li, 2011). Lane blockage occurs when upstream spillback traffic prevents upstream traffic to move or switch to other lanes for right-turn or straight movements. Link blockage occurs when the spillback traffic from the second spillback upstream intersection block the traffic by preventing them from entering the intersection, on green, at the first spillback upstream intersection (Li, 2011).

A better representation of the impact of spillback traffic and the two different types of blockage could be seen in **Figure 2.12**. The direction of traffic will be different for South African conditions, as **Figure 2.12** is based on right-hand side driving.

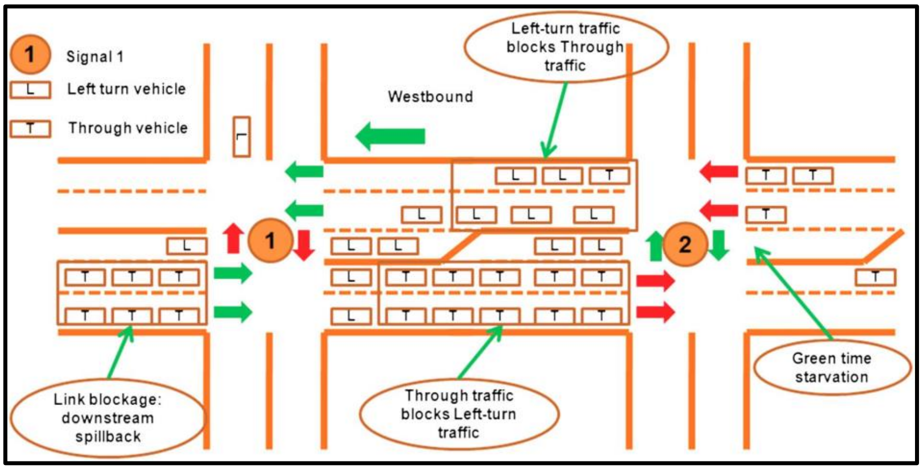

Figure 2.12: Impact of spillback traffic (Li, 2011)

During spillback congestion, when upstream vehicles could not enter or make a turning movement at the affected intersection at green time, valuable green time gets wasted (Argote et al., 2012). Real-time signal control networks could be implemented to avoid wasting of green time when spillback congestion occurs.

2.10 Travel Demand Management

Population growth, expansion of cities and people streaming to larger cities for better opportunities (urbanisation) over the past few years, have a direct negative effect on the transport system. As the number of vehicles (transportation demand) on city roads continues to grow, negative impacts will be imposed on the community life due to the increase in congestion levels. If capacity improvements have been made to a certain road, congestion will re-occur as road users, who usually used the road and currently bypass it by using alternative roads, start using it again.

According to Morimoto (2015), transportation demand can be regulated by implementing policies, called travel demand management (TDM). According to the Road Access Guideline (2002), TDM can be defined as a tool, which is aimed to reduce the number of private vehicles on road networks in cities. Morimoto mentioned that the demand can be regulated by shifting it to other transport modes (preferably public transport) and by changing the peak times.

2.11 Land Use / Transportation Interaction

Land use and transportation are connected. If any changes are made to land use, the transportation system will directly be influenced, since trips are generated by land development. However, if the transportation system is improved, opportunities for further development are triggered which will have an impact on the land use, since the accessibility to land use is increased.

Land use can be described as the activity system which associates itself with information such as the location of the land use, what is happening at the land use and how it interacts with other land uses, whereas the transportation system can be described as the movement system which connects the activities (PGWC, 2002). Since land use and transportation are linked, the nature of the activity system determines the demand for movement and the economic growth of the activity on land depends on the effectiveness of the movement system.

Expanding road systems in cities and towns will cause urban sprawl due to the increased attractiveness of undeveloped areas for further development (FHWA, 1999). Expanding roads to serve higher capacities does not always result in the best solution to reduce the level of congestion, but rather create the opportunity for growth in the number of road users.

According to Morimoto (2015), Japan has experienced difficulties with keeping up with expanding roads to serve the demand, and therefore, they implemented TDM policies to regulate the transportation demand. By implementing such policies, road systems are fully enabled to operate optimally. Without implementing any regulations or policies, the level of congestion will increase, and certain roads will be affected to a higher degree than other roads. Therefore, as the level of congestion starts to increase, the number of vehicles trying to bypass the congested road to save travel time, by using other alternatives, will also increase.

2.12 Route Choice and Rat-Running

As the level of congestion increases, people who normally used the congested road become frustrated and consider alternative routes to reach their destinations in order to minimise their travel times. When drivers select lower order roads, such as local streets instead of arterial roads for long distance travel, it is called rat-running. An illustration of the deference between the desired route and the rat-run route can be seen in **Figure 2.13**. According to a study done in Toyohashi, Japan by Sakuragi et al. (2017), the amount of rat-run traffic increases as the level of congestion increases. Drivers normally use information about the travel time for a certain route in order to make a decision on the best route to follow (Tarrant, 2016).

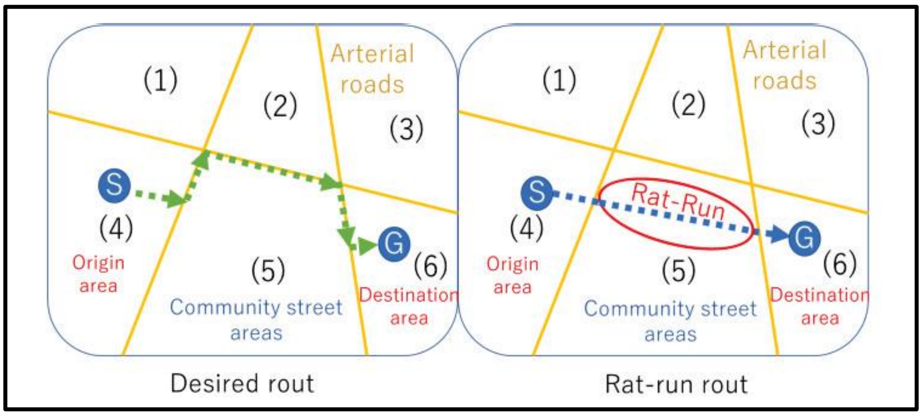

Figure 2.13: Desired route vs Rat-run route (Sakuragi et al., 2017)

2.12.1 Route Choice

According to Li et al. (2005), there are two characteristics which need to be taken into consideration during the dynamic route choice decision making process, namely socioeconomic and trip characteristics. Socioeconomic characteristics could be defined as a combination of drivers' sociological (age, gender and other similar factors) and economical (income, education level and other similar factors) characteristics (Jan et al., 2000). Trip characteristics are defined as the factors which influenced the decisions made by the drivers before and during the trips they made (Jan et al., 2000), including the location, time of day, traffic conditions and other similar factors.

The route choice decision making process is dynamic because road users use information gathered from previous experience in order to help them to make decisions. The importance of some characteristics are not the same for all the alternative routes and therefore the final decision on the route chosen depends on the characteristics which best suit the on-time needs of the driver (Li et al., 2005).

A survey done by Abdel-Aty *et al.* (1993), during 1992 in the area of Los Angeles, California, found that only 15.5% of the people who completed the survey made use of one of a few available alternative routes to work, on a regular basis. 34% of this 15.5% tend to be people with a higher income or a higher level of education and people who decided to use another alternative due to their observation of the on-time traffic. According to a study done by Mannering (1989), based on the Poisson regression model, route changes were found especially among younger, unmarried and male road users. A study done by Mannering *et al.*

(1994), found that route changes were also found among road users, who spend more time on the road on a daily basis, users who have flexible departure times and users who are more accustomed to other alternatives.

2.12.2 Possible Solutions to Reduce Rat-Run Volumes

Over the past few decades, a lot of research has been done internationally on possible solutions to reduce rat-run volumes. Solutions, such as traffic calming measures, are discussed below.

2.12.2.1 Physical traffic calming measures

Physical measures, such as volume and speed control measures, have been identified as possible solutions to reduce rat-run traffic on road networks (Jobanputra, 2010). Rat-run traffic can be reduced by controlling vehicle access using volume control measures, and thereby guiding or forcing road users to use mobility roads for the purpose of mobility rather than access roads. Rat-run traffic could also be prevented by making it uncomfortable to use a lower order road for the purpose of mobility instead of access using speed control measures. The following volume and speed control measures were adapted from a conference paper written by Jobanputra (2010):

Volume control measures:

- Full road closure
- Half road closure
- Diagonal diverters
- Median barriers

Speed control measures:

- Speed humps
- Chokers
- Chicane
- Traffic circle/Roundabout
- Road Diet
- Tight Radius

Four volume control measures and two of the six speed control measures are discussed independently in more detail below. The two speed control measures are speed humps and chokers. These two speed control measures are more applicable to this study and study area, since their main benefit is that they reduce traffic speed and volume on the road section where implemented.

Full closure

The calming measure full closure can be described as a measure where the access road (usually minor road) is completely closed to any traffic. The road is usually closed by putting obstacles in place, as seen in **Figure 2.14**, to stop road users from using the entrance. Signs need to be put in place to make road users aware of the closed road. By implementing this calming measure, road users cannot consider certain roads as one of their available route choices.

Figure 2.14: Full-closure traffic calming (City of Stockton, 2016)

<u>Half closure</u>

The half closure calming measure can be described as a measure where the access road (usually minor road) is partially closed for traffic and only allows traffic to either enter or exit the major road from or to the minor road. This allows only one directional flow of traffic for a small part of a two-way road. The road is normally closed by putting obstacles in place, as seen in **Figure 2.15**, to stop road users from illegally using the entrance. Signs need to be put in place to warn road users of the closed road.

Figure 2.15: Half-closure traffic calming (FHWA, 2017, fig. 3.23.3)

<u>Diagonal diverters</u>

The diagonal diverter is a calming measure where an obstacle is placed diagonally over a four-way intersection, as seen in **Figure 2.16**. The obstacle blocks through movement of traffic at the intersection and creates an L-shape street which only allows turning movements.

Figure 2.16: Diagonal diverters traffic calming (FHWA, 2010)

Median barriers

Median barrier calming measures comprise obstacles that are placed on the median between two different directional lanes to ensure that road users cannot cross the median. The purpose of this calming measure is often to block through traffic at intersections. As seen in **Figure 2.17**, this calming measure only allows road users to turn left from the minor road into the major road.

Figure 2.17: Median barriers traffic calming (FHWA, 2017, fig. 3.24.4)

Speed humps

Speed hump can be defined as a rounded raised section of pavement across the width of a road, as seen in **Figure 2.18**. According to Jobanputra (2010), the height of the hump should vary between 75mm and 150mm and the width of the hump depends on the operating speed on the road where the hump should be implemented. For a lower operating speed on the road section, the width should decrease. The main purpose of a speed hump is to reduce the speed of the approaching vehicles and thereby control the operating speed on the road section.

Figure 2.18: Speed hump traffic calming (Zaal, 2014)

Chokers

Chokers narrow the street by extending the kerb using a sidewalk or planting strip for a small portion of the road, as seen in **Figure 2.19**. Two-lane chokers narrow the cross section and therefore vehicles need to slow down, since the choker cross section is narrower than the rest of the road cross section. One-lane chokers narrow the cross section of the two-lane road to a one-lane only cross section, for a small part of the road. Vehicles need to slow down and wait for an acceptable gap, since the one-lane cross section only allows one directional flow at a time.

Figure 2.19: Chokers traffic calming (AYRES ASSOCIATES, 2019)

2.12.2.2 International studies

After many years of research done internationally on traffic calming measures, different measures were identified and the impact thereof was determined. After Jobanputra (2010) investigated various documents, reports and journal articles, he compiled **Figure 2.20** with the positive change in volume percentages for different traffic calming measures.

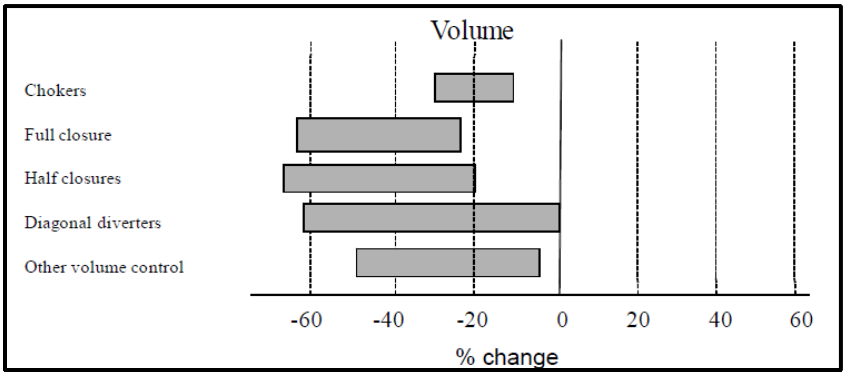

Figure 2.20: Effects of traffic calming measures (Jobanputra, 2010)

In **Figure 2.20**, all calming measures resulted in a volume reduction. Up to 60% reduction in volume for full closure, half closure and diagonal diverter measures were identified. Half closure was identified with the highest volume reduction.

2.12.2.3 Local effects

The traffic calming measures were also modelled for Cape Town in South Africa, to determine how the local conditions compare with the international conditions. After a study done by Jobanputra (2010) on the conditions of Cape Town, similar effects were found as for international studies. The local results vs the international results can be seen in **Figure 2.21**.

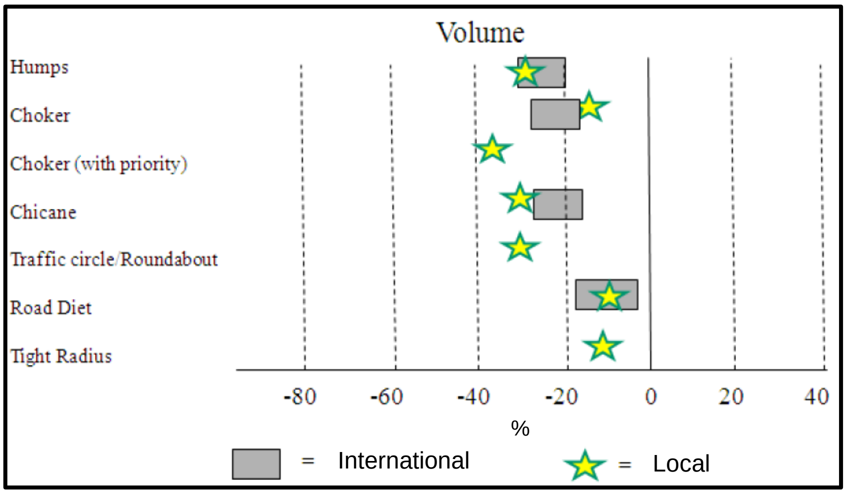

Figure 2.21: Effects of traffic calming measures internationally vs local (Jobanputra, 2010)

In **Figure 2.21**, the effects of the Hump and Road Diet traffic calming measure, were identified with predominantly similar effects. For the Choker and Chicane measure, approximately the same effect was identified, within a 10% error.

2.13 NMT Facilities

Any form of transport that does not rely on an engine for movement can be categorised as non-motorised transport (NMT). The most common forms of NMT are walking and cycling. NMT is an integral part of transport, since people need to walk either from their private vehicles, bus stops or train stations to work, shopping centres or other attractions.

Similarly to mobility and access roads for vehicles, NMT networks also consist of routes, corridors and access points. The principles regarding access and mobility, as previously discussed, also apply to NMT networks. Respectively, the routes for walking and cycling are sidewalks and cycle paths. Situations occur where vehicular traffic networks and NMT networks operate in the same area, for example at intersections. Therefore, in these situations, the combination of networks should be designed and developed together.

According to the South African Department of Transport (2014), NMT and vehicular networks should allow integration between each other to a certain level, complement each other and form a sustainable transport system together.

2.13.1 Sidewalks / Walkways

Sidewalks or walkways can be described as a pedestrian path which is typically designed to serve only pedestrian movement, which is separated from motorised transport routes. According to the TRH 26 manual, constructed pedestrian footways are only allowed along certain urban motorised transport road classes, as seen in **Table 2.5**.

Table 2.5: Sidewalks / Walkways allowed per road class (COTO, 2012b)

Road Classification	Class name	Pedestrian footways (constructed)
1	Principal arterial	No
2	Major arterial	Off road
3	Minor arterial	Yes
4a	Collector street (Commercial)	Yes
4b	Collector street (Residential)	Yes
5a	Local street (Commercial)	Normally yes
5b	Local street (Residential)	Not normally, pedestrians can use roadway

According to the Highway Capacity Manual (2000), there are respectively a primary performance measure, supplementary analysing criteria and a service measure which can be used to determine the effectiveness of current walkways/sidewalks. The primary performance measure is space (m^2/ped), which is the inverse of density. The density of pedestrians on a walkway is an indication of the maximum number of pedestrians found on a certain area of a specific walkway at a given time and is measured in pedestrians per unit area (ped/m^2). The supplementary analysis criterion is the speed of the pedestrian movement (m/s) and the service measure is the pedestrian unit flow rate (ped/min/m). The pedestrian unit flow can be determined by **Equation 2-4**.

$$V_p = \frac{V_{15}}{15 \times W_E} \qquad \text{Equation 2-4}$$

Where: V_p = pedestrian unit flow (ped/min/m)

V_{15} = peak 15-min flow rate (ped/15-min)

W_E = effective walkway width (m)

With information such as the space, speed or flow rate of the pedestrians, **Table 2.6** can be used to determine the LOS, giving an indication of the effectiveness of walkways.

Table 2.6: Average flow LOS criteria for walkways and sidewalks (TRB, 2000)

LOS	Space (m^2/ped)	Flow Rate (ped/min/m)	Speed (m/s)	v/c Ratio
A	> 5.6	≤ 16	> 1.3	≤ 0.21
B	> 3.7 – 5.6	> 16 – 23	> 1.27 – 1.3	> 0.21 – 0.31
C	> 2.2 – 3.7	> 23 – 33	> 1.22 – 1.27	> 0.31 – 0.44
D	> 1.4 – 2.2	> 33 – 49	> 1.14 – 1.22	> 0.44 – 0.65
E	> 0.75 – 1.4	> 49 – 75	> 0.75 – 1.14	> 0.65 – 1.0
F	≤ 0.75	Variable	≤ 0.75	Variable

According to the Highway Capacity Manual (2000), the LOS criteria is different if platooning or other traffic patterns are observed at the specific walkway section. The LOS thresholds for platooning or other traffic pattern conditions were determined using information from a research study conducted by Gartner, Messer and Rathi (1997). The adjusted LOS criteria can be seen in **Table 2.7**.

Table 2.7: Platoon-adjusted LOS criteria for walkways and sidewalks (TRB, 2000)

LOS	Space (m^2/ped)	Flow Rate[1] (ped/min/m)
A	> 49	≤ 1.6
B	> 8 – 49	> 1.6 – 10
C	> 4 – 8	> 10 – 20
D	> 2 – 4	> 20 – 36
E	> 1 - 2	> 36 – 59
F	≤ 1	> 59

2.13.2 Cycling Paths

According to the Highway Capacity Manual (2000), bicycle lanes are designed to accommodate bicycles exclusively. With on-street bicycle lanes, lanes should be separated from motorised traffic by way of pavement markings. There should be one lane on both sides of the road with flow only in one direction. According to the TRH 26 manual, cycle lanes are only allowed at certain urban motorised transport road classes, as seen in **Table 2.8**. There can also be seen that the application of the cycle lanes differs for the different road classes.

Table 2.8: Cycle lanes allowed per road class (COTO, 2012b)

Road Classification	Class name	Cycle lanes
1	Principal arterial	No
2	Major arterial	Yes – widen roadway
3	Minor arterial	Yes – widen roadway
4a	Collector street (Commercial)	Yes, widen road or on verge
4b	Collector street (Residential)	Yes, on road or verge
5a	Local street (Commercial)	Use roadway
5b	Local street (Residential)	Use roadway

According to the Highway Capacity Manual, the measure which can be used to determine the effectiveness of on-street bicycle lanes on urban streets, is the average bicycle travel speed (km/h). The average bicycle travel speed can be determined from information such as the average amount of time it took cyclers to traverse from point A to point B along a certain cycle path on urban streets, including stops, and the distance between point A and B. The average travel speed over an entire road section can be calculated by using **Equation 2-5**.

[1] Rates in the table represent average flow rates over a 5- to 6-min period.

$$S_{ats} = \frac{L_T}{\left(\sum \frac{L_i}{S_i} + \frac{\sum d_j}{3600}\right)}$$ Equation 2-5

Where: S_{ats} = Bicycle travel speed (km/h)

L_T = Total length of urban street under analysis (km)

L_i = Length of segment i (km)

S_i = Bicycle running speed over segment i (km/h)

d_j = Average bicycle delay at intersection j (s)

Note: “Each segment consists of a signalized intersection and an upstream segment of bicycle facility, beginning immediately after the nearest upstream signal” (TRB, 2000).

With information, such as the average bicycle travel speed, **Table 2.9** can be used to determine the LOS, which gave an indication of the effectiveness of cycling paths.

Table 2.9: LOS Criteria for bicycle lanes on urban streets (TRB, 2000)

LOS	Bicycle Travel Speed (km/h)
A	> 22
B	> 15 – 22
C	> 11 – 15
D	> 8 – 11
E	≥ 7 – 8
F	< 7

2.13.3 Shared Pedestrian-Bicycle Facilities

Shared pedestrian and bicycle facilities (paths) are commonly used by multiple modes of NMT. According to the Highway Capacity Manual, the LOS and pedestrian capacity on paths can be negatively affected by cyclists using the same path, due to the speed difference between bicycles and pedestrians. Since there are speed differences between pedestrians and cyclers on the same path, passing and approaching activities will be present (TRB, 2000).

According to the Highway Capacity Manual, interferences between different modes of NMT, on shared paths, can be used to determine the LOS thereof. The interferences can either be a passing or a meeting event with other users. Passing events happen in the same direction whereas meeting evens happen in the opposite direction. The number of passing events and the number of meeting events can be calculated by **Equation 2-6** and **Equation 2-7**.

$$F_p = Q_{sb}\left(1 - \frac{S_p}{S_b}\right) \quad \text{Equation 2-6}$$

$$F_m = Q_{ob}\left(1 + \frac{S_p}{S_b}\right) \quad \text{Equation 2-7}$$

Where:	F_p	=	Number of passing events (events/h).
	F_m	=	Number of opposing events (events/h).
	Q_{sb}	=	Bicycle flow rate in the same direction (bicycles/h).
	Q_{ob}	=	Bicycle flow rate in the opposing direction (bicycles/h).
	S_p	=	Mean pedestrian speed on the path (m/s).
	S_b	=	Mean bicycle speed on the path (m/s).

With information such as the total number of events happening on a path, **Table 2.10** can be used to determine the LOS of the path, which gives an indication of the effectiveness of the shared path. The total number of events happening on a certain path can be calculated by using **Equation 2-8**. In case of a 50/50 directional split of bicycles, the bicycle service volume per direction (bicycles/h) can be used to determine the LOS of the shared path from **Table 2.10**, otherwise the total number of events should be used.

$$F = F_p + 0.5\, F_m \quad \text{Equation 2-8}$$

Where:	F	=	Total number of events on the path (events/h).
	F_p	=	Number of passing events (events/h).
	F_m	=	Number of meeting events (events/h).

Table 2.10: Pedestrian LOS Criteria for shared two-way paths[2] (TRB, 2000)

Pedestrian LOS	Number of Events/h[3]	Corresponding Bicycle Service Volume per Direction[4] (bicycles/h)
A	≤ 38	≤ 28
B	> 38 – 60	> 28 – 44
C	> 60 – 103	> 44 – 75
D	> 103 – 144	> 75 – 105
E	> 144 – 180	> 105 – 131
F	> 180	> 131

2.13.4 NMT Facilities Separation

According to the South African Department of Transport (2014), the most important elements of NMT facilities' safety is the degree of separation between vehicles and NMT facilities. The degree of separation between NMT facilities and vehicles are separated into six levels, as seen in **Table 2.11**.

[2] Path 2.4 m wide.

[3] An "event" is a bicycle meeting or passing a pedestrian.

[4] Assuming 50/50 directional split of bicycles.

Table 2.11: NMT Degree of Separation (DOT, 2014)

NMT Separation	Description
1: NMT Only	The NMT facility is separate and removed from vehicular traffic over most of its extent.
2: Total	No conflict will occur between motorised and NMT even in the event of loss of control of the motorised or NMT vehicle. A heavy barrier or sufficient separation of 1 to 9m can be provided between the shoulder breakpoint and the NMT lane.
3: Partial	No conflict can occur under normal operating conditions. This is generally achieved by means of a level difference between the travelled ways such as a kerb and sidewalk or by means of light barriers.
4: Road Marking	Motorised and NMT traffic run on the same surface but are separated by means of continuous road marking and signage to identify the lane as a bicycle lane or pedestrian walkway.
5: Priority	A section of road where NMT has priority and slow speeds are mandatory – no continuous road markings only signage.
6: None	NMT competes with motorised vehicles for space on the road.

Each of the six degree of separation levels are categorised in **Table 2.12**, for different road classes and for each of the two common NMTs.

Table 2.12: Mode Separation Requirements (DOT, 2014)

Road Class	Bicycle	Pedestrians
1	Total Separation	Total Separation
2	Total Separation	Total Separation
3	Partial Separation	Total Separation
4	Marked Separation	Partial Separation
5	Priority Streets / Mixed Shoulder (Rural)	Partial Separation / Mixed Shoulder (Rural)

2.13.5 Intersection Design for NMT

According to the South African Department of Transport (2000), at all road intersections, whether there are marked pedestrian crossings or not, legal pedestrian crossings occur with priority given to pedestrians, with some exceptions. One of the exceptions occur at signalised intersections for a certain phase, where vehicles receive green and pedestrians red for a specific period.

At intersections where both NMT and vehicular traffic exists, conflict points occur between the different road users, as seen in **Figure 2.22**. The number of conflict points can be managed by implementing appropriate link and intersection designs. Since crashes occur at conflict points, the number of crashes can be minimised by managing the number of conflict points.

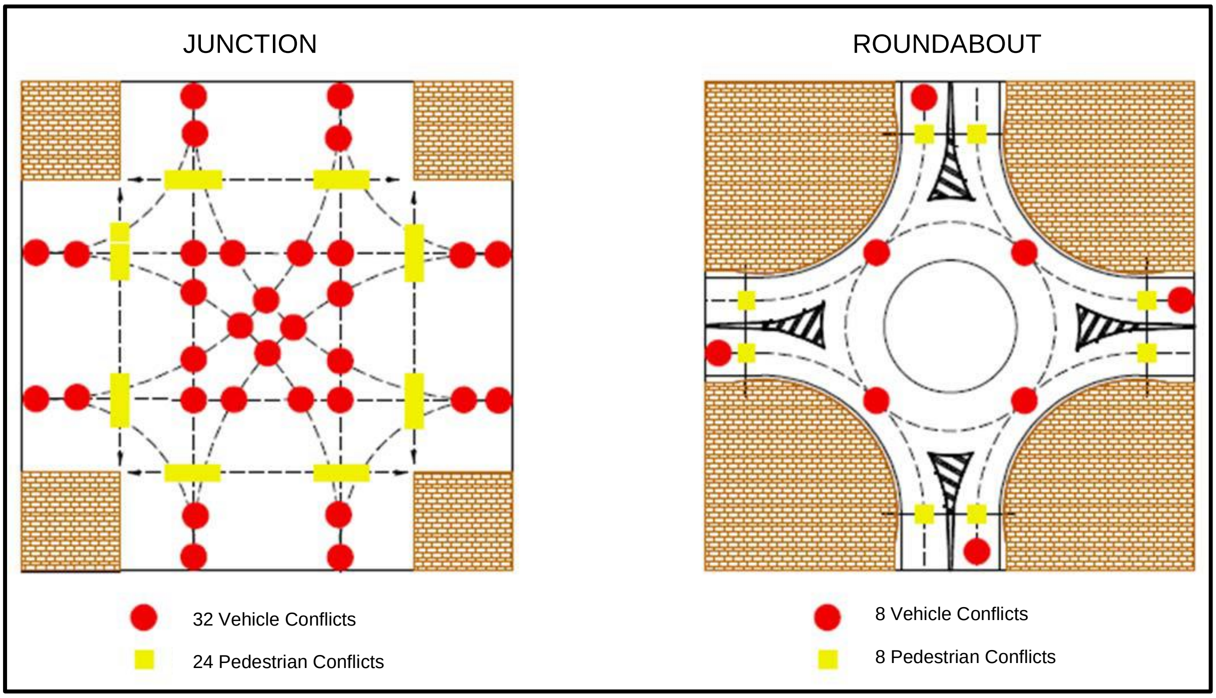

Figure 2.22: Conflict points (DOT, 2014)

The conflict points can be managed by way of signalised intersections or roundabouts. At signalised intersections, the right of way between NMT and vehicular traffic can be separated and controlled by way of different phases, as seen in **Figure 2.23**. As seen from the figure, certain vehicular traffic streams get right of way at the same time as pedestrian streams, however, if they intersect with each other, pedestrians should be given priority. At unsignalised intersections, conflict points can be minimised by implementing roundabouts, since they have significantly fewer conflict points than normal four-way unsignalised intersections.

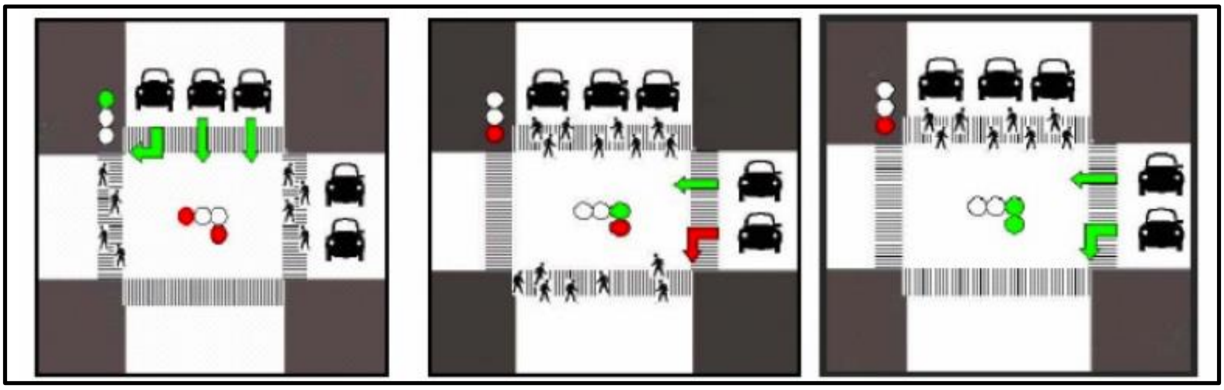

Figure 2.23: Traffic signal phase including NMT and vehicular traffic (FHWA, 2013)

2.13.6 Pedestrian Crossings

The location of the pedestrian crossings should be located where the natural pedestrian path intersects with the vehicle path and where the majority of pedestrians who need to cross the vehicle path are served (DOT, 2014). The crossing should be wide enough to accommodate the pedestrian demand.

The location of pedestrian crossings should not be too close to road intersections or other elements that can distract drivers' attention, since drivers need an average reaction time of 2.5 seconds to observe and react to any distractions (DOT, 2014). Therefore, it is important for the pedestrian crossing to be at a certain distance from intersections or other elements, such as merge areas, bus and mini-bus stops or midblock crossings. The separation distance between pedestrian crossings and intersections or other elements, for different operating speeds or speed limits, can be seen in **Table 2.13**.

Table 2.13: Minimum distance between crossings or road elements (DOT, 2014)

Operating Speed or Speed Limit (km/h)	Separation Distance (m)
20	15
30	20
40	30
50	35
60	45

2.13.7 Bicycle Crossings

According to the South African Department of Transport (2003), bicycle crossings should be marked under the following conditions:

- Exclusive bicycle path crosses a roadway.
- Shared bicycle or pedestrian path crosses a roadway.
- Where a bicycle lane, parallel to a vehicular road, crosses an adjoining road.

When both pedestrian and bicycle crossings are required at the same location, the two crossings should be adjacent to each other (DOT, 2003).

2.14 Conclusion

In **Chapter 2**, a detailed review of the literature, covering different components of the study, was discussed. From the literature, the outcomes of the functional classification and access management system, intersection types, intersection control techniques and the integration of non-motorised facilities within a vehicular network were identified. Different techniques were identified and the required background knowledge was acquired, which will be used for further development of the research methodology, in the context of the study.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

In **Chapter 3**, an overview of the study methodology is provided. An illustration of the research design summary is presented in **Section 3.2.6**.

3.2 Research Design

3.2.1 Data Collection Methods

The study requires specific and accurate raw data, which needs to be analysed by appropriate data analysis methods in order to achieve the aims and objectives identified for the study. Six data collection methods will be used to gather data for the study. The six methods are listed below and each of them will be discussed in more detail in **Chapter 4**.

- Floating Car Data analysis
- Traffic counts
- Pedestrian counts
- Study area information collection
- Parking study
- Signal plan survey

3.2.2 Data Analysis Methods

Two methods will be used for the analysis of the data. An overview of each method is given below, which will be discussed in more detail in **Chapter 5** and **Chapter 6** respectively.

<u>Vehicle movement data analysis</u>

Traffic data will be used to create a better understanding of the period representing the peak hour (worst traffic condition), as well as vehicle movement patterns within the network. The vehicle movement patterns will be used to identify any problem areas within the network.

<u>Traffic volume analysis</u>

Data collected from the traffic counts will be used for traffic volume analysis. The traffic volumes will be adjusted in order to calibrate data collected outside of the worst traffic condition periods, outdated data and data possibly influenced by external factors, such as weather and human activities (accidents and strikes). The data will be calibrated to a reference data source. This will ensure that all data sets are comparable to each other. From the calibrated data, the vehicle composition and intersection capacity of the signalised intersection, close to the major input points, will be determined for further use in other components of the study.

3.2.3 Functional Classification

Study area information and results obtained from the vehicle movement data analysis will be used to classify Bird Street according to the functional classification system techniques stated in literature. The classification of Bird Street will be considered under two conditions, namely the current designed condition and the current operating condition. The functional classification component of the study will be discussed in more detail in **Chapter 7**.

3.2.4 Scenario Development

Study area information and results obtained from the functional classification will be used to develop different scenarios, which will be analysed to determine the actual operating conditions of Bird Street and evaluate the impact of various improvements to the road. The scenario development component of the study will be discussed in more detail in **Chapter 8**.

3.2.5 Microscopic Traffic Modelling

In order to compare the different scenarios, a microscopic traffic model will be used to simulate each of the scenarios. For the study PTV Vissim, will be used. All of the previous mentioned components will be integrated into the model. The microscopic traffic modelling component of the study will be discussed in more detail in **Chapter 9**.

3.2.6 Research Design Summary

For the research study, the research design (how all the different components are integrated into each other), is illustrated by **Figure 3.1**.

3.3 Results Interpretation and Summary

From the microscopic traffic modelling component of the study, results will be collected for each of the scenarios simulated. The results of all the scenarios will be interpreted in order to identify the impact of the techniques tested in each scenario. The interpretations will be used to develop conclusions and recommendations for the study.

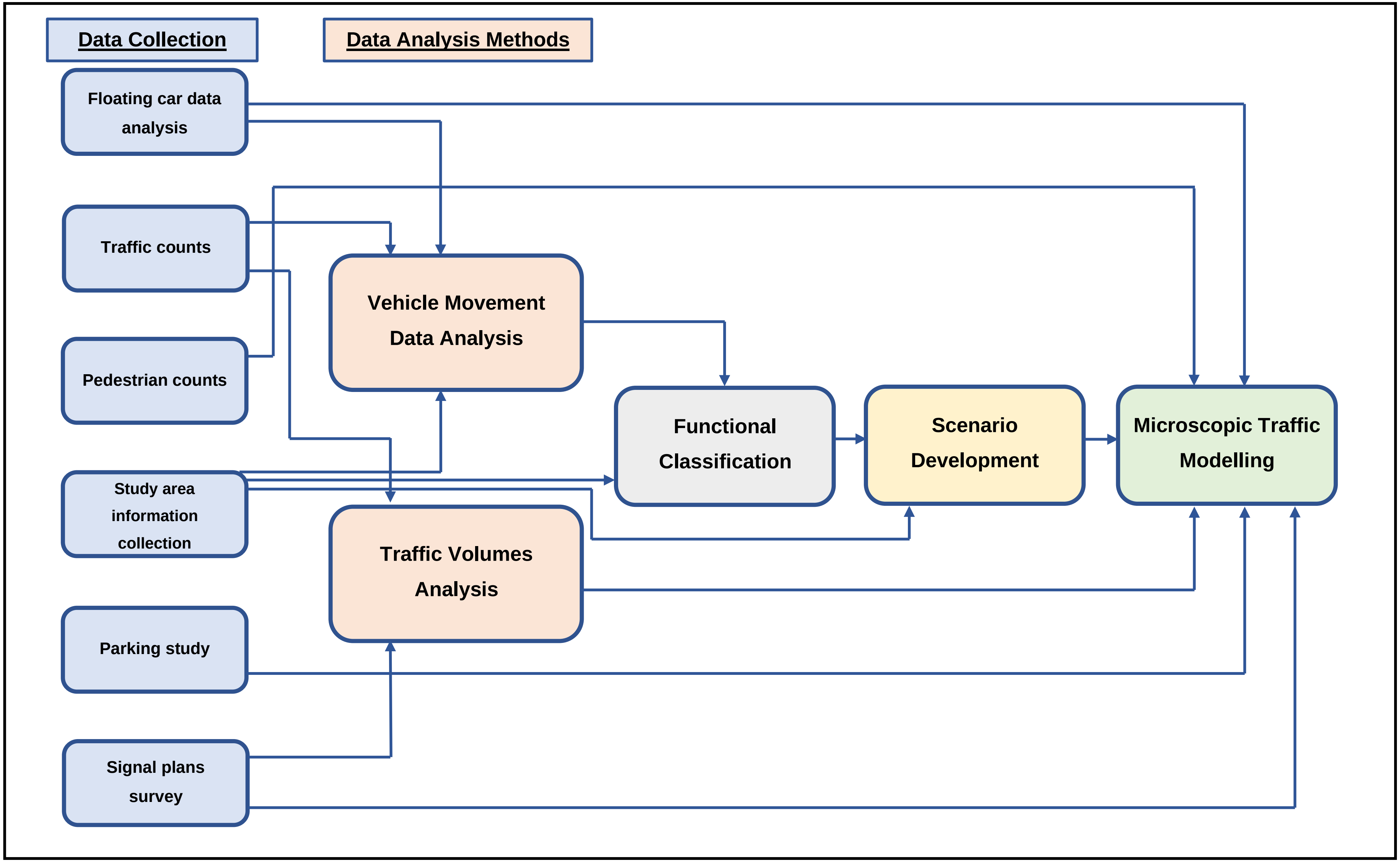

Figure 3.1: Research design summary for the study

CHAPTER 4 : DATA COLLECTION

4.1 Introduction

Traffic and transport related data is important for transport planning studies. Such data has to be collected to enable engineers and traffic or transport specialists to make predictions, conclusions and recommendations regarding the road network.

For this research study, data is required to serve other components (data analysis, functional classification, scenario development and microscopic traffic modelling) of the study, as mentioned in the research design. Most of the data was collected in-field by the student, some was received from data sources and the rest was determined through assumptions, discussed in this chapter.

4.2 Floating Car Data Analysis

4.2.1 Background

The collection of Floating Car Data (FCD) enables users to measure average speed and travel time on road sections in a certain area. From the average speed and travel time results, the performance of road sections can be determined. FCD entails data gathered from probe devices, such as cell phones or GPS devices within vehicles.

For the study, FCD was obtained from TomTom's historical traffic database product, "Traffic Stats - Custom Area Analysis". TomTom has access to historical data from 2008, stored in their traffic database. According to TomTom (2015), this historical data-base contains trillions of anonymous GPS based measurements, collected from users around the world.

4.2.2 Objectives

The following objectives will be accomplished using FCD:

- Identify the problem traffic areas in Stellenbosch.
- Identify or select the study area.
- Identify the operational level of the study area.
- Validate the results obtained from the microscopic traffic model.

4.2.3 FCD Data Obtained

Historical FCD was obtained from TomTom for all vehicle types within the road network of Stellenbosch. The data was received as two data types in different file formats, namely the road network (shape file) and the traffic/route information (database file), that is analysed using a GIS software package. The data was received for a specific time (hourly intervals) and date period, as indicated in **Table 4.1** below.

Table 4.1: Time and date ranges for data received from TomTom

Time sets			Calendar period	Days excluded
AM	06:00 – 09:00	Tuesday – Thursday	2018/02/01 – 2018/03/31	Rest of the week and public holidays
PM	15:00 – 18:00			

The data was processed using ArcMap. The following information was obtained from the FCD as discussed in **Chapter 5** and **Chapter 9** respectively:

- Harmonic average speed for the specific time period (km/h)
- Number of hits or probes

4.3 Traffic Counts

4.3.1 Background

Manual or automatic traffic count techniques can be used to obtain traffic volume data. The manual traffic count technique is more expensive compared to automatic counting techniques because more manpower is needed for collecting data. Automatic traffic count techniques use instruments such as: inductive loops, radar detectors, video cameras or similar types of technologies. However, the availability of instruments for conducting data via such methods is a concern (Planning Tank, 2015).

For this study, traffic counts at certain intersections were received from different sources, while some were manually conducted by the student with assistance from other students from the SSML. The traffic counts were manually conducted due to the availability constraint of collection methods, at locations within the study area where no data was available.

4.3.2 Objectives

The following objectives will be accomplished using the traffic counts:

- Identify the morning (AM) and afternoon (PM) peak periods for the study area.
- Identify vehicle travel patterns.
- Serve as input for the microscopic traffic model.
- Validate the results obtained from the microscopic traffic model.

4.3.3 Assumptions

For the historical data, it was assumed that historical traffic counts within a range of 5 years were still useable and represent similar travel patterns as 2019, but were adjusted according to an applicable growth rate. The adjustments made to the historic traffic counts will be discussed in **Chapter 6**.

4.3.4 Data Sources

The traffic counts obtained from different sources were conducted at different time periods as shown in **Table 4.2**. The locations where the traffic volumes were collected, per source, can be seen in **Figure 4.1** to **Figure 4.3** below for three zones of the study area. **Figure 4.1** extends along Bird Street from Masitandane Road to Mount Albert Street, **Figure 4.2** from Mount Albert Street to Alexander Street, and **Figure 4.3** from Alexander Street to Dorp Street.

Table 4.2: Data conducting period per source

<table>
<tr><th>Source</th><th>Date</th><th>AM</th><th>PM</th></tr>
<tr><td rowspan="3">ITS (Innovative Transport Solutions)</td><td>11/02/2015;</td><td>06:30 – 09:30</td><td>15:30 – 18:30</td></tr>
<tr><td>27/08/2015;</td><td>06:30 – 09:30</td><td>15:30 – 18:30</td></tr>
<tr><td>08/03/2016</td><td colspan="2">06:00 – 18:00</td></tr>
<tr><td>Stellenbosch Municipality</td><td>22/02/2018</td><td colspan="2">06:00 – 18:00</td></tr>
<tr><td>Nick Venter Traffic Surveying</td><td>26/09/2018</td><td>06:00 – 10:00</td><td>16:00 – 20:00</td></tr>
<tr><td>Nick Venter Traffic Surveying</td><td>10/10/2018</td><td colspan="2">06:00 – 18:00</td></tr>
<tr><td>Alicia Potgieter</td><td>25/09/2018 – 11/10/2018</td><td>06:00 – 09:00</td><td>17:00 – 20:00</td></tr>
<tr><td>Nick Venter Traffic Surveying</td><td>23/10/2018</td><td colspan="2">06:00 – 20:00</td></tr>
<tr><td>Manually conducted*</td><td>08/04/2019 – 09/05/2019</td><td>07:00 – 08:00</td><td>16:30 – 17:30</td></tr>
</table>

* Traffic counts specific to this research

Figure 4.1: Traffic counts locations per source – Zone 1 (Google Earth Pro, 2019)

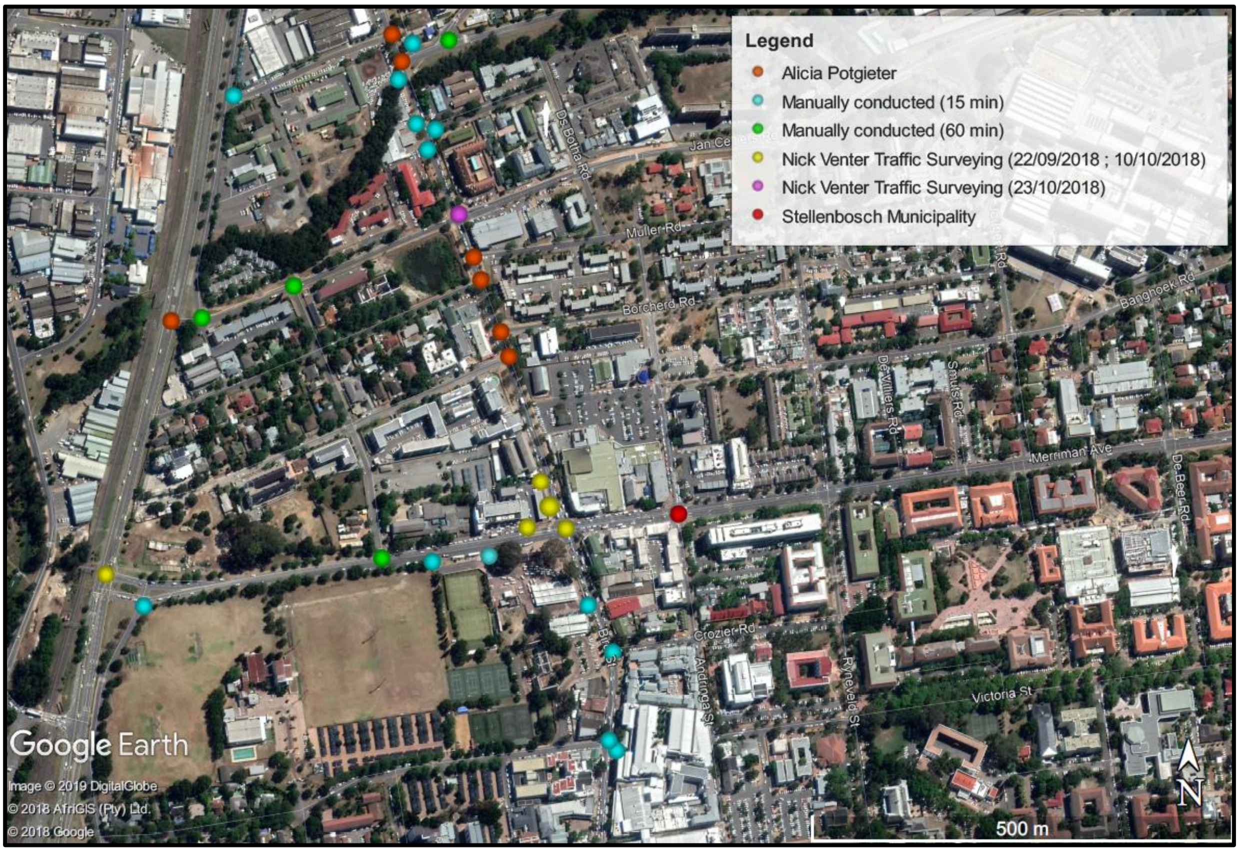

Figure 4.2: Traffic counts locations per source – Zone 2 (Google Earth Pro, 2019)

Figure 4.3: Traffic counts locations per source – Zone 3 (Google Earth Pro, 2019)

The counting periods of all five data sources include both the AM and PM period, except for previous MEng student Alicia Potgieter's data which was only collected over a 30 minute interval in the PM peak hour period. All traffic counts exclude public holidays, school holidays, Stellenbosch University holidays and weekends. The various sources of traffic count data are discussed below.

4.3.4.1 Innovative Transport Solutions (ITS) counts

Traffic counts were received from ITS for three intersections. No classification of vehicles was conducted.

4.3.4.2 Stellenbosch Municipality counts

Traffic counts were conducted for Stellenbosch Municipality by third party consultants and made available to the University for research purposes. Traffic counts were received for three intersections. Vehicles were classified as light and heavy vehicles.

4.3.4.3 Nick Venter Traffic Surveying counts

Nick Venter Traffic Surveying was employed by the SSML to collect traffic data. Traffic counts were received for 13 intersections. Traffic counts for ten of the 13 intersections were conducted on 26/09/2018, two of the 13 were conducted on 10/10/2018 and the remaining intersection on 23/10/2018. The vehicles were classified as light vehicles, taxis or minibus-taxis, buses and heavy vehicles.

4.3.4.4 Alicia Potgieter counts

Alicia Potgieter completed an MEng degree at Stellenbosch University in 2018 and did traffic counts for her own research. Traffic counts were obtained for eight intersections within the network. The observation period included the AM peak hour period and the second half of the PM peak hour period which was doubled in order to get the hourly volume for each of the eight intersections for the PM peak hour period. Vehicles were classified as light and heavy vehicles.

4.3.4.5 Counts conducted for this study

Traffic counts were conducted by the student, with assistance from other students from the SSML at 42 intersections within the network. At various minor intersections (37 of the 42 intersections), traffic counts were conducted for a 15 min period (in the peak hour) and multiplied by four to get an hourly volume. This was considered adequate as the intersections for which shorter periods were observed are all minor intersections with very little side street traffic and have a minimal impact on the overall traffic. At the remaining five intersections, traffic counts were conducted for a 60 min period (peak hour) during both the morning and afternoon peak hour. No classification of vehicles was conducted.

4.4 Pedestrian Counts

4.4.1 Background

One of the highest used Non-Motorised Transport (NMT) modes identified in the study area is the pedestrian mode. In the study area, there is a main NMT (pedestrian) movement link between Kayamandi and Central Stellenbosch. Over the entire network of the study area, 16 pedestrian crossings were identified, where pedestrians are allowed to cross Bird Street, and two areas were identified with a high incidence of jaywalking activities (pedestrians not using formal crossings).

For this research study, pedestrian counts at certain locations in the study area were received from different sources, and the rest were calculated. The pedestrian route identified between Kayamandi and Central Stellenbosch, 16 pedestrian crossings as well as the two jaywalking activity areas can be seen in **Figure 4.4** below. The pedestrian route is indicated by the red line, pedestrian crossings by the light blue dots and the jaywalking activity areas by the red boxes. The jaywalking areas are located between Bell Road and the Kayamandi Taxi Rank, as well as opposite the main taxi rank (Bergsigt Taxi Rank) between Merriman Road and Alexander Street.

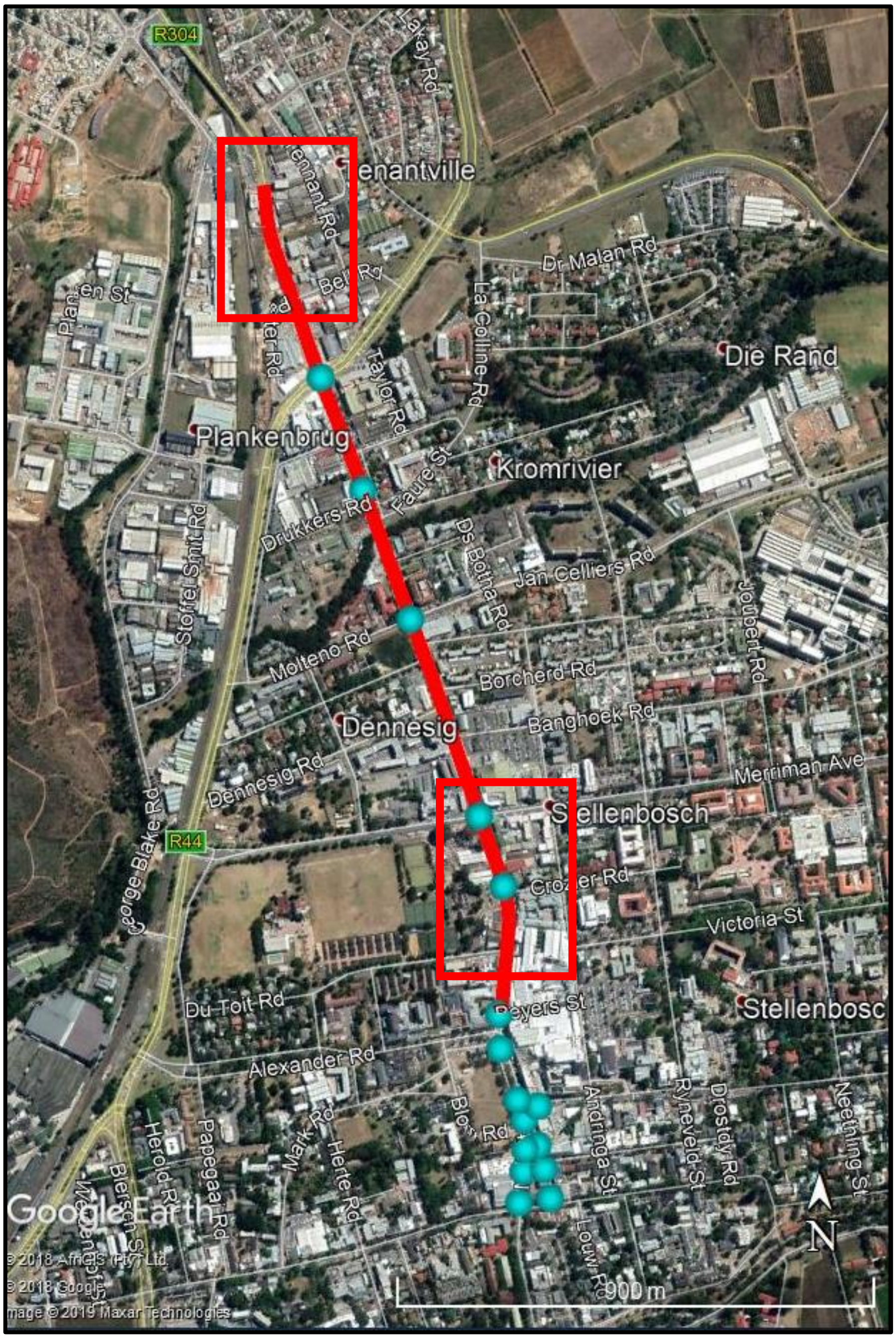

Figure 4.4: Pedestrian movement activities in the study area (Google Earth Pro, 2019)

4.4.2 Objectives

The following objective will be accomplished using the available pedestrian counts:

- Input for the microscopic traffic model.

4.4.3 Data Sources

For the study, pedestrian counts were obtained from different sources and collected at different time periods, as seen in **Table 4.3**. The locations where the pedestrian volumes were collected, per sources, can be seen in **Figure 4.5** below.

Table 4.3: Data conducting period per source

Source	Date	AM	PM
Stellenbosch Municipality	22/02/2018	06:00 – 18:00	
Nick Venter Traffic Surveying	26/09/2018	06:00 – 10:00	16:00 – 20:00
Nick Venter Traffic Surveying	10/10/2018	06:00 – 18:00	
Calculated	-	07:00 – 08:00	16:30 – 17:30

Figure 4.5: Pedestrian counts locations per source (Google Earth Pro, 2019)

4.4.3.1 Nick Venter Traffic Surveying footage pedestrian counts

Nick Venter Traffic Surveying captured footage of the transport activity movements at various intersections within the network in order to conduct traffic counts for the specific intersections. The capturing periods can be seen in **Table 4.3**. This footage was used by the student to count the pedestrian movement volumes at the specific locations, illustrated in **Figure 4.5** by the blue dots. Pedestrian volumes were counted for 15 minutes during the peak hour and multiplied by four in order to get the peak hour volume.

4.4.3.2 Stellenbosch Municipality pedestrian counts

Pedestrian counts at two of the 16 locations were received from Stellenbosch Municipality. The AM and PM peak hour collecting period and the locations at which the data were collected, can be seen in **Table 4.3** (time period) and **Figure 4.5** (yellow dot locations) respectively.

4.4.3.3 Calculated pedestrian counts

The rest of the pedestrian volumes required for the project were calculated by making a few assumptions. The specific locations in the study area, at which pedestrian volumes were calculated, for the AM and PM peak hour period, can be seen in **Figure 4.5**.

The following assumptions were made for the locations indicated by red markers (Locations 2, 3, 7, 12 and 15) in **Figure 4.5**:

Location 2:

Location 2 is a midblock pedestrian crossing. An assumption was made that the number of pedestrians crossing Bird Street at this specific pedestrian crossing is double the volume crossing Bird Street at the Molteno Road/Bird Street signalised intersection (Location 3). This assumption caters for the pedestrian movement route identified by the student between point A, B and C, as indicated in **Figure 4.6** below. It was observed from the available pedestrian counts, that no pedestrians crossed Bird Street at Location 1. Therefore, pedestrians who found themselves on the western side of the road, needed to cross Bird Street at Location 2 in order to reach either point A or B, depending on the walking direction.

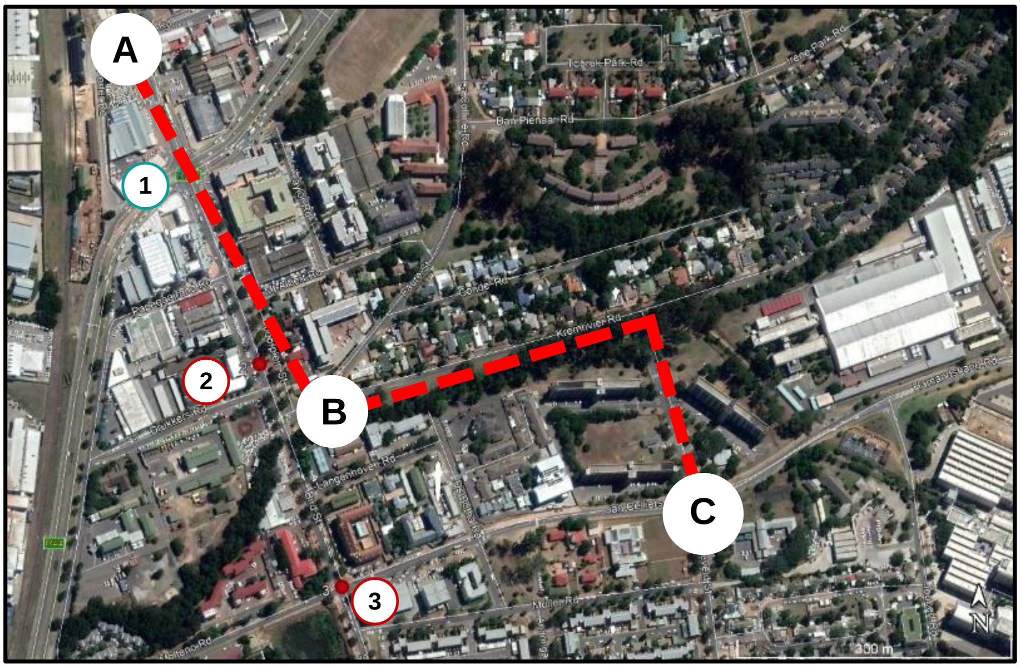

Figure 4.6: Pedestrian crossing 2 users' identification

Location 3:

An assumption was made that the number of pedestrians crossing Bird Street at Location 3, is 10% of the pedestrians crossing Bird Street at Location 4 (counted from the Nick Venter Traffic Surveying footage). A volume of 10% was assumed, since the main taxi rank is situated South – West of the intersection at Location 4, which results in a higher pedestrian volume. Since zero pedestrians cross Bird Street at Location 1 and a taxi rank was identified at Location 4, the assumption of 10% of the pedestrians crossing Bird Street at Location 3, was made to represent a realistic volume.

The pedestrian volumes crossing Molteno Road at Location 3, were assumed to be the average north-south pedestrian volume between Locations 1 and 4. Since Locations 1, 3 and 4 are located on the main pedestrian link between Kayamandi and Central Stellenbosch, and Location 3 is in the middle of Locations 1 and 4, the average was assumed to represents a realistic volume.

Locations 7, 12 and 15:

From observations and pedestrian counts, many pedestrian activities were identified in the area between Locations 4 and 13/14 for the AM and PM peak hour periods. However, a consistent movement pattern was identified over the area, which allowed the student the development of an assumption for determining the pedestrian volumes at specific intersections where there was no data available (Locations 7, 12 and 15). The pedestrian volumes at each of the locations were determined by assuming the volume as the average between the two closest locations, with available pedestrian counts. The average of Locations 6 and 8 was assumed for Location 7, average of Locations 11 and 13 was assumed for Location 12 and average of Locations 14 and 16 was assumed for Location 15.

4.5 Study Area Information Collection

4.5.1 Route Section Identification

The study area was subdivided into three similar sections, as illustrated in **Figure 4.7**. An illustration of the three sections individually, can be seen in **Figure 4.8** to **Figure 4.10**. In the rest of this document, these sections will be referred to as Section 1, 2 and 3. Section 1 is from the Masitandane Road/Bird Street intersection to the Adam Tas Road (R44)/Bird Street intersection, Section 2 is from the Adam Tas Road (R44)/Bird Street intersection to the Merriman Avenue/Bird Street intersection and Section 3 is from the Merriman Avenue/Bird Street intersection to the Dorp Street/Bird Street intersection.

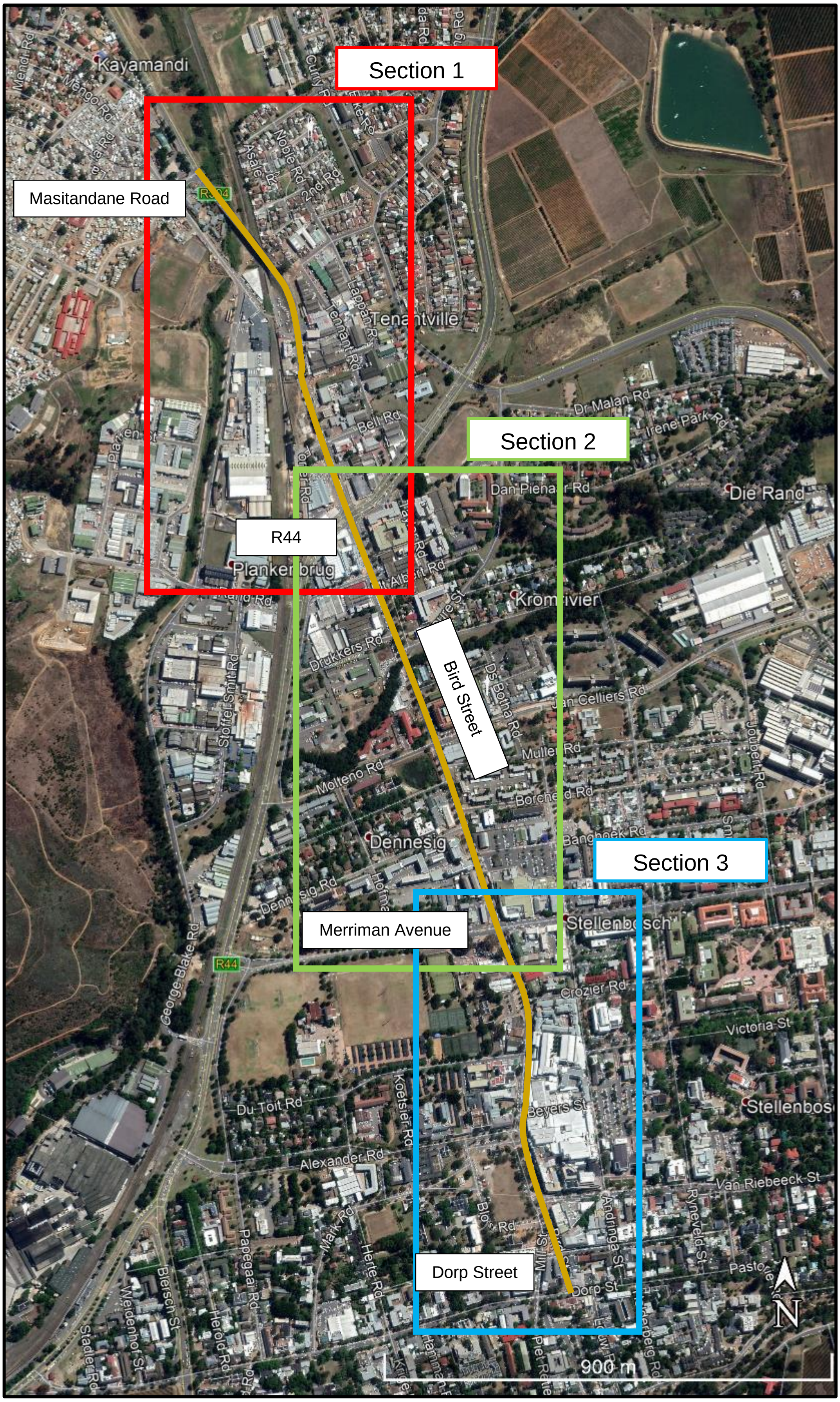

Figure 4.7: Illustration of Section 1 to 3 in study area (Google Earth Pro, 2019)

Figure 4.8: Section 1 (Google Earth Pro, 2019)

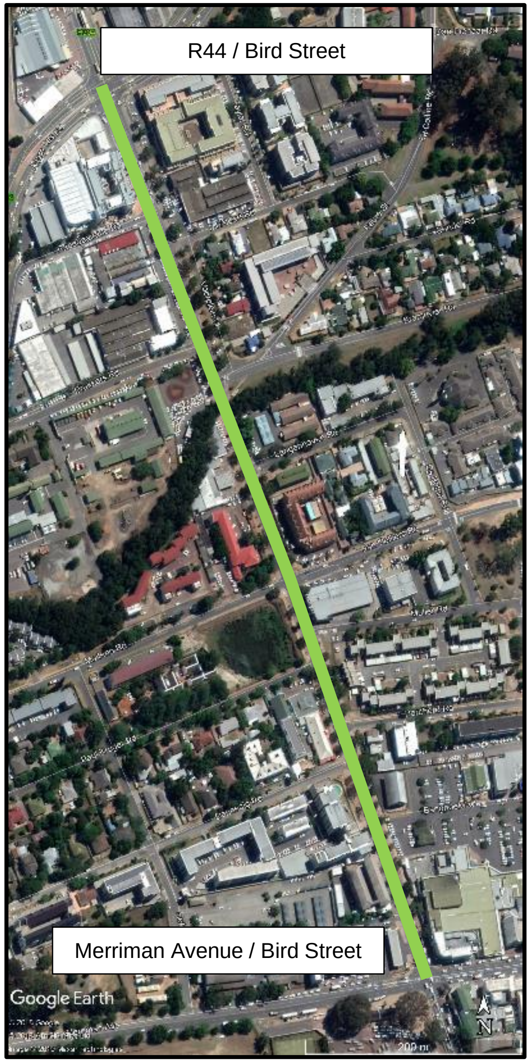

Figure 4.9: Section 2 (Google Earth Pro, 2019)

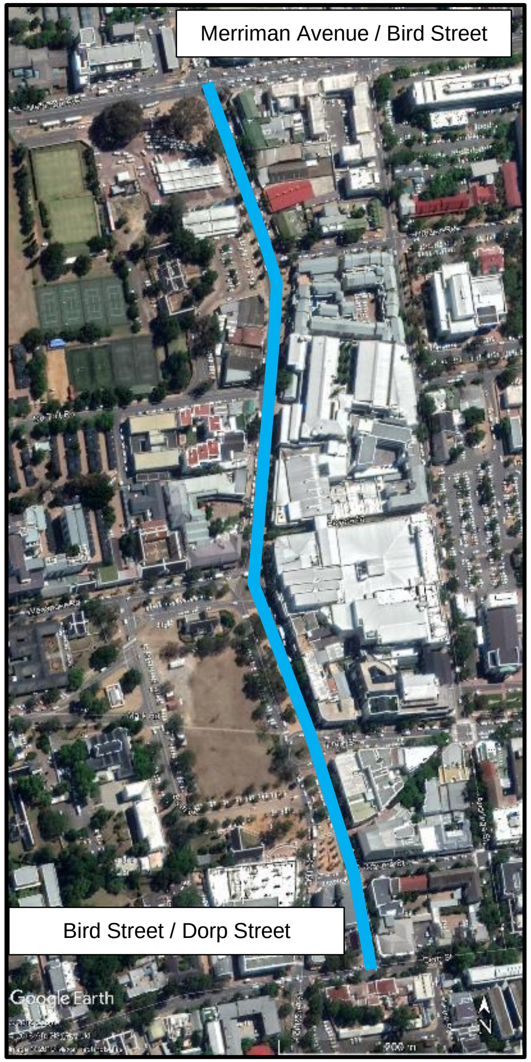

Figure 4.10: Section 3 (Google Earth Pro, 2019)

For each of the three sections, information was gathered by way of an in-field study, with the assistance of freeware software tools such as Google Earth Pro, Google Maps and LandsatLook.

4.5.2 Study Area Information Investigated

- Type of area (rural or urban)
- Intersection spacing
- Any accesses to properties
- Parking in the area
- Speed limit
- Typical cross section
    - Number of lanes
    - Lanes divided or undivided
    - Kerbed
    - Median at pedestrian crossing
    - Boulevard
    - CBD one-way
- Roadway / lane width
- Road reserve width
- Public transport stops and pedestrian crossings
- Pedestrian footways (constructed)
- Cycle lanes
- Traffic calming measures
- Land use information
- Length of auxiliary lanes
- Intersection control type
    - Roundabouts
    - Priority control
    - Signal control
- Intersection type

4.5.3 Results

A satellite image map, detailed map (illustrating the information observed in the area) and a table summarising the information gathered for each of the three sections, can be seen in **Appendix A**.

4.6 Parking Study

4.6.1 Background

On-street (roadside) parking was identified in the study area at different locations, as seen in **Figure 4.11** and **Figure 4.12**. Parking was found to be occupied at different rates and durations. The parking turnover (vehicles/space) can be defined as the rate of use of a parking space for a certain period of time or per time interval. By executing a parking study, the parking turnover per single observation (PTPSO) (for one individual timestamp), parking turnover per peak hour period (PTPPHP) and the parking duration was determined.

Figure 4.11: Parking zone locations (1 to 4)

Figure 4.12: Parking zone locations (5 to 18)

4.6.2 Objectives

The following objectives will be accomplished by using the data generated and assumed for each of the parking areas in the study area:

- Determine the PTPSO, PTPPHP and the parking duration distribution for the parking zones in the study area.
- Serve as input for the microscopic traffic model.

4.6.3 Data Source

From the footage captured by Nick Venter Traffic Surveying on 26/09/2018 and 10/10/2018, a detailed parking study was done for two of the 18 parking zones (parking zones 12 and 18), during the peak hours. The PTPPHP was determined by recording the total number of vehicles which had occupied the parking zone during the peak hour period and then dividing it by the number of parking spaces. The PTPSO was determined by recording the maximum number of vehicles which had occupied the parking zone at a specific timestamp and then dividing it by the number of parking spaces. The parking duration was determined by recording the average duration at which each vehicle had parked in the specific parking zone. The parking duration and the PTPPHP for the rest of the 16 parking zones were determined by developing and making assumptions, as described in **Section 4.6.4** and **Section 4.6.5**.

4.6.4 Assumption Development

Firstly, the number of parking spaces for each parking zone was determined in order to allow the student to compare the number of parking spaces available (at zero occupancy) with the number of vehicles which occupied the parking zone at a specific timestamp of the day. The maximum number of vehicles per single observation was determined for parking zones 12 and 18 from the detailed study results, as previously described in **Section 4.6**. Since the impact of vehicles entering and exiting parking zones under current conditions was identified, the maximum number of vehicles per single observation was used for the calculation of the PTPSO in order to cater for the worst-case condition (more vehicles entering and exiting a parking zone will cause a bigger distraction on the conflicting flow).

Two observations were executed on 16/05/2019, during the AM and PM peak hour period. For the specific periods of observation, the number of vehicles, which had occupied each of the 18 parking zones within the period of the specific timestamp, were determined. The change in vehicles parked per parking space was recorded for each period (at each parking space). From the recorded data, the parking duration can roughly be determined by investigating the change in vehicles for each parking space between the two recorded time periods. It was assumed that the minimum and maximum parking durations for the 16 parking zones fit in the minimum and maximum average parking duration range, calculated for the comparative data sets (parking zones 12 and 18).

The PTPSO (for both the AM and PM peak period) was determined for each of the 18 parking zones. The average PTPSO of the 18 parking zones was compared with the average PTPSO of parking zones 12 and 18. The comparison between the average PTPSO of parking zones 12 and 18, and all 18 parking zones, can be seen in **Table 4.4** below.

Table 4.4: Average PTPSO comparison

	PTPSO (Vehicles/Unit)	
	AM	PM
Parking zones 12 and 18	0.5	1
All parking zones	0.4	0.9

4.6.5 Assumptions

From **Table 4.4**, it can be seen that the PTPSO over the entire area is consistent. As previously mentioned, the parking duration pattern is also consistent over the study area. Therefore, since the PTPSO and the parking duration were consistent over the entire network, it was assumed that the data generated from the detailed study is applicable to all of the parking zones in the study area, for the AM and PM peak period respectively.

4.7 Signal Plans Survey

4.7.1 Background

There are four signalised intersections in the study area controlled by fixed-time and vehicle-actuated control systems. Information regarding the current implemented signal control technique as well as the data used by the controllers, was received from Stellenbosch Municipality.

4.7.2 Objectives

The following objective will be accomplished by using the data regarding signal plans, at the various signalised intersections in the study area:

- Required as input for the microscopic traffic model.

4.7.3 Data Received

Four signalised intersections were identified at different locations in the study area as indicated with blue dots (1 to 4) in **Figure 4.13** at the intersections of Bird Street with Masitandane Road, Adam Tas Road (R44), Molteno Road and Merriman Avenue. The study area for the microsimulation was extended to increase the accuracy of the model by taking components in the wider vicinity of the study area into consideration. An extra three signalised intersections were identified and added to the network at different locations as indicated with red dots (5 to 7) in **Figure 4.13** at the intersections of Adam Tas Road (R44)/Helshoogte Road, Merriman Avenue/Andringa Street and Adam Tas Road (R44)/Merriman Avenue.

Figure 4.13: Locations of the seven signalised intersections (Google Earth Pro, 2019)

For each of the seven signalised intersections, the signal plans were received. From the signal plans, the following information was incorporated into the microscopic traffic model.

- Type of traffic control technique
- Different phases
- Different stages
- Stage sequence
- Duration of yellow for each phase
- Duration of red for each phase
- Duration of green at AM and PM peak hours of the day for the different stages

4.8 Conclusion

For this research study, many different types of data were required and collected for further analysis in order to serve all the components identified by the research design. In **Chapter 4**, each of the required data collection methods were discussed and the objectives thereof were identified.

CHAPTER 5 : VEHICLE MOVEMENT DATA ANALYSIS

5.1 Background

Data from available sources, as discussed in **Chapter 4**, was used to develop a better understanding of the vehicle movements in the study area. Mainly three sources were used: Floating Car Data (TomTom), traffic counts and study area information.

In **Chapter 5**, available data refers to the traffic counts available before any traffic counts were conducted by the student. The vehicle movement analysis provided a better understanding in terms of the peak traffic periods representing the worst condition as well as vehicle movement patterns within the network.

5.2 Assumptions

It was assumed that the average AM and PM peak one-hour period (07:00 to 08:00 and 16:30 to 17:30 respectively), determined from the data of four intersections within the network (as discussed in **Section 5.3.2**), was consistent over the entire network.

5.3 Data Sources

5.3.1 Floating Car Data (FCD)

FCD was used to identify areas in Stellenbosch that experienced traffic problems, which served as a motivation for the selection of the study area. From the FCD, two data types (average speed and number of hits or probes) were used and illustrated in various figures to identify and illustrate the problem areas, representing the following conditions:

- **Figure 5.1** – Roads in Stellenbosch with the lowest average speed during the AM peak period.
- **Figure 5.2** – Roads in Stellenbosch with the lowest average speed during the PM peak period.
- **Figure 5.3** – Roads in Stellenbosch with the highest vehicular volume during the AM peak period.
- **Figure 5.4** – Roads in Stellenbosch with the highest vehicular volume during the PM peak period.

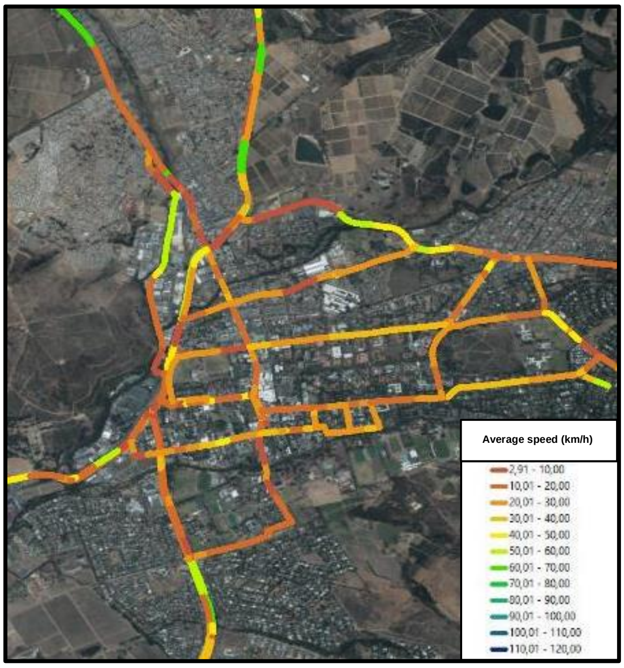

Figure 5.1: Congested roads in Stellenbosch - AM peak period (TomTom, 2018; ArgGIS, 2019)

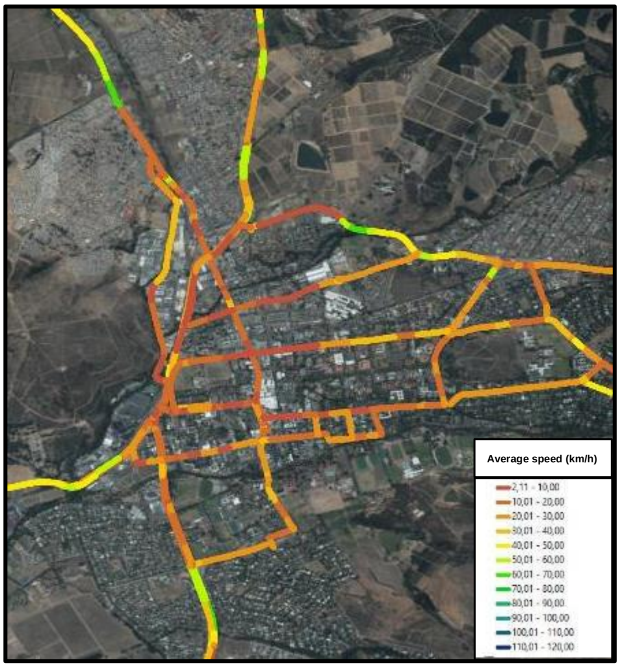

Figure 5.2: Congested roads in Stellenbosch - PM peak period (TomTom, 2018; ArgGIS, 2019)

Figure 5.1 and **Figure 5.2** identify road sections in Stellenbosch that experience the lowest average operating speed during the AM and PM peak period. From the two figures, Bird Street can be identified as one of the road sections that experiences the lowest average speed. In the AM and PM peak periods, Bird Street has a speed range of 2.91 km/h to 40 km/h and 2.11 km/h to 40 km/h respectively. The modal speed range for the road section appears to be 2.91 km/h to 20 km/h and 2.11 km/h to 20 km/h, for the AM and PM peak period respectively. Further investigation was executed by examining the number of hits (probes), per road section (in Stellenbosch), on a map (**Figure 5.3** and **Figure 5.4**).

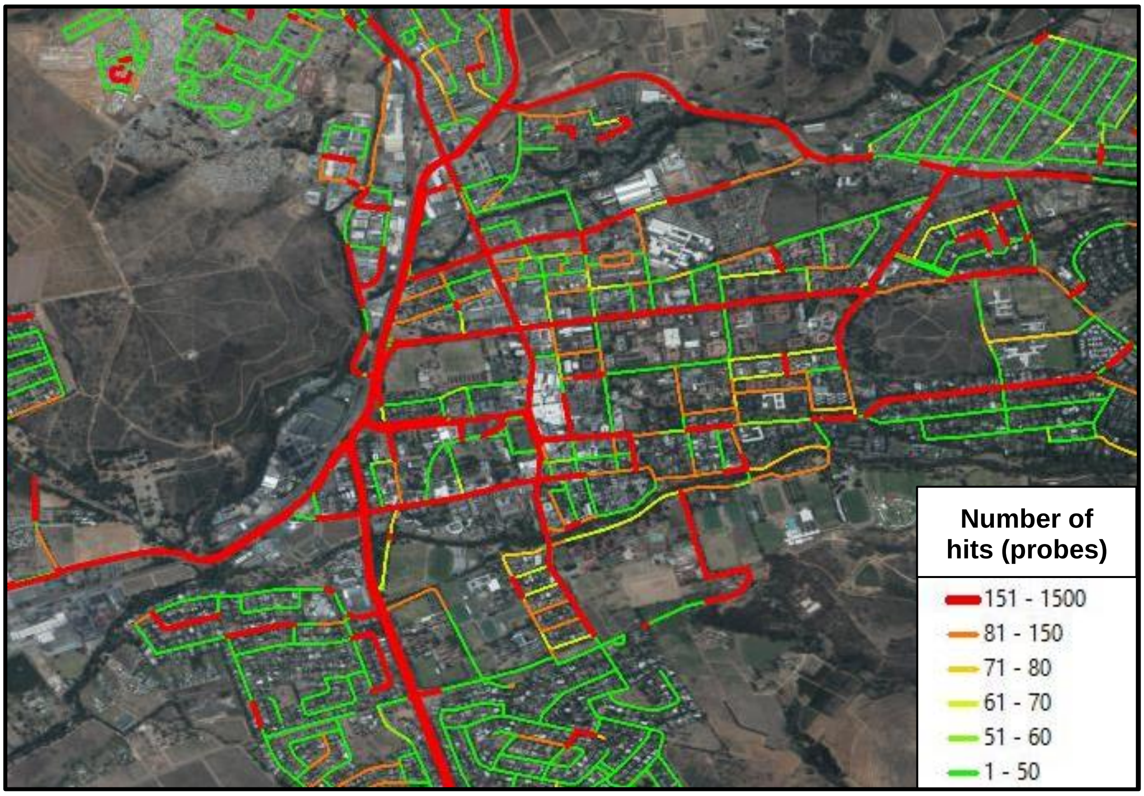

Figure 5.3: Number of hits per road section in Stellenbosch – AM peak period (TomTom, 2018; ArgGIS, 2019)

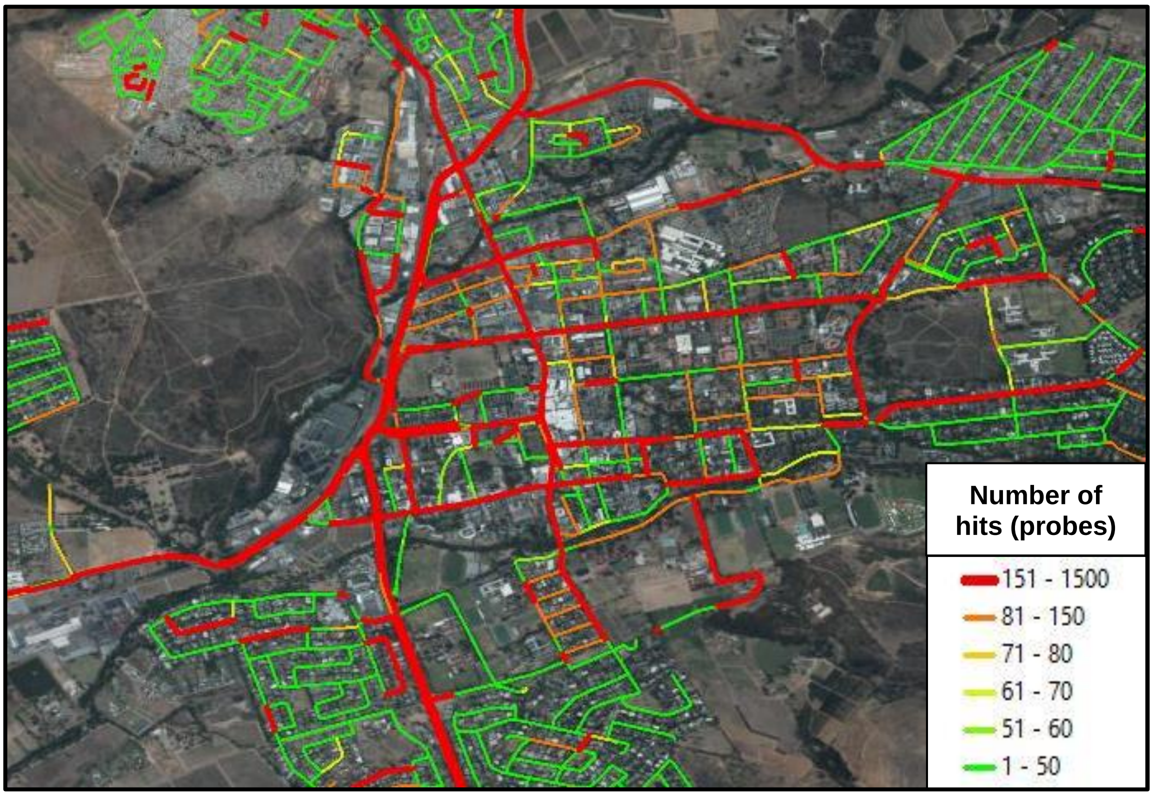

Figure 5.4: Number of hits per road section in Stellenbosch – PM peak period (TomTom, 2018; ArgGIS, 2019)

From **Figure 5.3** and **Figure 5.4**, Bird Street is identified as one of the road sections with the highest number of hits (probes) in Stellenbosch. From these four figures (**Figure 5.1** to **Figure 5.4**), Bird Street is identified as one of the road sections with the slowest movement and highest level of traffic and was thus selected as the study area.

5.3.2 Traffic Counts

Peak periods

Traffic counts were used to calculate the average AM and PM peak three-hour period for the network. The AM and PM peak three-hour periods were from 06:00 to 09:00 AM and from 15:00 to 18:00 PM respectively. The average AM and PM peak one-hour periods were then determined. The data of four intersections in the network was used to evaluate peak periods, the locations of which are illustrated by the green dots in **Figure 5.5**. The AM and PM peak one-hour periods of the four signalised intersections in the study area are: 07:00 to 08:00 for the AM period and 16:30 to 17:30 for the PM period.

Figure 5.5: AM and PM peak hour period calculation locations (Google Earth Pro, 2019)

Travel patterns

Vehicle movements along Bird Street are analysed per road section (Sections 1 to 3 previously specified). Analysing Bird Street per road section allowed a more detailed study which established a better understanding of vehicle movement activities within the network.

Traffic counts were used to calculate the percentage of vehicles entering, leaving or travelling through each road section (average of both directions) for the three sections respectively. The percentages and volumes (as indicated in brackets) entering, exiting and travelling through each road section, are indicated in **Table 5.1**.

Table 5.1: Percentages and volumes entering, exiting and through movement per section

Section	Intersections	AM			PM		
		Enter	Exit	Through	Enter	Exit	Through
1	Masitandane Road / Bird Street to R44 / Bird Street	8% (152)	12% (224)	80% (1514)	16% (268)	13% (220)	72% (1238)
2	R44 / Bird Street to Merriman Avenue / Bird Street	14% (245)	22% (405)	64% (1092)	28% (394)	22% (300)	50% (662)
3	Merriman Avenue / Bird Street to Bird Street / Dorp Street	14% (265)	28% (530)	58% (1050)	31% (549)	30% (542)	39% (673)

From **Table 5.1**, Section 2 was identified to potentially have more vehicles entering and exiting the road section from the surrounding areas than the surrounding areas can produce or attract. In line with this, two zones were identified, as illustrated in **Figure 5.6** below, to have potentially higher entering and exiting volumes than are actually generated in the zones themselves. Further investigation was done in order to compare the production/attraction volumes of the two zones with the volumes currently entering/exiting the network (Section 2) from/to the two zones. For comparison purposes, Section 2 was subdivided into two road sections (Sections 2a and 2b), as illustrated in **Figure 5.6**.

Figure 5.6: Zones 1 and 2 and road Sections 2a and 2b (Google Earth Pro, 2019)

The number of trips potentially produced/attracted in the AM and PM peak hours, for the two zones respectively, were calculated and compared with the number of trips entering and exiting Bird Street from/to each of the two zones. The number of trips produced/attracted by each zone were calculated by analysing the land use data, obtained from the study area information collection, and by applying the recommended trip generation rates for different types of land uses, as stated by South African DOT (1995). In order to cater for the worst-case scenario, it was assumed that all the vehicles entering/exiting each zone, do so via Bird Street. It was also assumed that Section 2a serves Zone 1 and Section 2b serves Zone 2. The results of the number of trips produced/attracted per zone vs the number of vehicles entering/exiting each road section are indicated in **Table 5.2**. Productions are compared with trips entering Bird Street, and attractions are compared with trips exiting Bird Street.

Table 5.2: Number of vehicles produced/attracted per zone vs entering/exiting per section

Zone / (Section)	AM				PM			
	Produced per zone	Enter*	Attracted per zone	Exit**	Produced per zone	Enter*	Attracted per zone	Exit**
1 / (2a)	146	76	292	232	234	329	121	123
2 / (2b)	401	108	169	134	169	114	401	162

* Vehicles entering the road section from the zone

** Vehicles exiting the road section to the zone

From **Table 5.2** it is clear that during the morning peak hour more trips are produced and attracted to Zone 1 and 2 than enter or exit Bird Street respectively. Other trips to and from Zone 1 and 2 are therefore assumed to be routed along the adjacent roads. In the afternoon peak hour, Section 2a was identified to have more vehicles entering Bird Street (329 vehicles > 234 vehicles) and exiting Bird Street (123 vehicles > 121 vehicles) from and to Zone 1 than what this zone can produce or attract. Since more vehicle activities were identified entering and exiting Zone 1 than what the area can potentially produce or attract, it is suspected that additional vehicles are using the roads around Zone 1 and 2 to avoid Bird Street by rat-running through the area. From observations, it was concluded that this assumption was correct, however, no data was collected for authentication. Future research is recommended for confirmation of the conclusion.

From the traffic counts, it was concluded that during the AM peak period, the direction of the main traffic stream is inbound (in the direction of Stellenbosch central) and during the PM peak period, the main traffic stream is outbound (in the opposite direction of Stellenbosch central).

5.4 Conclusion

In **Chapter 5**, three data sources were used to identify and select the study area, worst condition period and travel patterns within the network. However, it was concluded that the AM and PM worst condition period was between 07:00 and 08:00 AM and 16:30 and 17:30 PM. In Section 2 a problem area was identified with more vehicles entering and exiting the road section than what Zone 1 could produce or attract, which signifies rat-running activity.

CHAPTER 6 : TRAFFIC VOLUMES ANALYSIS

6.1 Background

Since traffic volume data was received from many different sources at different time periods it needs to be calibrated to a certain time period in order to increase the accuracy. In **Chapter 6**, the analysis and calibration procedure of traffic volumes will be discussed. The data from two sources (traffic counts and signal plans) was used for the analysis procedure, discussed in **Chapter 6**.

6.2 Objectives

The following objective will be accomplished by analysing the traffic volumes:

- Increase accuracy of the data.

6.3 Calibration of Data

By analysing the data gathered from different data sources, variance between the sources was observed. The variance was identified by comparing data from different sources, available at the same intersection and conducted in the same year group, as well as data conducted from different year groups.

Two methods were used to improve the realistic representation of the traffic volumes used for the research to ensure that all the data from different sources were comparable to each other. The two methods will be discussed in **Section 6.3.1** and **Section 6.3.2** respectively.

6.3.1 Traffic Growth Rate per Annum

The traffic volumes of all the intersections in the network were calibrated to the same time: May 2019. Traffic volumes conducted before the start of 2018 were increased using the Compound Annual Growth Rate (CAGR) formula (**Equation 6-1**), as seen below.

$$A = P \times \left(1 + \frac{R}{100}\right)^{N} \qquad \text{Equation 6-1}$$

Where: A = End volume at year N (vehicles)
P = Initial volume (vehicles)
R = Growth rate (%)
N = Number of years

From historical data at the same intersection, the overall annual traffic growth rate for the AM and PM peak hour period were calculated. The results can be seen in **Table 6.1** below.

Table 6.1: Traffic volume growth rate per annum

Peak period	Annual growth rate per year (%)
AM	4
PM	5

6.3.2 Conducting Period Adjustment

The data sets available at the same intersection and within the same peak hour period were compared to each other in order to identify how they correlate. Since the time period at which traffic counts were conducted plays an important role in the accuracy of the data, it had to be calibrated to a referencing data set to ensure that all the data are consistent. The referencing data source to which the data of other sources were calibrated, was the Nick Venter Traffic Surveying counts, conducting on the 26/09/2018 and 10/10/2018.

For the study, a data Conducting Period Adjustment Factor (CPAF) was calculated by using **Equation 6-2** below. If counts were collected outside of term time, then CPAF was applied.

$$CPAF = 1 + \frac{(Referencing\ data\ source - Other\ data\ source)}{Other\ data\ source} \qquad \text{Equation 6-2}$$

The CPAF results, which were calculated and used to calibrate the Stellenbosch Municipality data, can be seen in **Table 6.2**.

Table 6.2: Conducting period adjustment rate

Peak period	Conducting period adjustment rate (%)
AM	36.8
PM	18.7

6.3.3 Assumptions and Limitations

An assumption was made that the traffic growth rate and conducting period adjustment rate were applicable to all the necessary data sources.

6.4 Vehicle Composition

Different vehicle classes were identified in the network, which were categorised as one of three main categories; light vehicle (light vehicles + taxis or minibus-taxis), busses and heavy vehicles. The category heavy contains all the vehicles which can carry a load of more than 3500 kg. The rest which do not include bus or heavy vehicles were classified as light. In order to improve the accuracy of the microscopic traffic model component and to increase the realistic representation of the vehicle classes in the transport network (in the study area), the vehicle composition for the major vehicle input points were calculated.

Traffic volumes obtained from the data source were received per vehicle class at the locations of 21 vehicle input points, as illustrated in **Figure 6.1**. The volumes will be used to calculate the vehicle composition at the respective locations.

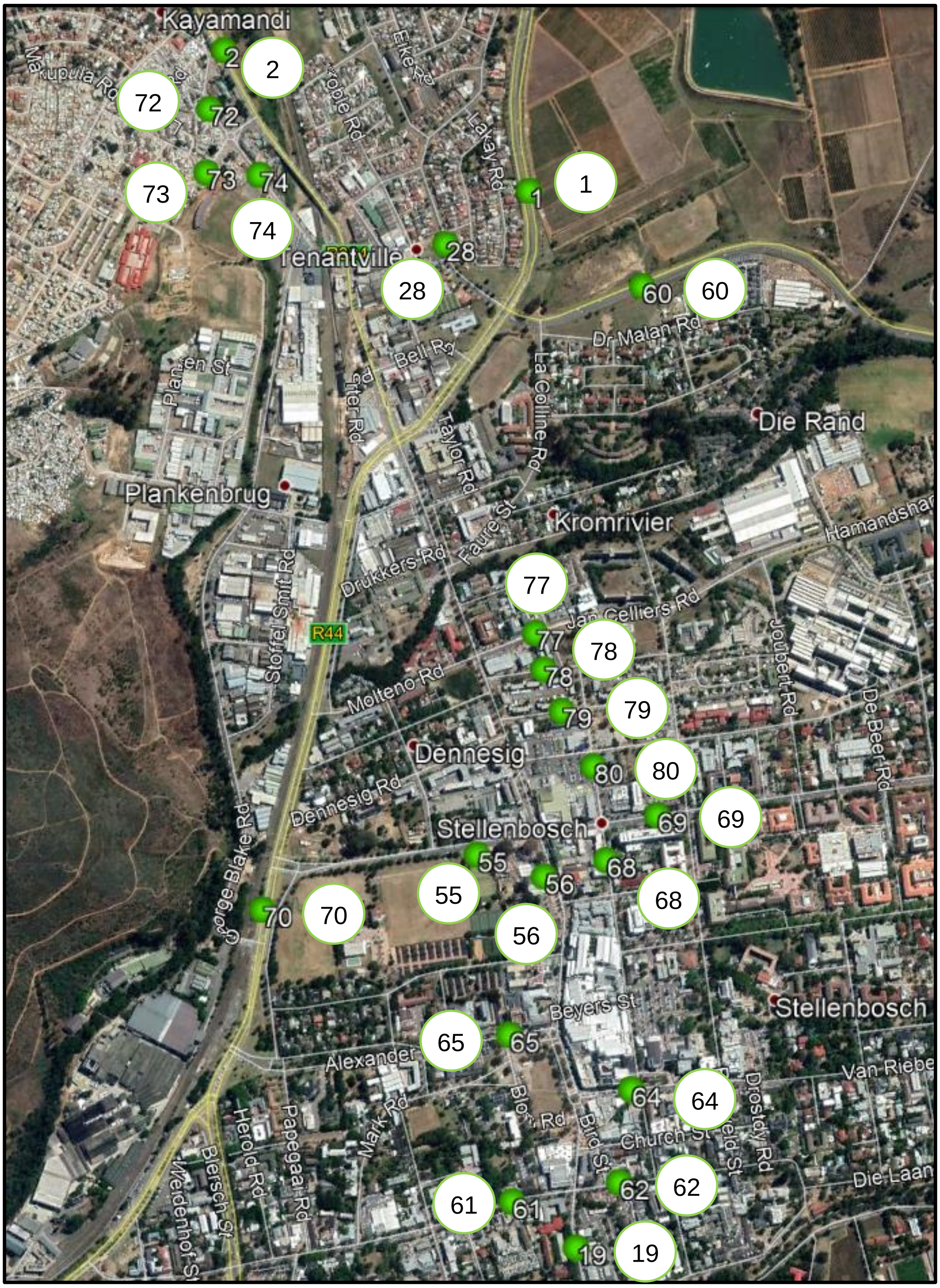

Figure 6.1: Vehicle composition - input points (Google Earth Pro, 2019)

The vehicle composition results for the AM and PM peak hour period, for each of the 21 vehicle input points, can be seen in **Table 6.3**.

Table 6.3: Vehicle composition results

Vehicle input point	AM			PM		
	Light + Taxi (%)	Bus (%)	Heavy (%)	Light + Taxi (%)	Bus (%)	Heavy (%)
1	97.9	0.0	2.1	97.9	0.0	2.1
2	97.9	0.0	2.1	97.0	0.0	3.0
19	99.0	0.0	1.0	99.6	0.0	0.4
28	99.3	0.0	0.7	98.6	0.0	1.4
55	100.0	0.0	0.0	100.0	0.0	0.0
56	100.0	0.0	0.0	100.0	0.0	0.0
60	97.5	0.3	2.2	99.1	0.0	0.9
61	98.9	0.2	0.9	100.0	0.0	0.0
62	99.1	0.0	0.9	99.3	0.7	0.0
64	97.8	0.3	1.9	99.2	0.0	0.8
65	99.1	0.0	0.9	99.7	0.3	0.0
68	98.3	0.0	1.7	98.9	0.0	1.1
69	97.3	0.0	2.7	98.7	0.0	1.3
70	96.3	0.1	3.6	97.1	0.0	2.9
72	98.0	0.0	2.0	97.3	1.4	1.4
73	98.5	1.0	0.5	95.1	0.8	4.1
74	98.2	0.0	1.8	98.7	0.2	1.1
77	98.6	0.0	1.4	98.8	0.0	1.2
78	100.0	0.0	0.0	100.0	0.0	0.0
79	100.0	0.0	0.0	100.0	0.0	0.0
80	99.5	0.0	0.5	99.5	0.0	0.5

6.5 Intersection Capacity

A road network can only accommodate a certain capacity; therefore, an indication needs to be developed to determine whether traffic volume growth is possible. The capacity of seven signalised intersection approach groups (group of left, straight and/or right turn approaches per directional approach) was calculated using **Equation 6-3** (van As and Joubert, 2002). The locations of the seven intersection approach groups are indicated by number 1, 2, 28, 60, 68, 69 and 80 in **Figure 6.1**.

$$Capacity = \frac{G \times S}{C} \qquad \text{Equation 6-3}$$

Where:

Where:	G	=	Effective green (seconds) ≈ (**Equation 6-4**)
	S	=	Saturation flow (vehicles/hour/lane)
	C	=	Cycle length (seconds)

$$G = G_r - L + Y_g \qquad \text{Equation 6-4}$$

Where:	G_r	=	Actual green (seconds)
	L	=	Starting lost time (seconds)
	Y_g	=	Amber (seconds)

In order to calculate the capacity, various types of information are needed. The actual green and amber time was established from the signal plans. The saturation flow rate and starting lost time values are standard values identified from the Traffic Flow Theory document (van As and Joubert, 2002). From the document, a starting lost time of 2 seconds was assumed and used. For Stellenbosch, the saturation flow rate was assumed to be 1800 pc/h/ln. The type of vehicle identified in the network does not only consist of passenger cars, therefore a factor was determined for each approach group to convert the pc/h/ln unit to veh/h/ln. **Equation 6-5** was used to calculation the factor for each approach group.

$$Factor = \frac{100}{\sum_i P_i \times PCU_i} \qquad \text{Equation 6-5}$$

Where:	P_i	=	Percentage of type i vehicles.
	PCU_i	=	PCU equivalent of type i vehicles.

For **Equation 6-5**, the P value per vehicle class (for each approach group), was obtained from the vehicle composition results, previously identified. The PCU per vehicle class were standard values identified from the Traffic Flow Theory document (van As and Joubert, 2002).

By using **Equation 6-3** to **Equation 6-5**, the total capacity of each of the seven signalised intersection approach groups were calculated. For the seven approach groups; left turn, through and right turn approaches were identified. In case of a protected right turn approach, the green time used for the calculation of the right turn approach capacity was assumed to be only the duration of the green period for the protected right turn. The assumption was made since there was observed that the approaching traffic in the AM and PM peak hour period only allows minimal vehicles that intend on turning right, to find a gap. Therefore, the assumption takes the worst case into account by assuming zero vehicles find a gap during the unprotected green phase.

For the study, the total number of vehicles per approach group (left + through + right) before calibration, after calibration and the calculated capacity results, can be seen in **Table 6.4**. From the results, it was identified that some of the intersections would not allow the traffic volume to grow according to anticipated traffic growth (highlighted in red), since the approach group already operates near full capacity. Therefore, for these specific intersections, the maximum volume of either the approach group capacity (highlighted in green) or the volume before calibration (highlighted in blue) was used as the vehicle input volume in other components of the study (microscopic traffic modelling component).

Table 6.4: Intersection approach group capacity vs volume before and after calibration

Vehicle input point	AM			PM		
	Capacity	Volume before calibration	Volume after calibration	Capacity	Volume before calibration	Volume after calibration
1	1417	1409	1928	1043	1310	1555
2	1587	824	1127	1121	331	393
28	562	410	561	454	417	495
60	553	639	760	885	1148	1418
68	590	242	331	692	355	421
69	1987	301	412	1817	713	846
80	1194	375	513	1393	411	488

6.6 Conclusion

In **Chapter 6**, the consistency and accuracy of the traffic volume data, collected from different data sources, was reviewed. Variation of the data at the same intersection was identified. Therefore, the data used for the study was calibrated to a referencing data source. Since the data was calibrated, the growth boundary was determined by calculating the capacity for certain signalised intersection approach groups. It was identified that some of the approach groups operate near capacity, which only allowed a certain percentage of growth during the calibration process. From the data counts, the vehicle composition was determined for each of the major input points.

For the study, all the results and conclusions calculated and identified in **Chapter 6**, will be incorporated in other components of the study, as described by the research design.

CHAPTER 7 : FUNCTIONAL CLASSIFICATION

7.1 Background

The classification techniques identified in the literature study were used to classify Bird Street for two conditions, namely the current designed condition and the current operating condition. Bird Street was analysed and classified per road section (Sections 1 to 3). The TRH 26 manual (COTO, 2012b) was used for the classification of roads in the Stellenbosch Roads Master Plan (VELAVKE and Jeffares & Green, 2012) and so the TRH 26 manual is used as the referencing source for the functional classification of Bird Street in this research.

7.2 Objectives

The following objectives will be accomplished by applying the functional classification techniques on Bird Street:

- Establish the current functional classification (road class) of Bird Street for the current designed condition as well as the current operating condition.
- Serve as referencing point for the development of different scenarios.

7.3 Current Designed Condition

The three sub-sections were classified according to the functional classification system, set out by the TRH 26 manual (COTO, 2012b). Study area information and results from the data analysis were used to classify Bird Street according to the requirements and typical features criteria identified per road class, as set out by the manual. According to the TRH 26 manual, requirements are different to typical features: requirements are described as compulsory provisions necessary to ensure the road performs its function, while typical features are described as desirable characteristics per road class which are not mandatory but are listed for information only. The requirements and typical features used to classify each road sub-section are summarised in **Table B.1** in **Appendix B**.

The functional classification results for each of the three sections, based on the classification process according to the different requirements and typical features, can be seen below:

7.3.1 Section 1

Table 7.1: Requirements and typical features results - Section 1

		Observed	Notes	Road Class
REQUIREMENTS	**Intersection spacing (m)**		See **Table 7.2*** and **Table 7.3***	4
	Access to property	Yes	Various accesses	4 or 5
	Parking	Yes	Few perpendicular parking's	4
TYPICAL FEATURES	**Speed (km/h)**	60 km/h		4
	Intersection control type	Traffic signal and Priority	See **Table 7.4**	4
	Typical cross section	Two lane undivided and kerbed		3 or 4
	Roadway / lane width (m)	3.3 m - 3.5 m lanes		3 or 4
	Road reserve width (m)	20 m – 30 m		4
	Public transport stops and ped. xing.	No		-
	Pedestrian footways (constructed)	Yes	Sidewalk	3 or 4
	Cycle lanes	No		-
	Traffic Calming	No		-

* For road Sections 1 to 3, the road class is determined based on the smallest intersection spacing according to the spacing requirement. However, if the intersection spacing is less than the minimum spacing requirement for all road classes (150 m) but one of the spacings agree to the requirement of a specific road class, the specific road class will be assigned to the road section.

Table 7.2: Intersection spacing results - Section 1

Intersection spacing (m)		
Bird St/Masitandane Rd - Bird St/Bell Rd	607 m	
Bird St/Bell Rd - Bird St/R44	156 m	> 150 m ≈ Class 4

Table 7.3: Access to garage spacing results - Section 1

Access to Garage (m)		
Bird St/Masitandane Rd - Bird St/Caltex	536 m	> 150 m ≈ Class 4
Bird St/Caltex - Bird St/Bell Rd	35 m	Class 5

Table 7.4: Intersection type and control type results - Section 1

Intersection	Intersection control type	Intersection type
Bird St/Masitandane Rd	Signalised	Cross-type intersection
Bird St/Bell Rd	Priority	Cross-type intersection

7.3.2 Section 2

Table 7.5: Requirements and typical features results - Section 2

		Observed	Notes	Road Class
REQUIREMENTS	**Intersection spacing (m)**		See **Table 7.6** and **Table 7.7**	4
	Access to property	Yes	Various accesses	4
	Parking	Yes	Various on - street parking's	4
TYPICAL FEATURES	**Speed (km/h)**	60 km/h		4
	Intersection control type	Traffic signal and Priority	See **Table 7.8**	4
	Typical cross section	Two lane undivided and kerbed		3 or 4
	Roadway / lane width (m)	3.3 m – 3.5 m lanes		3 or 4
	Road reserve width (m)	20 m – 30 m		4
	Public transport stops and ped. xing.	Public transport stops - No Pedestrian crossing - Yes		4
	Pedestrian footways (constructed)	Yes	Sidewalk	3 or 4
	Cycle lanes	No		-
	Traffic Calming	No		-

Table 7.6: Intersection spacing results - Section 2

Intersection spacing (m)		
Bird St/R44 - Bird St/Papegaairand Rd	122 m	Class 5
Bird St/Papegaairand Rd - Bird St/Mount Albert Rd	34 m	
Bird St/Mount Albert Rd - Bird St/Drukkers Rd	98 m	
Bird St/Drukkers Rd - Bird St/Kromrivier Rd	31 m	
Bird St/Kromrivier Rd - Bird St/Langenhoven Rd	89 m	
Bird St/Langenhoven Rd - Bird St/Molteno Rd/Jan Celliers Rd	110 m	
Bird St/Molteno Rd/Jan Celliers Rd - Bird St/Muller Rd	51 m	
Bird St/Muller Rd - Bird St/Paul Kruger Rd	32 m	
Bird St/Paul Kruger Rd - Bird St/Borcherd Rd	63 m	
Bird St/Borcherd Rd - Bird St/Dennesig Rd	34 m	
Bird St/Dennesig Rd - Bird St/Merriman Ave	213 m	> 150 m ≈ Class 4

Table 7.7: Access to garage spacing results - Section 2

Access to Garage (m)		
Bird St/Kromrivier Rd - Bird St/Engen	62 m	Class 5
Bird St/Engen - Bird St/Molteno Rd/Jan Celliers Rd	77 m	
Bird St/Dennesig Rd - Bird St/Caltex	174 m	> 150 m ≈ Class 4
Bird St/Caltex - Bird St/Merriman Ave	27 m	Class 5

Table 7.8: Intersection type and control type results - Section 2

Intersection	Intersection control type	Intersection type
Bird St/R44	Signalised	Cross-type intersection
Bird St/Papegaairand Rd	Priority	T-type junction
Bird St/Mount Albert Rd	Priority	T-type junction
Bird St/Drukkers Rd	Priority	T-type junction
Bird St/Kromrivier Rd	Priority	T-type junction
Bird St/Langenhoven Rd	Priority	T-type junction
Bird St/Molteno Rd/Jan Celliers Rd	Signalised	Cross-type intersection
Bird St/Muller Rd	Priority	T-type junction
Bird St/Paul Kruger Rd	Priority	T-type junction
Bird St/Borcherd Rd	Priority	T-type junction
Bird St/Dennesig Rd	Priority	T-type junction

7.3.3 Section 3

Table 7.9: Requirements and typical features results - Section 3

		Observed	Notes	Road Class
REQUIREMENTS	**Intersection spacing (m)**		See **Table 7.10**	4
	Access to property	Yes	Few accesses	4
	Parking	Yes	Various on-street parking's	4
TYPICAL FEATURES	**Speed (km/h)**	60 km/h		4
	Intersection control type	Traffic signal, Priority and Roundabout	See **Table 7.11**	4
	Typical cross section	Two lane mostly divided and kerbed		3 or 4
	Roadway / lane width (m)	3.3 m - 3.5 m lanes		3 or 4
	Road reserve width (m)	20 m - 30 m		4
	Public transport stops and ped. xing.	Public transport stops - No Pedestrian crossing - Yes		4
	Pedestrian footways (constructed)	Yes	Sidewalk	3 or 4
	Cycle lanes	No		-
	Traffic Calming	No		-

Table 7.10: Intersection spacing results - Section 3

Intersection spacing (m)		
Bird St/Merriman Ave - Bird St/Crozier Rd	152 m	> 150 m ≈ Class 4
Bird St/Crozier Rd - Bird St/Du Toit St	113 m	Class 5
Bird St/Du Toit St - Bird St/Alexander St	151 m	> 150 m ≈ Class 4
Bird St/Alexander St - Bird St/Plein St	121 m	Class 5
Bird St/Plein St - Bird St/Church St	99 m	
Bird St/Church St - Bird St/Dorp St	81 m	

Table 7.11: Intersection type and control type results - Section 3

Intersection	Intersection control type	Intersection type
Bird St/Merriman Ave	Signalised	Cross-type intersection
Bird St/Crozier Rd	Priority	T-type junction
Bird St/Du Toit St	Priority	T-type junction
Bird St/Alexander St	Roundabout	Roundabout
Bird St/Plein St	Roundabout	Roundabout
Bird St/Church St	Priority	Cross-type intersection
Bird St/Dorp St	Priority	T-type junction

From **Table 7.1**, **Table 7.5** and **Table 7.9**, it can be seen that Sections 1 to 3 were designed as a Class 4 road, based on the **requirements** and **important** **typical features** road class results. Each of the three sections are located within a commercial area, therefore, Sections 1 to 3 were classified as a Class 4a road.

7.4 Current Operating Condition

For the current operating condition, the three sections were classified according to the functional road classification criteria, set out by the TRH 26 manual (COTO, 2012b). The criteria consists out of three parts (trip generator, reach of connectivity and the travel stage), which distinguish between different road classes. With reference to **Table 5.1** together with local knowledge, Sections 1 and 2 were identified to predominantly carry through traffic and Section 3 was identified to have a mixture of through traffic and local traveling (short connections).

From **Table 5.1**, Sections 1, 2 and 3 were identified also accommodating access activities. According to the literature, if a road section complies with any of the functional classification criteria for mobility roads, it should be classified as a mobility road. Therefore, Sections 1 and 2 were classified as a lower order mobility road (Class 3 – minor arterial).

In Section 3; high pedestrian movement activities, parking areas and high amount of traffic were identified. As stated by the literature, designing the road section as an access/activity road, will increase the safety of the pedestrians in the area. Since Section 3 was identified with a mixture of through traffic and local traveling, high pedestrian movement activities and a few parking areas, it was classified as a higher order activity road (Class 4). Section 3 is located in a commercial area; therefore, it was classified as a Class 4a road.

7.5 Conclusion

In **Chapter 7**, study area information and the analysed vehicle movement data were used to classify each of the three subsections, for the two conditions (current design and current operating conditions). For the current designed condition; it was concluded that Sections 1, 2 and 3 respectively could be classified as a Class 4a road. However, for the current operating condition, it was concluded that Sections 1 and 2 should be classified as a Class 3 road and Section 3 as a Class 4a road.

This discrepancy in the classification of the design and operating condition highlights the traffic progression problem along Bird Street. The function and operation of Sections 1 and 2 are mobility and for Section 3, activity, but Sections 1 to 3 are designed for access. According to the literature, roads must be classified exclusively on the basis of their function (COTO, 2012b). The classification results of the three sections (for each of the two conditions) will be used in the scenario development component of the study.

CHAPTER 8 : SCENARIO DEVELOPMENT

8.1 Background

Bird Street was classified based on two conditions: current design and current operating condition. Based on the classification results of the two conditions, various scenarios are developed representing different road design techniques identified by the literature, particularly the TRH 26 manual (COTO, 2012b) and the TMH 16 manual (COTO, 2014). The scenarios will be simulated by constructing a microscopic traffic model and the results obtained from the model will be used to identify the impact of different road designs implemented in the network. Thereby, the impact of outdated functional classification and access management and reclassifying roads according to its function will be determined.

Firstly, six scenario categories are developed (Scenario categories A to F). Two of these six categories (Scenario categories A and F) are based on the current design (Class 4a) and the remaining four categories (Scenario categories B, C, D and E) are based on the current operating condition classification (Sections 1 and 2 – Class 3 and Section 3 – Class 4a). The four current operating condition scenario categories were developed by redesigning the road network. Each of the four scenario categories represent a different design technique. The design techniques were developed in the context of the functional classification system, and by taking identified limitations into consideration.

For each scenario category, four scenarios were developed according to the outline, illustrated by **Figure 8.1**. There are two peak period groups (highlighted by the dotted line square) and for each peak period group there are two scenarios. The blue square highlights the two scenarios for the AM peak period group and the red square highlights the two scenarios for the PM peak period group.

The two scenarios in the specific peak period group have the same vehicle inputs and turning volumes. Each of the four scenarios have different signal plans and the current signal plans refer to the signal plans currently implemented in the study area, as in 2019.

Since there are four scenarios for each scenario category, a total of 24 scenarios are generated for the study.

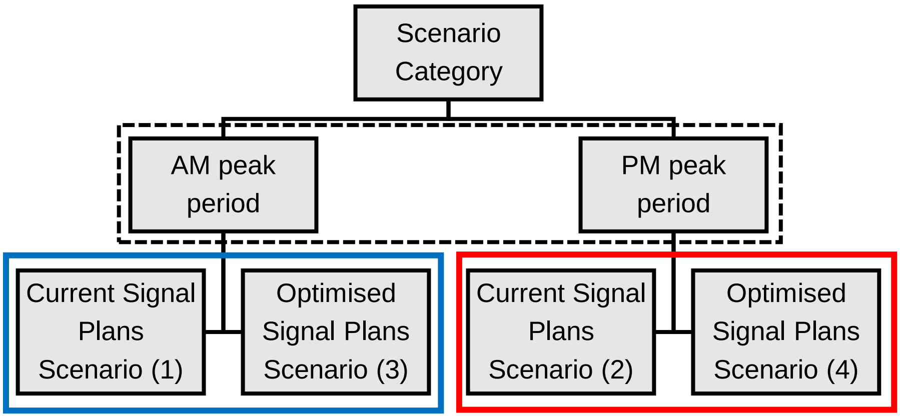

Figure 8.1: Scenario category outline

8.2 Objectives

The following objectives will be accomplished by developing different scenarios for the research study:

- Identify the impact of pedestrian activities in the network, not managed effectively, with regards to the functional classification system.
- Identify whether optimal signal plans are currently implemented at signalised intersections in the network.
- Identify the impact of the functional classification of the road network in the study area, based on the following two conditions:
    - Unrealistic condition strictly designed according to the literature.
    - Realistic conditions designed according to the literature.
- Serve as design for the scenarios simulated by the microscopic traffic model.

8.3 Assumptions and Limitations

8.3.1 Assumptions

A few assumptions were made for this component of the study. The assumptions made for **Chapter 8**, will be discussed in each of the applicable subsections (**Section 8.4.2** - **8.4.7**). It was assumed that for Scenario categories B, C, D and E, jaywalking activities identified within the network will be controlled and managed by measures which are not in the scope of the study. Therefore, jaywalking activities were excluded from Scenario categories B, C, D and E. Originally, pedestrians crossing Bird Street at the signalised intersections can cross the road during the protected pedestrian green phase. From the pedestrian volumes at the signalised intersection close to the two jaywalking areas, it was identified that limited pedestrians cross

Bird Street during the allocated green time. Therefore, if jaywalking volumes were transferred to the closest signalised intersection, they could be accommodated by the allocated green time. A sensitivity analysis was not done, however the pedestrian movements that were assumed at the remaining allocated pedestrian crossings are relatively high and therefore the results are conservative. It was not the main objective of this study to investigate the influence of jaywalking on traffic progression (it was to evaluate road classification factors) and therefore future research is recommended to control and manage jaywalking activities within the area.

8.3.2 Limitations

The following limitations were identified for the scenario development component of the study:

- Legislation set out by the government, in terms of the right to land access.
- Constraints (requirements and typical features) set out by the literature for redesigning a road segment according to the functional classification system.
- Budget constraints.

8.4 Scenarios

8.4.1 Scenario Categories A to F Outline

The first and third scenarios of each category (as indicated in **Figure 8.1**) are based on the conditions identified in the AM peak hour period and the second and fourth scenarios of each category are based on the conditions identified in the PM peak hour period, as in 2019. For the first and second scenarios, current signal plans were implemented for the signalised intersections within the network and for the third and fourth scenarios the current signal plans were optimised based on the redesigned network conditions for the specific scenario category. An illustration of the network, designed for each category, can be seen in **Appendix C**.

8.4.2 Category A (Scenarios 1 to 4): Current Condition

Scenarios 1 to 4 represent the current design condition which were generated to serve as reference scenarios to which Scenarios 5 to 24 are compared. For the current design condition, as operating in 2019, the current signal plans were optimised in order to identify whether the signal plans currently implemented within the network, function optimally.

8.4.3 Category B (Scenarios 5 to 8): Redesigned Condition, Unrealistic

8.4.3.1 Background

Scenarios 5 to 8 were developed to identify the impact of classifying roads strictly according to the functional classification system. For the redesigned network of Scenario category B, the current signal plans were optimised.

8.4.3.2 Design

The three road sections of the study area were redesigned for Scenario category B based on the classification of each road section (current operating condition). It was redesigned strictly according to the functional classification system in line with the standards identified by the literature. Changes were made to the intersection and access spacing, auxiliary lanes, parking and pedestrian crossings.

The standards (requirements) specified by the literature, can be seen in **Appendix C** (**Section C7**). The layout of each of the redesigned road sections for Scenario category B, are illustrated by **Figure 8.2** to **Figure 8.4** below. The layout of the entire redesigned network for Scenario category B, can be seen in **Appendix C** (**Section C2**).

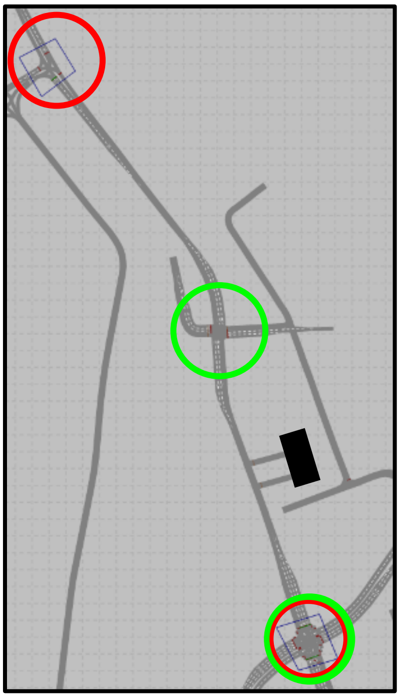

Figure 8.2: Scenarios 5 to 8 - Section 1

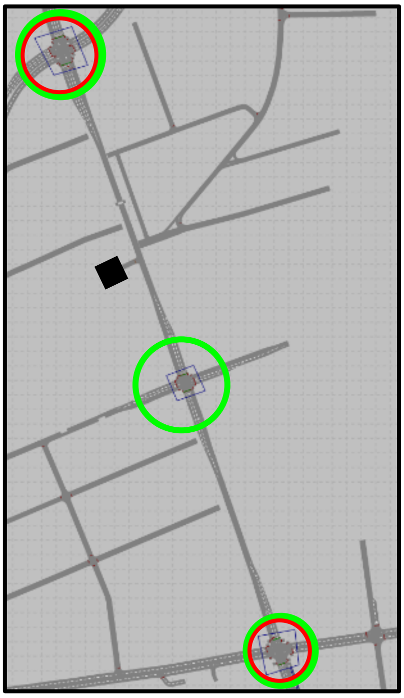

Figure 8.3: Scenarios 5 to 8 - Section 2

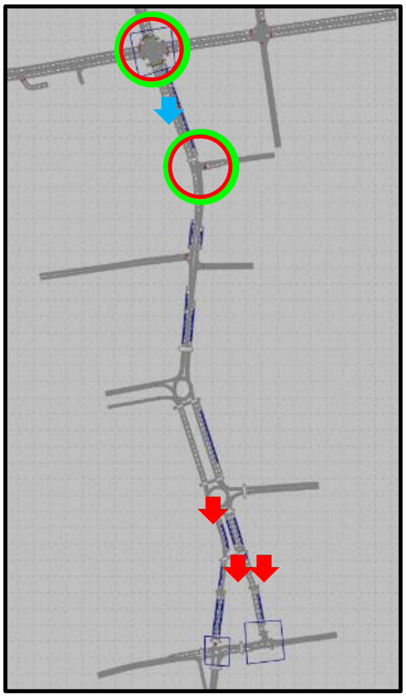

Figure 8.4: Scenarios 5 to 8 - Section 3

The following changes were made to Sections 1 to 3 of Scenario category B:

Intersection and access spacing:

For Section 1, all accesses and intersections, excluding the accesses to the service station (indicated by a black square block in **Figure 8.2**), which do not meet the spacing requirements set out by the literature, were removed from the network. A four-way intersection was added to the network in Section 1, located in the middle of the road section to allow vehicles access to Bird Street. The four-way intersection was included in the required spacing distances.

In Section 2, all accesses and intersections, excluding the access to Group1 Nissan (indicated by a black square block in **Figure 8.3**) and the signalised intersection in the middle of Section 2 were removed from the network, since they did not meet the spacing requirements set out by the literature. The signalised intersection located in the middle of Section 2 was identified to be just outside the required measurements, however, it was also identified as a major intersection accommodating high volumes. Therefore, it was decided to retain the intersection within the network of Scenario category B. The two service stations located in Section 2 were removed from the network, since they did not meet the specified spacing requirements.

In Section 3, one access and three intersections were removed from the network, since they did not meet the spacing requirements set out by the literature. The intersections and access which were removed are illustrated by the blue (access) and red (intersections) arrows in **Figure 8.4**.

Auxiliary lanes:

In Sections 1 to 3, the length of the existing auxiliary lanes as well as the application thereof were reviewed. Auxiliary lanes which do not satisfy the required length according to the requirements identified for the specific road class were identified. By analysing the turning volumes at each intersection in Sections 1 to 3, the lack of auxiliary lanes was also identified at various intersections. The length of certain auxiliary lanes was adjusted at locations indicated by red circles in **Figure 8.2** to **Figure 8.4**. At certain intersections, indicated by green circles in **Figure 8.2** to **Figure 8.4**, auxiliary lanes were added to the intersection in line with the requirements to increase the capacity thereof.

Parking:

Since Sections 1 and 2 were classified as a Class U3 road according to the functional classification system, the application of existing on-street parking areas was reviewed. However, on street parking areas were removed from the network in Sections 1 and 2, since it was not allowed on Class U3 roads, as stated by the literature.

According to the literature, on-street parking areas may be implemented in roads classified as Class U4 roads, if conditions allow. However, since Section 3 was classified as a Class U4a road, it was concluded that due to the conditions identified for Section 3, on-street parking areas were allowed. One of the conditions motivated as ideal, was the identification of high pedestrian activities in the area. Parking areas will cause drivers to be more cautious in the area, which directly affect the operating speed (decrease the speed), therefore a safer environment will be created.

Since there was conclude that the conditions in Section 3 allow on-street parking areas, the existing parking areas remain the same.

Pedestrian crossings:

In Sections 1 to 3, pedestrian crossings and jaywalking activity areas were identified. There was observed, from previously generated data that the locations of the existing pedestrian crossings were in line with the requirements. However, the width of the pedestrian crossings at the R44/Bird Street intersection and the Merriman Ave/Bird Street intersection was increased to 3m, to allow the pedestrian demand to cross the intersection within the given green time period. Jaywalking activities were ignored for Scenario category B, due to the assumption made for Scenario categories B, C, D and E.

Assumptions:

There was assumed, since various routes or properties were denied access to the specific road section, the vehicle volumes were transferred to the nearest intersection in order to gain access to Bird Street. It was assumed that the number of vehicles entering each of the two service stations, which were removed from Section 2, were the same as the number of vehicles exiting each service stations. Therefore, the volumes entering and exiting Bird Street from/to the two service stations, cancelled out and were ignored. The volumes were ignored since the service stations only gain access from Bird Street; therefore, the volumes could not be transferred to the nearest intersection.

8.4.4 Category C (Scenarios 9 to 12): Redesigned Condition, Realistic 1

8.4.4.1 Background

Scenarios 9 to 12 were designed according to the functional classification system conditions (identified for the road classes of the three road sections) with a more realistic application of accesses to properties and streets which currently have access.

Scenarios 9 to 12 were designed according to a left-in, left-out access managed concept (marginal intersection) in order to redesign Sections 1 to 3 according to the standards set out for the specific road class of each section. The concept was used to enhance the application of access to properties conditions in the study area, to be more realistic in the context of the literature. The scenarios were created to identify the impact of classifying roads according to the functional classification system, by redesigning each road section according to the marginal intersection concept. For the redesigned road network of Scenario category C, the current signal plans were optimised.

8.4.4.2 Design

The three road sections of the study area were redesigned for Scenario category C based on the classification of each road section (current operating condition). It was redesigned according to a marginal intersection concept in line with the standards identified by the literature. Changes were made to intersection and property accesses, auxiliary lanes, parking and pedestrian crossings.

The standards (requirements) specified by the literature, can be seen in **Appendix C** (**Section C7**). The layout of each of the redesigned road sections, are illustrated by **Figure 8.5** to **Figure 8.7** below. The layout of the entire redesigned network for Scenario category C, can be seen in **Appendix C** (**Section C3**).

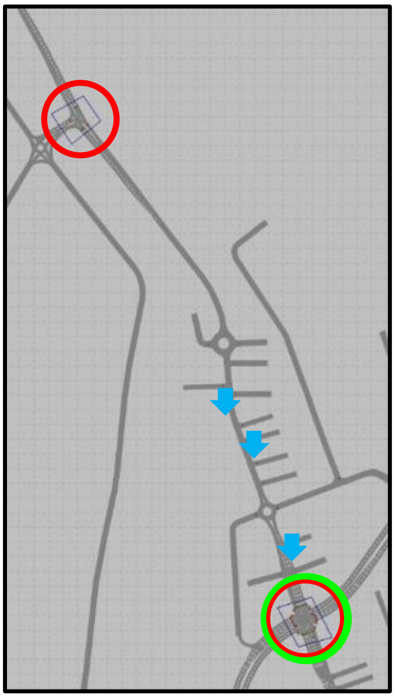

Figure 8.5: Scenarios 9 to 12 - Section 1

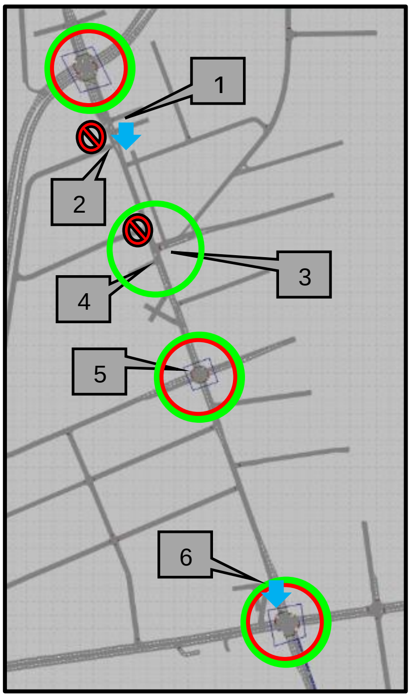

Figure 8.6: Scenarios 9 to 12 - Section 2

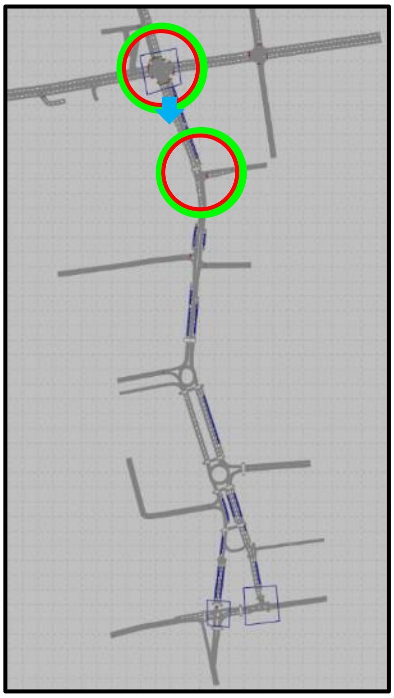

Figure 8.7: Scenarios 9 to 12 - Section 3

The following changes were made to Sections 1 to 3 of Scenario category C:

Intersection and property accesses:

In Sections 1 to 3, property access and intersection spacings were reviewed and redesigned according to the requirements set out for the specific road class for each road section, bearing in mind the access to property rights identified in the limitations section (**Section 8.3.2**). Properties which were identified with more than one access point per property, were limited to only one access point.

In Section 1, the number of access points per property was reviewed and three properties were limited to only one access point. The locations where the access points were removed from the current network are illustrated by the blue arrows in **Figure 8.5**. Access points to the remaining properties remained unchanged, but access was gained only by a left-in and left-out procedure. In order to accommodate restricted right-turn movements (crossing the approaching stream), to gain access to properties located in the road section, two roundabouts were added to the road section for access management purposes, as seen in **Figure 8.5**.

In Section 2, the number of access points per property was reviewed and two properties were limited to only one access point. The locations where the access points were removed from the current network are illustrated by the blue arrows in **Figure 8.6**. At the locations indicated by 1, 3, 4, 5 and 6 in **Figure 8.6**, property accesses and intersections were designed with all of the current turning movements, as in 2019. Properties or service stations with only one access remained the same as currently implemented.

The two intersections indicated by the red no-entry sign in **Figure 8.6**, were limited to a left-in movement to restrict rat run traffic, however, the intersection at the location indicated by 2 and with the red no-entry sign was identified to have an auxiliary lane accommodating right turning movements, therefore, a right-in movement was also allowed. The same two intersections were designed without access to Bird Street, since there was found that the intersections have accommodated much more vehicles entering Bird Street than what the area potentially can produced. However, these two intersections are not the only connection points between Zone 1 and Bird Street, therefore access to Section 2 was restricted at the respective intersections. The remaining intersections in Section 2 were designed with left-in left-out movements only.

In Section 3, the number of access points per property was reviewed and only one property was limited to one access point only. The location where the access point was removed from the current road network is illustrated by the blue arrow in **Figure 8.7**. It was observed that the remaining intersections were in line with the requirements and therefore they remained unchanged from the current condition scenario category.

The left-in left-out movements within the network of Scenario category C can be controlled by applying physical traffic calming measures, as identified by the literature.

Auxiliary lanes:

In Sections 1 to 3, the length of the existing auxiliary lanes as well as the application thereof were reviewed. Thereafter, auxiliary lanes which do not satisfy the required length according to the requirements identified for the specific road class, were identified. By analysing the turning volumes at each intersection in Sections 1 to 3, the lack of auxiliary lanes was also identified at various intersections. The length of certain auxiliary lanes was adjusted at locations indicated by red circles in **Figure 8.5** to **Figure 8.7**. At certain intersections, indicated by green circles in **Figure 8.5** to **Figure 8.7**, auxiliary lanes were added to the intersection in line with the requirements to increase the capacity thereof.

Parking:

For Scenario category C, the conditions remain the same as for Scenario category B, therefore, on-street parking areas were designed to be the same as for Scenario category B.

Pedestrian crossings:

For Scenario category C, the conditions remain the same as for Scenario category B, therefore, pedestrian crossings were designed to be the same. However, the two roundabouts in Section 1 generate the opportunity for possible pedestrian crossings, but the decision was made not to incorporate pedestrian crossings at the roundabouts since it did not meet the requirements set out by the literature for the specific road class.

Assumptions:

It was assumed that, since various routes were denied access, the vehicle volumes were transferred to the nearest intersection to gain access to Bird Street.

8.4.5 Category D (Scenarios 13 to 16): Redesigned Condition, Realistic 2

8.4.5.1 Background

Scenarios 13 to 16 were designed according to the functional classification system identified for the road classes of the three road sections, with a more realistic application of accesses to properties and streets, which currently have access. Scenarios 13 to 16 were designed according to a more realistic representation, for the same intention as for Scenarios 9 to 12.

For Scenarios 13 to 16, Sections 1 to 3 were redesigned according to an auxiliary-lane (right turn lane) access managed concept. Auxiliary/right turn lanes were used to accommodate right turning movements at various intersections and accesses within the network. The concept was used to enhance the application of access to properties conditions in the study area, to be more realistic in the context of the literature.

Scenarios 13 to 16 were created to identify the impact of classifying roads according to the functional classification system, by redesigning each road section according to the auxiliary/right turn lane concept. For the redesigned road network of Scenario category D, the current signal plans were optimised.

8.4.5.2 Design

The three road sections of the study area were redesigned for Scenario category D based on the classification of each road section (current operating condition). It was redesigned according to an auxiliary-lane (right turn lane) access managed concept in line with the standards identified by the literature. Changes were made to intersection and property accesses, auxiliary lanes, parking and pedestrian crossings.

The standards (requirements) specified by the literature, can be seen in **Appendix C** (**Section C7**). The layout of each of the redesigned road sections, are illustrated by **Figure 8.8** to **Figure 8.10** below. The layout of the entire redesigned network for Scenario category D, can be seen in **Appendix C** (**Section C4**).

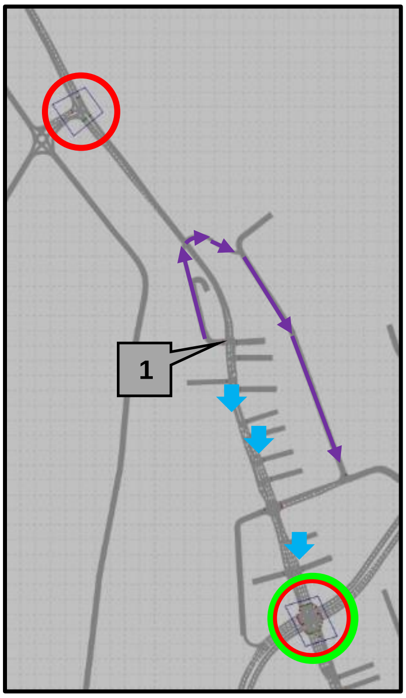

Figure 8.8: Scenarios 13 to 16 - Section 1

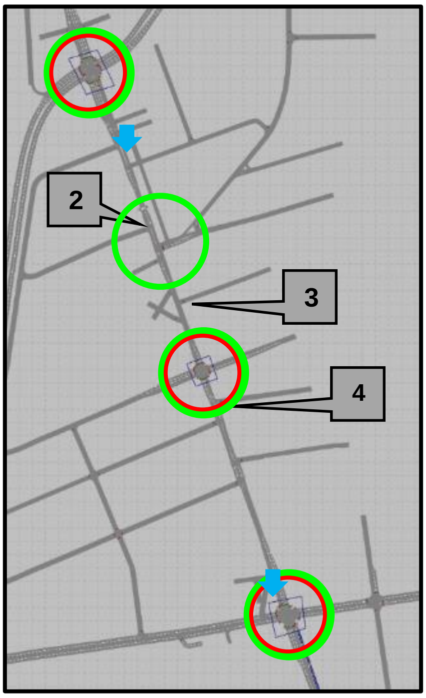

Figure 8.9: Scenarios 13 to 16 - Section 2

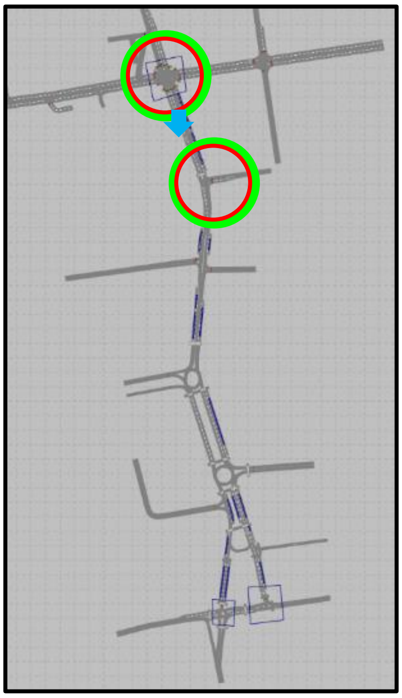

Figure 8.10: Scenarios 13 to 16 - Section 3

The following changes were made to Sections 1 to 3 of Scenario category D:

<u>Intersection and property accesses:</u>

In Sections 1 to 3, the number of access points per property were reviewed and the same modifications were made to Sections 1 to 3 of Scenario category D than the modifications made for Scenario category C. The locations where the access points were removed from the current road network, are illustrated by the blue arrows in **Figure 8.8** to **Figure 8.10**.

For Sections 1 to 3 of Scenario category D, each section was designed with the same intention as Scenario category C, but another concept was used. However, in Scenario category D, accesses to properties and intersections were designed according to the auxiliary/right turn lane concept. Property accesses and intersections controlled by the left-in left-out (marginal intersection) concept, as for Scenario category C, were replaced with the auxiliary/right turn lane concept with exceptions at four locations.

The locations of the four exceptions are indicated by 1 to 4 in **Figure 8.8** to **Figure 8.10**. At Location 1, right turn movements, in order to gain access to Section 1, were prohibited to exclude the conflicting point developed by intersecting the opposing flow. However, access to Section 1 can be gained by the route indicated with purple arrows in **Figure 8.8**. At Location 2, Scenario category C only allowed left-in movements, but, in Scenario category D an auxiliary lane was added to the intersection to allow right-in movements. At Locations 3 and 4, the intersection design concept (left-in left-out) from Scenario category C was used. The left-in left-out (marginal intersection) concept was implemented, since minimal businesses were identified in the area to which accesses were gained. However, it was identified that some of the businesses in the area have more than one access point to their property, therefore, the left-in left-out concept was motivated to control the accesses at Locations 3 and 4, which will not have a major effect on the businesses.

The left-in left-out movements within the network of Scenario category D can be controlled by applying physical traffic calming measures, as identified by the literature.

Auxiliary lanes:

The application of auxiliary lanes in Sections 1 to 3 of Scenario category D were investigated and designed with the same intention as Scenario category C. The locations indicated by the red and green circles, as seen in **Figure 8.8** to **Figure 8.10**, were designed to be the same as for Scenario category C. At certain intersections in Sections 1 and 2, short auxiliary/right turn lanes were added to accommodate the right turn movement at the priority-controlled intersections. The length of the sort auxiliary lanes were designed with a minimum length of 15 to 25 m, as stated by the TMH 16 Manual (2014).

Parking:

For Scenario category D, the conditions remain the same as for Scenario category C, therefore, on-street parking areas were designed to be the same as for Scenario category C.

Pedestrian crossings:

For Scenario category D, the conditions remain the same as for Scenario category C, therefore, pedestrian crossings were designed to be the same as for Scenario category C.

Assumptions:

There was assumed, since various routes have not gotten access to each road section, that the vehicle volumes were transferred to the nearest intersection to gain access to Bird Street.

8.4.6 Category E (Scenarios 17 to 20): Redesigned Condition, Realistic 3

8.4.6.1 Background

Scenario category E was designed to be the same as for Scenario category C, with one exception. The exception was motivated in order to identify the impact of changes made to a certain area within the network of Scenario category C. The changes made and the design thereof will be discussed below:

8.4.6.2 Design

For Scenario category E, modifications were made to the R44/Bird Street and Bell Road/Bird Street intersections. Certain access movements to Bird Street via the two intersections were removed, indicated by blue arrows in **Figure 8.11**, however, the volumes which required access to Bird Street, will be accommodated by the route, indicated by red arrows in the same figure.

Movement category 1, as indicated in **Figure 8.11**, was implemented to identify the impact of the Bell Road/Bird Street intersection on the main traffic stream (Bird Street). However, Movement category 2 was implemented to identify the impact of diverting the flow, which required access to Bird Street, via a slip lane to reduce the number of vehicles entering the Bell Road/Bird Street roundabout (intersection), from the South-East direction. The implementation of Movement category 2 was motivated by the literature, since the statement was made that roundabouts can only accommodate a certain capacity. Therefore, the impact of roundabouts located in a Class 3 road, will be determined.

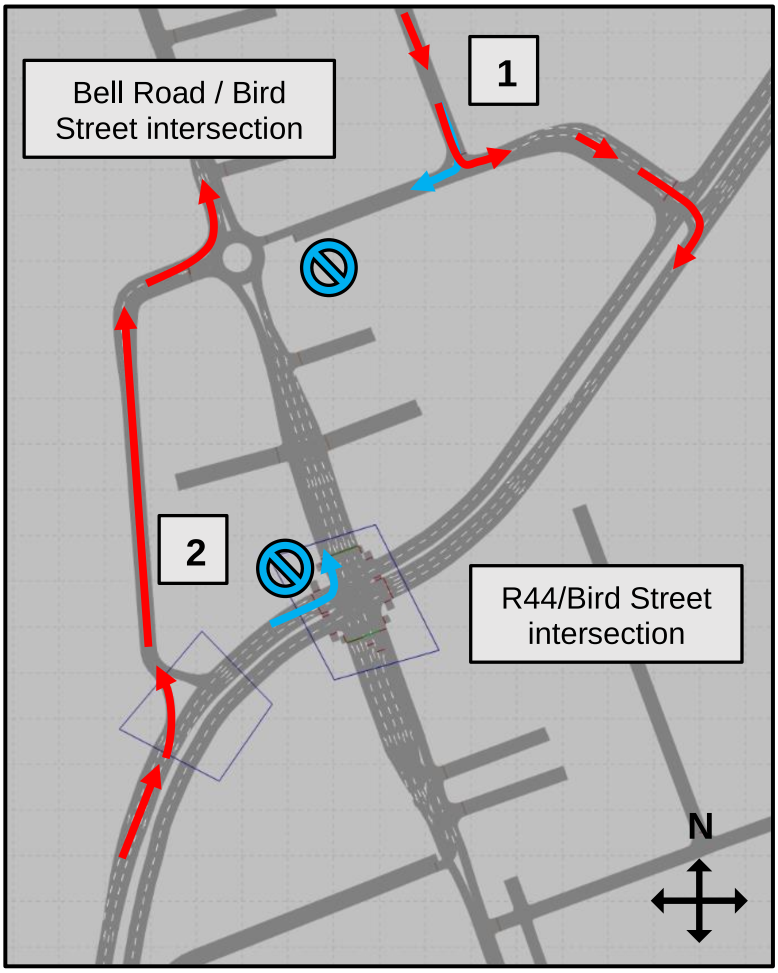

Figure 8.11: Scenario category E modifications

8.4.7 Category F (Scenarios 21 to 24): Current Condition, Without Jaywalking

8.4.7.1 Background

Scenarios 21 to 24 represent the current design condition (without jaywalking activities). These scenarios were created to identify the impact of jaywalking activities on the traffic operations of the network. By comparing Scenarios 21 to 24 with Scenarios 1 to 4, the impact of jaywalking activities will be determined.

8.4.7.2 Design

The only change in the design of the road network for Scenario category F, with regards to Scenario category A, was the exclusion of the two jaywalking areas. Identified jaywalking areas were removed from the current condition at the two locations indicated with red rectangles, as illustrated in **Figure 8.12** to **Figure 8.14** below. The existing pedestrian crossings in the network remained the same, since it was in line with the specifications stated by the literature.

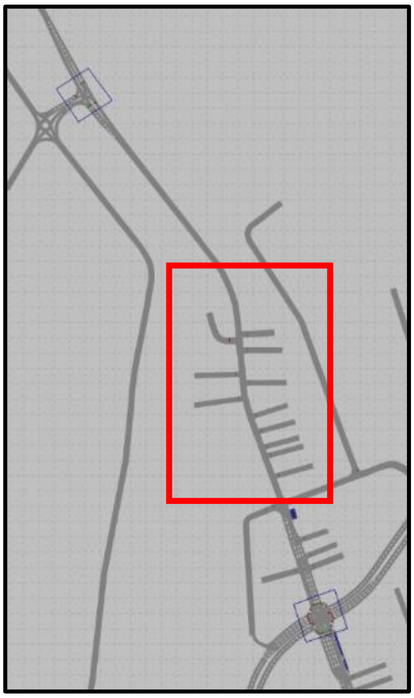

Figure 8.12: Scenarios 21 to 24 – Section 1

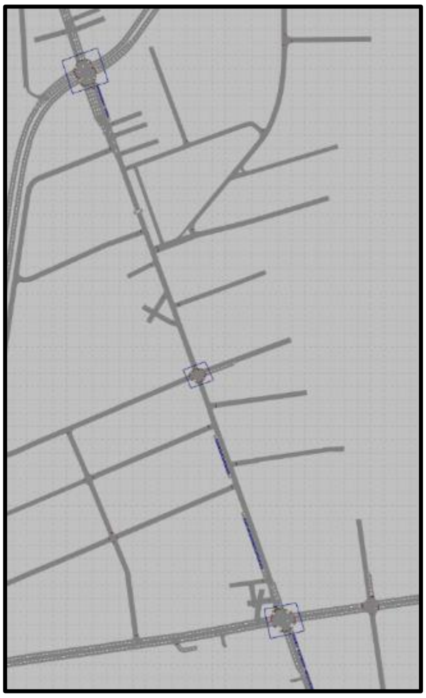

Figure 8.13: Scenarios 21 to 24 – Section 2

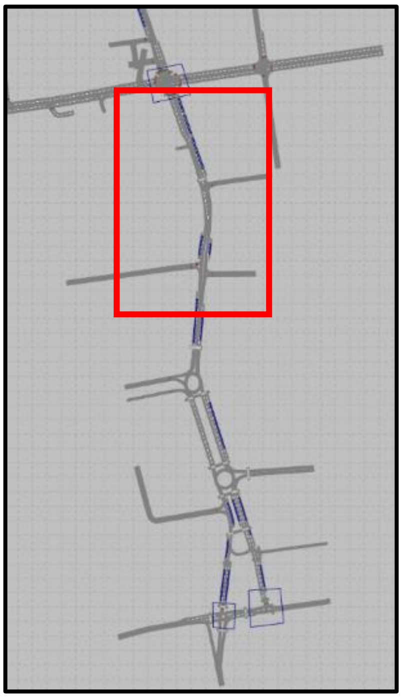

Figure 8.14: Scenarios 21 to 24 – Section 3

8.5 Structure of Scenarios

For the study, 24 scenarios were developed. The structure of the 24 scenarios and the 6 scenario categories can be seen in **Figure 8.15** and **Table 8.1** respectively.

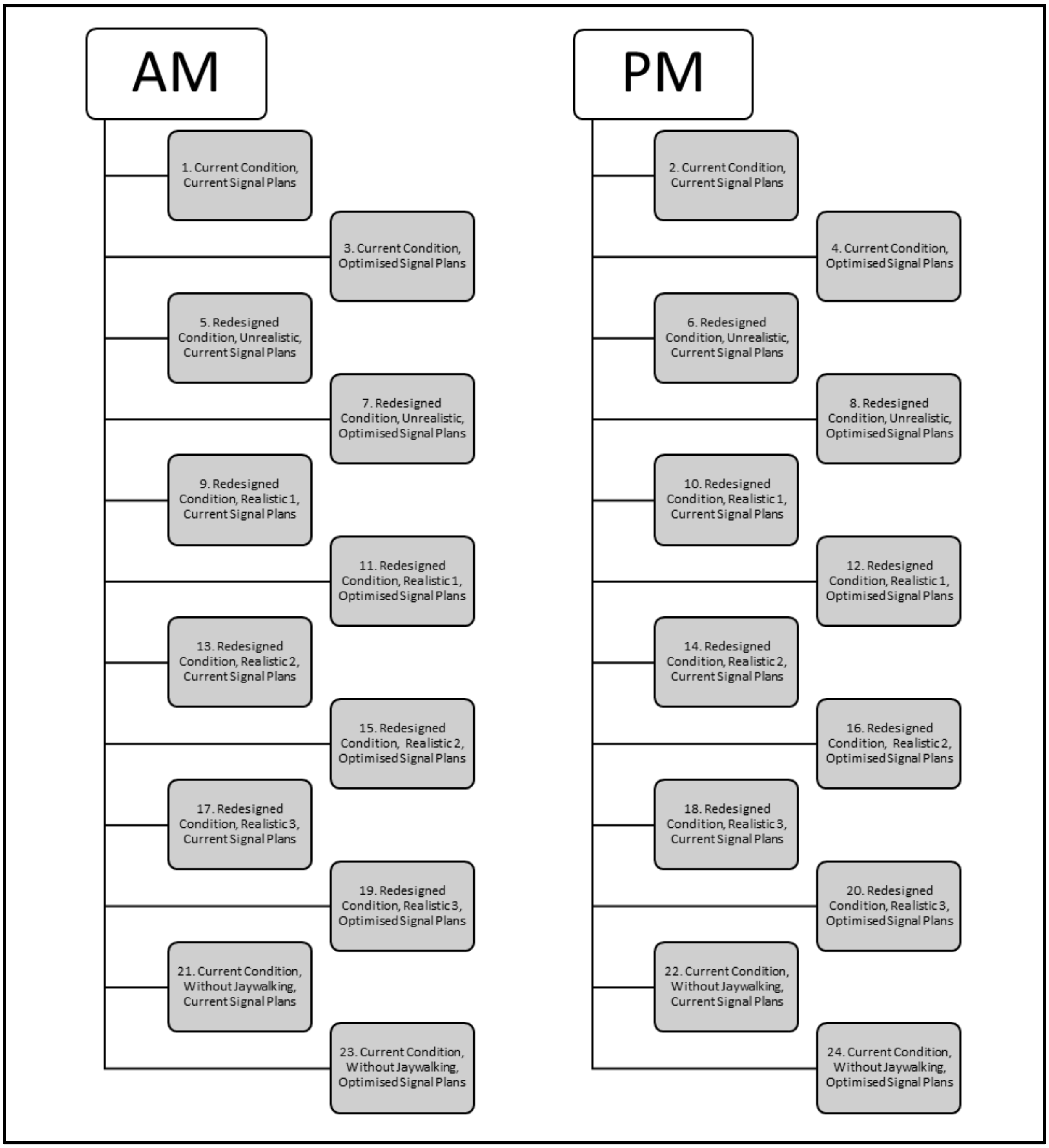

Figure 8.15: Structure of scenarios

Table 8.1: Structure of scenarios

Scenario Category	Scenario	Description		
		Peak hour period	Condition (Summary)	Signal Plans
A	1	AM	**Current design condition**	Current
	2	PM		Current
	3	AM		Optimised
	4	PM		Optimised
B	5	AM	**Redesigned - Unrealistic** (strictly according to the functional classification system)	Current
	6	PM		Current
	7	AM		Optimised
	8	PM		Optimised
C	9	AM	**Redesigned – Realistic 1** (left-in left-out access managed concept - marginal intersection)	Current
	10	PM		Current
	11	AM		Optimised
	12	PM		Optimised
D	13	AM	**Redesigned – Realistic 2** (auxiliary/right turn lane access managed concept)	Current
	14	PM		Current
	15	AM		Optimised
	16	PM		Optimised
E	17	AM	**Redesigned – Realistic 3** (Scenario category C with modification to Bell Road*)	Current
	18	PM		Current
	19	AM		Optimised
	20	PM		Optimised
F	21	AM	**Current design condition – without jaywalking** (Scenario category A with exclusion of jaywalking)	Current
	22	PM		Current
	23	AM		Optimised
	24	PM		Optimised

* Access movements at the Bell Road/Bird Street intersection were modified

8.6 Conclusion

In **Chapter 8**, six scenario categories were developed based on the two classified conditions of the three road sections, as discussed in **Chapter 7**. However, Scenario categories A and F were based on the current designed conditions and B, C, D and E on the current operating condition. As discussed in **Chapter 8**, Scenario category A was used as the referencing scenario to which the rest were compared to. The signal plans implemented at signalised intersections within the network, for the AM and PM peak hour period scenarios, were optimised in order to identify whether the current network operates under optimised traffic signal conditions and to determine the impact of redesigning the network as well as optimising the signal plans based on the redesigned conditions.

Therefore, the scenarios discussed in **Chapter 8** were developed to identify the impact of optimised signal plans based on the current conditions and to identify the impact of redesigning the network for unrealistic conditions, realistic conditions and without jaywalking activities. The scenarios were simulated by developing a microscopic traffic model, discussed in **Chapter 9**, and results were obtained for further analysis, discussed in **Chapter 10**.

CHAPTER 9 : MICROSCOPIC TRAFFIC MODELLING

9.1 Background and Motivation

Traffic modelling software packages are used to compare various scenarios with each other in order to identify the best solution, without the actual implementation thereof. The software allows the user to generate different data sets for each scenario, which can be used to identify the impact of changes made in various scenarios.

Scenarios can be modelled by way of either macroscopic or microscopic traffic simulation. Macroscopic models simulate aggregate flows, usually for a large area and with a low level of network detail. Microscopic traffic models simulate individual movements, usually for a small area with a high level of network detail (detailed design). For the study, a detailed investigation was executed, which contains detailed designs. Therefore, a microscopic traffic model was used for the traffic modelling component of the study.

9.2 Software Used

For the study, different software packages were used to develop a microscopic traffic model for the simulation of each scenario. The following software packages were used:

- ArcMap 10.5.1
- OpenStreetMap (OSM)
- PTV Visum 16
- PTV Vissim 11

9.3 Parameters

9.3.1 Background Image

Geometry related information of the road network is important for the model development process. Background images were generated and imported to PTV Vissim, which were used as a reference background tool during the development of the model.

The background image of the study area was exported from ArcMap. For accuracy purposes, it is important to ensure that the image is located at the correct location and scale. Since Vissim does not use map projection to project images to the correct location (coordinates), within the study area, the standard OSM background road network function (provided by Vissim) was used to project each image to the correct location.

9.3.2 Network

To construct the transportation network, geometric properties and similar data of the network were exported from OSM, which is an open source online software package. The data exported from OSM, was imported to PTV Visum (macroscopic simulation package) to refine the network and to generate an ANM file, which was then imported to Vissim.

The ANM file exported from Visum and imported to Vissim, was used to develop a transportation network, based on the geometric properties of the roads within the network. The ANM file contains geometric information of the network and can be used to develop a Vissim network with the geometry of roads within the network of the specific area (PTV AG, 2018). The Vissim network generated from the ANM file, was identified to be inaccurate and some differences were identified. Therefore, the network was modified and refined to develop a model to simulate each scenario.

9.3.3 Modelling Periods

The modelling period was chosen to fall within the period representing the worst case (peak hour period). From **Chapter 5**, the AM and PM peak hour periods were identified to be as follows:

- AM peak hour: 07:00 to 08:00
- PM peak hour: 16:30 to 17:30

For the modelling periods, an extra 30 minutes (15 min before and 15 min after) were added to the peak hour periods. The extra 30 minutes were added to the network to load the network beforehand to ensure that the network is not empty at the beginning of the analysis period. This increased the realistic representation of the actual traffic operations within the network. Results were only collected within the actual peak hour periods. Therefore, the simulation time for the AM and PM peak hour periods were as follows: AM – 06:45 to 08:15 and PM – 16:15 to 17:45.

9.4 Number of Runs Required

In any transportation network, the vehicle flow and movements vary stochastically. In order to account for the variance in flow and movements of the vehicles, a random seed value was assigned as one of the simulation parameters of the model. The random seed number assigned for each simulation run allows Vissim to assign a different value sequence and to make changes to the traffic flow (PTV AG, 2018).

When assigning random seed numbers to incorporate stochastic variances into the model, it is important to note that the original input values, such as vehicle volume, pedestrian volume, vehicle composition and other similar data remains the same for each simulation run, but the assignment thereof changes for each run. The results of each simulation run will therefore not be the same. It is important to run the simulation for a certain minimum number of runs and then to determine whether the average of the results is within a certain confidence level.

For this study, five runs were executed for each scenario, to compute the standard deviation of the average network speed (s) (km/h), for each scenario. The standard deviation of the average network speed was then used to compute whether the five runs comply with the minimum sample size for different confidence levels. The minimum sample size required, based on two permitted errors as a proportion of speed (km/h) and according to two confidence levels, was calculated by using **Equation 9-1** below.

$$N \geq \frac{c^2 \times s^2}{e^2} \qquad \text{Equation 9-1}$$

Where:	N	=	Minimum sample size required (runs).
	c	=	Confidence level constant.
	s	=	Sample standard deviation as a proportion of speed (km/h).
	e	=	Permitted error as a proportion of speed (km/h)

For the study, the minimum number of runs overall (for all 24 scenarios), were calculated for a few combinations between a 95% or a 99% confidence level and a permitted error of 5 km/h. The results of the different combinations can be seen in **Table 9.1**, where it can be seen that the five simulation runs are in line with the minimum number of runs per scenario. The original number of runs (five) is adequate for a 95% and 99% confidence level.

Table 9.1: Minimum number of runs per peak hour period scenario

Permitted error (km/h)	Confidence level		Min number of runs		Minimum (runs)
	%	Constant (c)	AM peak period scenarios	PM peak period scenarios	
5	**95%**	**1.96**	0.15	0.07	0.15
5	**99%**	**2.57**	0.26	0.12	0.26

The maximum permitted error was calculated for a 95% and a 99% confidence level, as seen in **Table 9.2** below. For a 99% confidence level, a maximum error of 1.1 km/h can be expected from the average network speed, which is negligible. It was concluded that five simulation runs are adequate to obtain accurate results from the model for the study.

Table 9.2: Maximum expected permitted error of five runs per peak hour period scenario

Number of simulation runs	Confidence level		Maximum expected error (km/h)		Maximum error (km/h)
	%	Constant (c)	AM peak period scenarios	PM peak period scenarios	
5	**95%**	**1.96**	0.9	0.6	0.9
5	**99%**	**2.57**	1.1	0.8	1.1

9.5 Pedestrian Inputs

Pedestrian volumes were observed and calculated. These pedestrian volumes were added to the network by generating a pedestrian volume input point in a pedestrian area. Pedestrian movements between different locations were assigned using pedestrian routes. Two types of pedestrian mobility road-crossings were identified in the study area and were incorporated into the model. These two types are crossing at pedestrian crossings and jaywalking, both discussed below.

9.5.1 Pedestrian Crossings

Pedestrian crossings are paths assigned to pedestrians to safely cross roads. At pedestrian crossings, pedestrians get preference to cross the road and vehicles need to yield to pedestrians crossing the road. Pedestrian input points were allocated at the specific locations where pedestrian crossings were observed.

9.5.2 Jaywalking

Two areas were identified in the study area with a high probability of the occurrence of jaywalking activities, as previously mentioned in **Section 4.4**. Provision was made to incorporate these pedestrian movements to improve the realistic representation of the model. Such activities were modelled by creating random pedestrian crossings in the study area where high jaywalking activities occur. The vehicular stream was assigned preference to pass the conflict point between the vehicle and the pedestrian so pedestrians crossing the road need to yield for the vehicular traffic stream, as in real life situations.

An example where such pedestrian crossings were constructed in the model, at the two high-jaywalking-activities areas, are indicated by number 1 to 6 in **Figure 9.1** below.

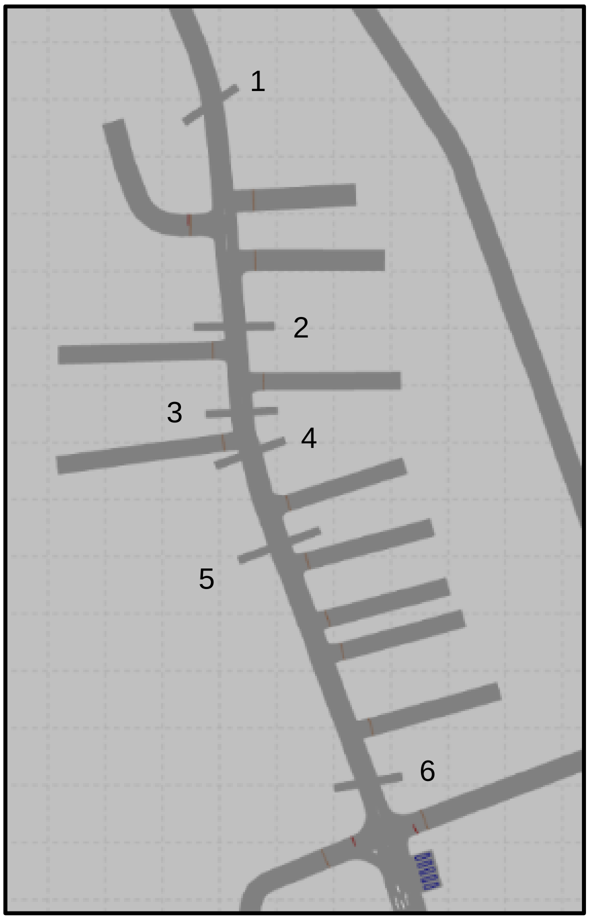

Figure 9.1: Example of jaywalking crossings in the Vissim model

<u>Assumptions made</u>

It was assumed that 100 pedestrians will cross Bird Street at each jaywalking-pedestrian-crossing. Therefore, a pedestrian volume of 50 pedestrians was assigned to each pedestrian area on either side of the jaywalking-pedestrian crossing links.

9.6 Vehicle Route Assignment

Vehicle routes (paths) can be assigned according to two methods, either static or dynamic assignment. Static vehicle route assignment can be defined as the more detailed assignment method in which vehicles are assigned a specific route. The routes are manually defined by the user and vehicles are forced to follow the route between the start and end point of their trip. Static vehicle route assignment is usually appropriate for the vehicle route (path) assignment of relatively small road networks.

With dynamic vehicle route assignment, each vehicle agent decides which route to take since there are usually various route options between the origin and destination of a trip. The assignment of vehicles to different route options are based on various external factors, such as travel time, distance and congestion level. Dynamic vehicle route assignment is appropriate for the vehicle route assignment of relatively large road networks.

For this study, static vehicle route assignment was used as the platform for assigning routes to vehicle agents within the network. Static assignment was used because of the relative size of the study area and to ensure that specific detailed route variations could be simulated in order to identify the impact of the proposed infrastructure changes.

9.7 Parking

Parking was added to the model where it was identified in the study area. In order to incorporate parking in the Vissim model, two major components are required: the parking space and the parking route, which connects the vehicle travel way with the parking space.

Parking zones consist of a certain number of parking spaces. The number, dimensions and the type of parking space for each parking zone was incorporated into the model environment. Parallel parking and 45-degree (diagonal) parking spaces were identified and incorporated into the Vissim model. The type of parking space was identified as either a loading zone or a normal parking space. Specific vehicle classes were assigned to either the loading zone or the normal parking space, depending on the type of vehicle and the reason for parking.

In order to connect the vehicle classes to the parking space, parking routes were incorporated. The model requires two input variables to simulate parking, the Park Rate and Parking Duration, as described in the following sections.

9.7.1 Park Rate

The park rate can be described as the percentage of vehicles which are assigned to a specific parking zone or space per time interval. In the model, the park rate was assigned to a specific parking zone or space by way of a parking route decision. The location of the parking routing decision marker was located upstream of the parking zone or space, at an appropriate distance, which allows the driver agent to make an accurate decision by giving them sufficient amount of time.

The parking turnover per time period for the AM and PM peak hour period was calculated from observations for parking zones 12 and 18, and was assumed to be the same over the entire network. The parking turnover per time period for the AM peak hour period was calculated as 0.7 vehicles/space and for the PM peak hour period it was calculated as 1.6 vehicles/space.

The park rate for each of the 18 parking zones was calculated as a percentage of vehicles crossing the marker assigned to the specific parking zones. The percentages were calculated by using **Equation 9-2**, as seen below.

$$Park\ rate = \frac{(Spaces\ \times \mathrm{PTPPHP}\ )}{Volume} \qquad \text{Equation 9-2}$$

Where:	Park rate	=	Percentage of vehicles which are assigned to a specific parking zone or space per time interval (%).
	Spaces	=	Parking spaces available.
	PTPPHP	=	Parking turnover per peak hour period (Veh/Spaces).
	Volume	=	Number of vehicles passing the parking routing decision marker (Vehicles).

9.7.2 Parking Duration

The parking duration can be described as the amount of time at which vehicles were parked in a parking space. The average parking duration of each parking space was specified for the vehicles using the parking space during the simulation period. To ensure that the vehicles parked for a certain duration in the specific parking space, a time distribution function was specified and linked to the parking routing decision marker. The parking routing decision marker assigns both the park rate and parking duration to each vehicle that parks in a specific parking space.

A normal time distribution function was assigned to each vehicle using the parking spaces in the study area. The normal time distribution function requires certain input, including the minimum and maximum parking duration in seconds, standard deviation of the parking durations and the mean of the values between the minimum and maximum parking duration. The minimum duration, maximum duration, standard deviation and the mean parking duration were calculated for parking zones 12 and 18 from the data collected during the parking study as previously discussed. The average values for the two parking zones was used for the AM and PM peak hour periods to set up the normal time distribution function. The normal time distribution function was applied to all the parking zones in the study area according to the assumption that the results obtained for parking zones 12 and 18 are applicable to all of the parking zones in the study area.

9.8 Traffic Signals

9.8.1 Fixed Time Signal Plans

The signal plans received from Stellenbosch Municipality were incorporated in the model at the respective locations for the current signal plan scenarios. For the optimised signal plan scenarios, the signal plans were optimised by using the "optimise all fixed time signal controllers'" function in Vissim, as discussed below.

9.8.2 Green Time Optimisation of Stage-Based Fixed Time Controllers

The signal plans of all the signal controllers in the network were optimised to improve operation. During the optimisation procedure, simulations were run by disabling all the controllers within the network, except the controller which undertook optimisation. Thereby, the upstream signal controllers had no effect (PTV AG, 2018).

During the optimisation process of a specific signal plan, the signal group with the highest delay was determined for each stage of the signal plan (PTV AG, 2018). The stage with the lowest maximum average delay and the stage with the highest maximum average delay was selected as the best and worst stage respectively. A second of green time was deducted from the best stage and added to the worst stage. If the best stage reached a point where a second of green time could not be deducted, it was deducted from the second-best stage. This process proceeds iteratively, until no stage can be shortened. When this point is reached, the optimisation is complete.

9.8.3 Original Signal Plan versus Optimised Signal Plan Illustration

The signal plans originally implemented at signalised intersections in the network were optimised for each scenario category. An illustration of the original signal plan input in Vissig (a Vissim add-on module), for the Bird Street/R44 signalised intersection can be seen in **Figure 9.2** for the AM peak hour period.

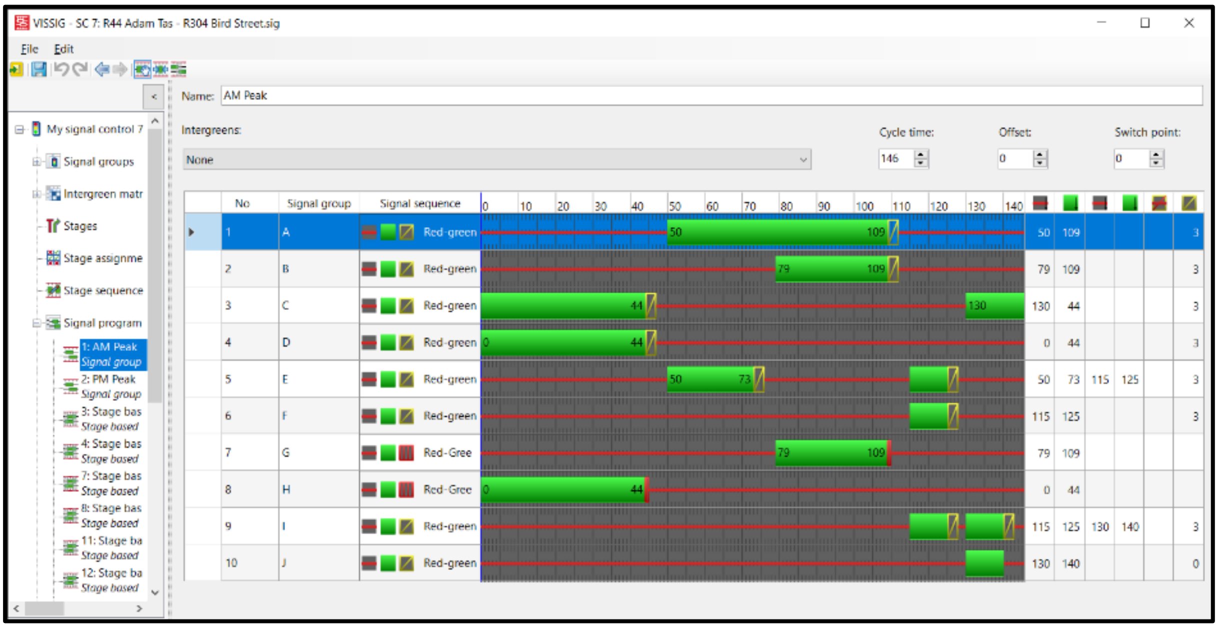

Figure 9.2: Current signal plan (Bird Street/R44 intersection) – Scenario 1

As mentioned before, signal plans were optimised using the "optimise all fixed time signal controllers'" function of Vissim. For the optimised signal plans, changes in the length of green time for the different signal groups were identified. The signal plan illustrated in **Figure 9.2** was optimised and the impact thereof can be seen by comparing the signal plan before (**Figure 9.2**) and after (**Figure 9.3**) optimisation with each other. By comparing the two signal plans, the change in green time duration of each signal group can be seen.

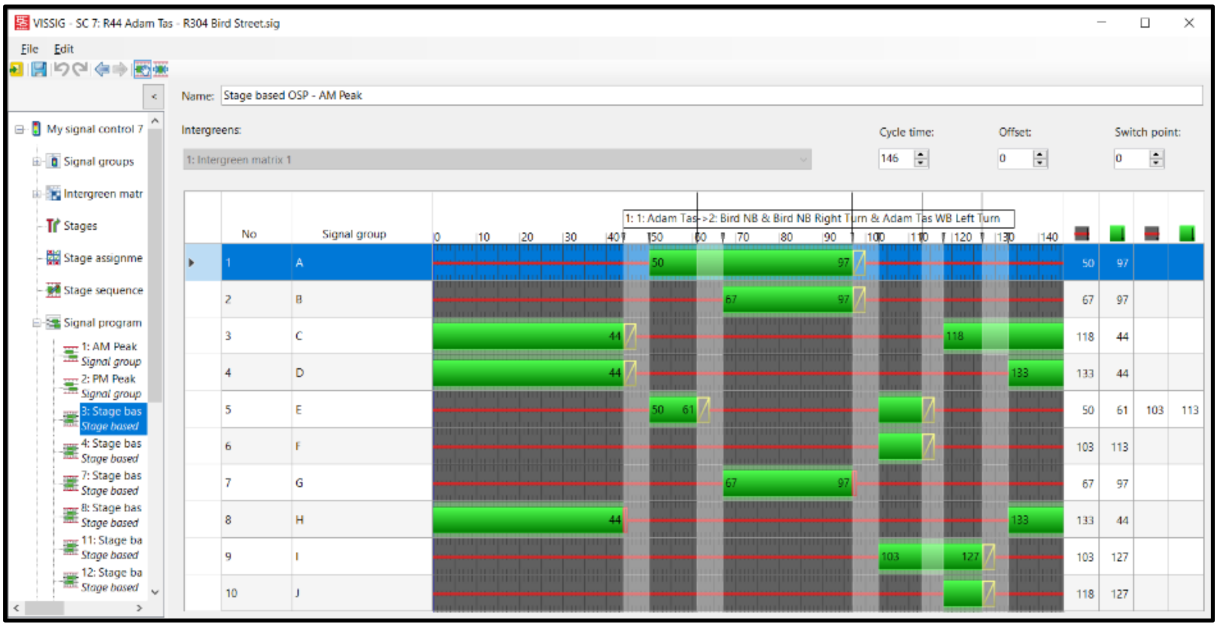

Figure 9.3: Optimised signal plan (Bird Street/R44 intersection) – Scenario 3

9.9 Data Measurements in the Model

In order to evaluate the operation of the simulated road network, the model is initialised with various data collection measures at particular locations in the model. Four types of data collection/evaluation measures, namely data collection points, node evaluation, network performance evaluation and vehicle travel time measurements, were incorporated into the model at certain locations. The locations of the evaluation nodes and travel time measurements are illustrated by the red squares and the green dots respectively in **Figure 9.4**. The data collection point measurements were located at all the accesses within the network and the network performance evaluation results were measured for the entire network.

Figure 9.4: Data measurement locations (Google Earth Pro, 2019)

Each of the four data collection/evaluation measurement types contain certain parameters. The respective parameters applied for each measure can be seen in **Table 9.3** below.

Table 9.3: Data measurements parameters

Measurements			
Data collection measurements	**Node evaluation**	**Vehicle network performance evaluation**	**Vehicle travel time measurements**
• Number of vehicles	• Queue length (m) • Queue length (Max) (m) • Vehicles (All) (No of vehs) • LOS value • Vehicle delay (All) (s) • Stopped delay (All) (s) • Stops (All) • Fuel consumption (Litres) • Emissions CO (grams) • Emissions NOx (grams) • Emissions VOC (grams)	• Delay (avg) (s) • Stops (avg) • Speed (avg) (km/h) • Delay stopped (avg) (s) • Distance (total) (km) • Travel time (total) (s) • Delay (total) (s) • Stops (total) • Delay stopped (total) (s) • Vehicles (arrived) • Delay (latent) (s) • Demand (latent)	• Vehicles (All) • Travel time (All) (s) • Distance travelled (All) (m)

For more information regarding the definitions of the data measurement parameters, refer to **Appendix D**.

9.10 Model Validation

The accuracy of the model was evaluated through a validation procedure to identify how the model base scenarios (Scenarios 1 and 2) compare to the actual road system. The volumes and certain routes were also validated. Two validation procedures were used for the evaluation of the accuracy of the model, discussed below.

9.10.1 TomTom Data

TomTom FCD was used to validate the base scenarios according to the harmonic mean speed (space mean speed) of two road sections (both directions) within the network.

The average speed of the road segment (both directions) obtained from TomTom, and the results obtained from the model were compared. The two road sections are: Masitandane Road/Bird Street to Merriman Avenue/Bird Street and Merriman Avenue/Bird Street to Bird Street/Dorp Street. The average speed per road section, for the two data sources, can be seen in **Figure 9.5** below.

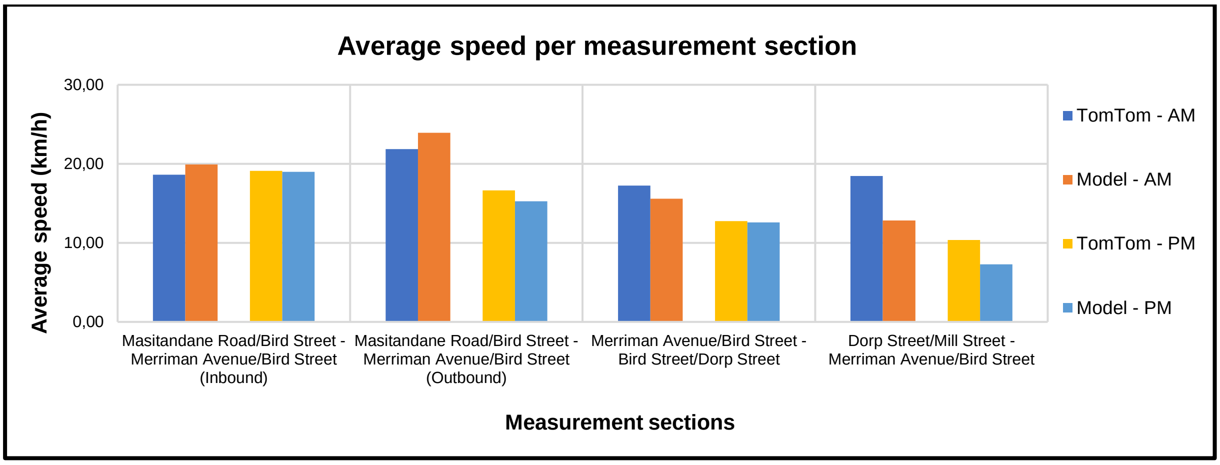

Figure 9.5: Average speed per road section

From **Figure 9.5**, it can be seen that the results obtained from the model are similar to the TomTom FCD. According to Jain and Vedagiri (2012), an error of up to 10% between the results obtained from the model and a comparative in-field or probe data set, is adequate. Therefore, the percentage error between the TomTom data and the results obtained from the model (base scenarios), per road section, was determined. The percentage error for the AM and PM peak hour period respectively, can be seen in **Figure 9.6** and **Figure 9.7**.

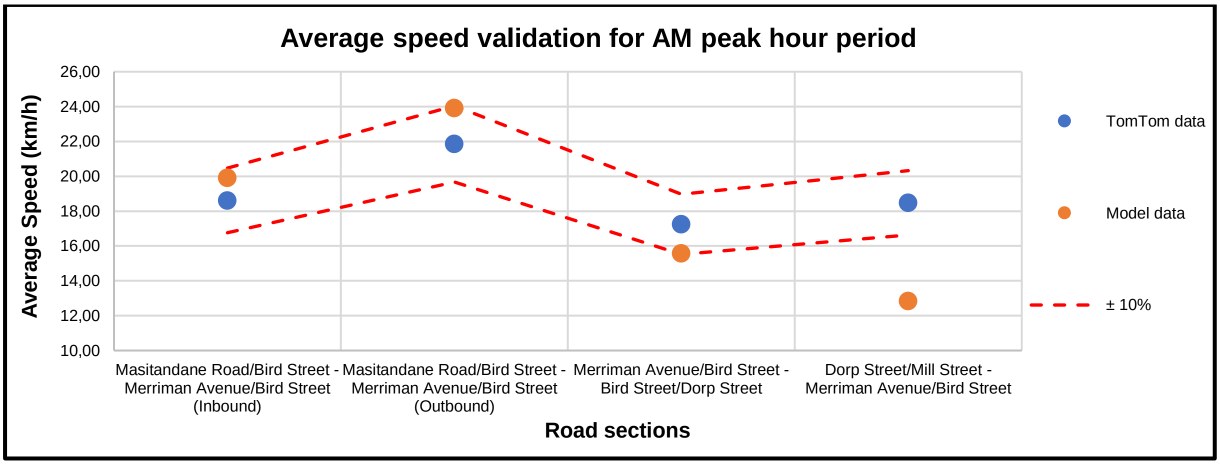

Figure 9.6: Error percentages per road section for AM peak period

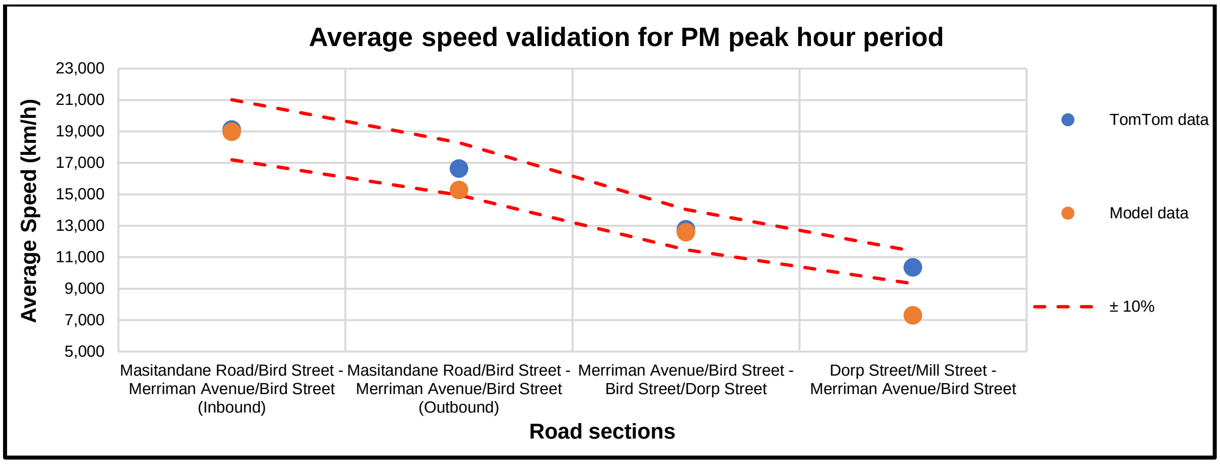

Figure 9.7: Error percentages per road section for PM peak period

From **Figure 9.6** and **Figure 9.7**, it was identified that only one road section direction (Dorp Street/Mill Street to Merriman Avenue/Bird Street) did not meet the 10% acceptable error margin. This section was identified to have a minor impact on the outcome of the results. Since most road sections met the acceptable error margin, it was concluded that the model was sufficiently accurate, based on the average speed.

9.10.2 Traffic Volumes

The accuracy of the model was also determined by comparing traffic volumes collected in the study area to results obtained from the data collection measurements at specific locations within the network. The infield traffic volumes were compared with data from two groups of data collection measurements, namely:

1. The data from all data collection measurements at different locations within the network, as discussed in **Section 9.9**, for the base scenarios.
2. The data from only the data collection measurements at accesses/intersections within the network that remained unchanged through all 24 scenarios.

The infield traffic volumes collected for each of the 42 accesses/intersections (at specific locations), were compared with the data from Group 1. The percentage change was determined for each of the 42 locations and the average thereof was used to validate the model for the AM and PM peak period respectively. The data from Group 2, was compared with the volumes collected infield at each of the respective locations. It was found that only seven accesses/intersections remained unchanged in each of the 24 scenarios. Therefore, the infield data was compared with the results obtained from the model, at the locations of the seven accesses/intersections respectively. The percentage change was determined for each of the seven locations, for each of the 24 scenarios, and the average thereof was used to evaluate the consistency of the model.

The average percentage change for each of the two data collection measurement groups (DCMG), for the AM and PM peak hour period respectively, was calculated and the results thereof can be seen in **Table 9.4** below.

Table 9.4: Average percentage change per data collection measurement group

Infield data vs Vissim model DCMG data	Average percentage change	
	AM	PM
Group 1	15%	14%
Group 2	4%	3%

According to Lehrke and Hourdos (2017), an error of up to 15% (for peak and analysis periods) between the results obtained from the model and a comparative in-field data set, is accurate for a microscopic traffic model. From **Table 9.4**, it was observed that the average percentage change in volumes between the infield and traffic model, for the two DCMGs respectively, was within the 15% error margin. Therefore, it was concluded that the model was sufficiently accurate and consistent for all the 24 scenarios.

9.11 Conclusion

In **Chapter 9**, the microscopic traffic modelling component of this research was discussed in terms of the incorporation of different components of the study. A microscopic static model was developed to simulate the different road design scenarios developed for the study. PTV Vissim was used as the microsimulation software. For the study, a total number of 24 scenarios were simulated for a certain number of runs for which the average results were obtained. It was concluded that five runs were adequate to obtain accurate results from the model with negligible maximum expected errors.

The results of the base scenario (Scenarios 1 and 2) were compared with the results obtained from TomTom data and infield traffic volumes in order to validate and determine the consistency of the Vissim model. From the results, it was concluded that the model was sufficiently accurate and consistent over all scenarios.

CHAPTER 10 : TRAFFIC MODELLING RESULTS

10.1 Background

In **Chapter 10**, results obtained from the Vissim model for each of the 24 scenarios will be used to analyse the impact of jaywalking, optimised signal plans and redesign of the road according to functional classification rules. The impact of redesigning the road network according to functional classification rules and jaywalking will be compared in order to identify which one contributes the most positively to current traffic operations observed in the study area. For the best realistic scenario category, the economic impact as well as the impact on emissions will also be determined.

As previously identified, the direction of the main traffic stream is inbound (in the direction of Stellenbosch central) during the AM peak period and outbound during the PM peak period. The vehicle travel time measurement results (one of the data measurements used to obtained data from the model) for the AM and PM peak hour periods were analysed in these respective directions.

10.2 Impact of Jaywalking Activities in the Network

In this section, the vehicle travel time measurement and node evaluation results of Scenarios 1 and 2 (Scenario category A – current design condition and current signal plans) were compared with the vehicle travel time measurement and node evaluation results of Scenarios 21 and 22 (Scenario category F – current design condition, without jaywalking and current signal plans). The results were compared with each other to determine the impact of jaywalking activities in the network.

10.2.1 Vehicle Travel Time Measurement Results

Vehicle travel time measurement results were obtained from the model for Scenario categories A and F, as illustrated by **Figure 10.1** and **Figure 10.2**. The number of vehicles per measurement road section represent the number of vehicles travelling through the **entire** section. The Masitandane Road/Bird Street to Merriman Avenue/Bird Street measurement section encompasses three measurement road sections: Masitandane Road/Bird Street to R44/Bird Street, R44/Bird Street to Molteno Road/Bird Street and Molteno Road/Bird Street to Merriman Avenue/Bird Street. The volume represents the number of vehicles travelling through the **entire** Masitandane Road/Bird Street to Merriman Avenue/Bird Street measurement section, not the sum of vehicles of the intermediate measurement road sections.

The number of vehicles and the average speed results are illustrated in the same figure to identify the impact of the respective scenarios on speed and volume. It is important to take both the number of vehicles and the average speed results into consideration when determining the best scenario. If a higher speed was observed, it does not necessarily mean the impact was positive, this may be indicative of lower vehicle throughput which would be a negative result. Therefore, the number vehicles also had to be considered.

AM peak hour period - Inbound

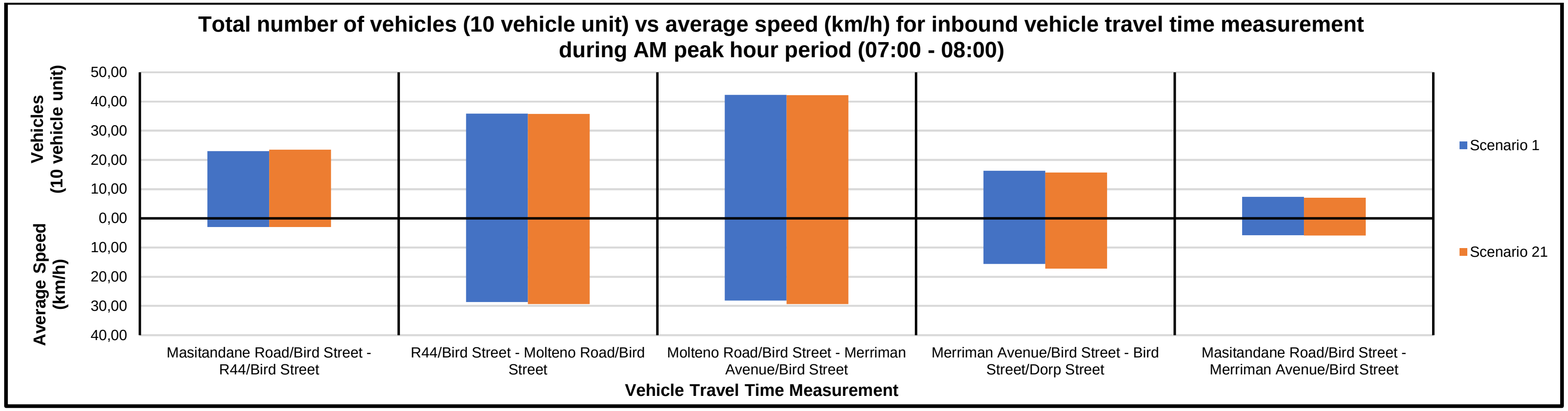

Figure 10.1: Impact of jaywalking activities on the number of vehicles and average speed during AM peak period - inbound

PM peak hour period - Outbound

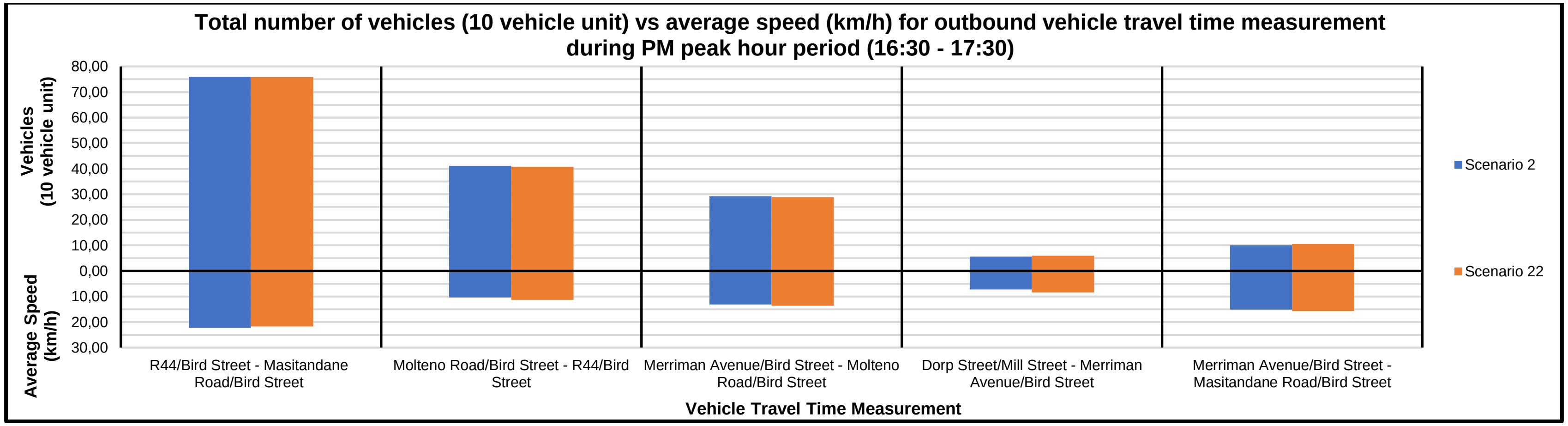

Figure 10.2: Impact of jaywalking activities on the number of vehicles and average speed during PM peak period - outbound

From **Figure 10.1**, an increase in the number of vehicles (5 vehicles) was identified for only one (Masitandane Road/Bird Street to R44/Bird Street) of the five vehicle travel time measurement sections, while an average decrease of 3 vehicles was identified for the rest of the vehicle travel time measurement sections. The average speed remained the same for the Masitandane Road/Bird Street to R44/Bird Street section and an average increase of 0.7 km/h was identified for the rest of the vehicle travel time measurement sections.

From **Figure 10.2**, an increase in the number of vehicles (3 and 6 vehicles) was identified for two (Dorp Street/Mill Street to Merriman Avenue/Bird Street and Merriman Avenue/Bird Street to Masitandane Road/Bird Street) of the five vehicle travel time measurement sections, while an average decrease of 3 vehicles was identified for the rest of the vehicle travel time measurement sections. From the same figure, a decrease in the average speed (0.58 km/h) was identified for only one (Masitandane Road/Bird Street to R44/Bird Street) of the five vehicle travel time measurement sections, while an average increase of 0.78 km/h was identified for the rest of the vehicle travel time measurement sections.

From **Figure 10.1** and **Figure 10.2**, it was identified that the jaywalking activities within the network do not have a major impact on the volume or the average speed achieved. However, two measurement road sections, known with major traffic problems, were investigated in more detail to analyse the impact of jaywalking activities within the network. The two sections are: Masitandane Road/Bird Street to Merriman Avenue/Bird Street (Sections 1 and 2) and more specifically Masitandane Road/Bird Street to R44/Bird Street (Section 1). Section 1 is known with high pedestrian crossing movements away from designed crossing points. The greater impact of jaywalking will be determined by investigating the change in the number of vehicles and the average speed for the two respective measurement road sections.

From the vehicle travel time measurement results of Scenario categories A and F (illustrated by **Figure 10.1** and **Figure 10.2**), it was identified that during the AM peak hour, the volume and average speed for the two sections increased at most by 3% and 4% respectively between Scenario 1 (current design condition) and Scenario 21 (current design condition without jaywalking). For the PM peak hour period, the volume and average speed increased at most by 11% and 9% respectively between Scenario 2 (current design condition) and Scenario 22 (current design condition without jaywalking).

10.2.2 Node Evaluation Results

Node evaluation results were obtained from the model, which were used to determine the impact on the LOS of the nodes/intersections evaluated within the network. The LOS results obtained at the seven nodes/intersections for Scenario categories A (Scenarios 1 and 2) and F (Scenarios 21 and 22) were compared to each other to identify the impact of jaywalking on the overall LOS of each node. The LOS results can be seen in **Figure 10.3** and **Figure 10.4** below.

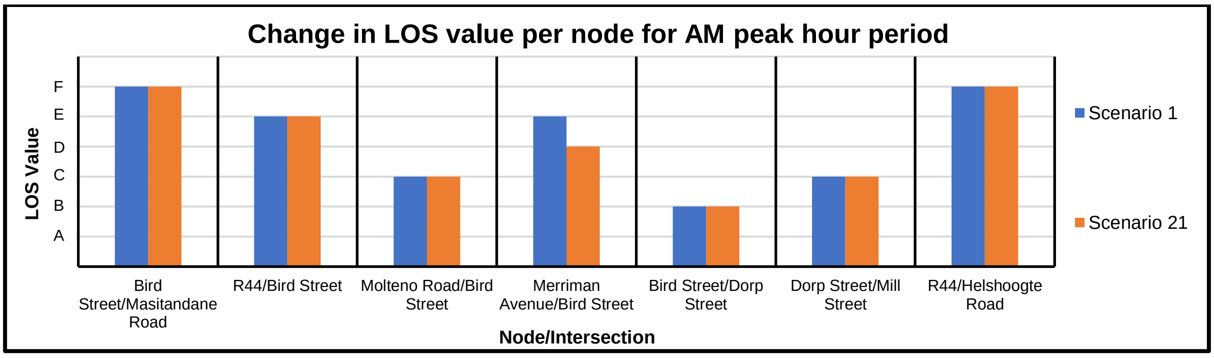

Figure 10.3: Impact of jaywalking activities on the LOS per node during AM peak period

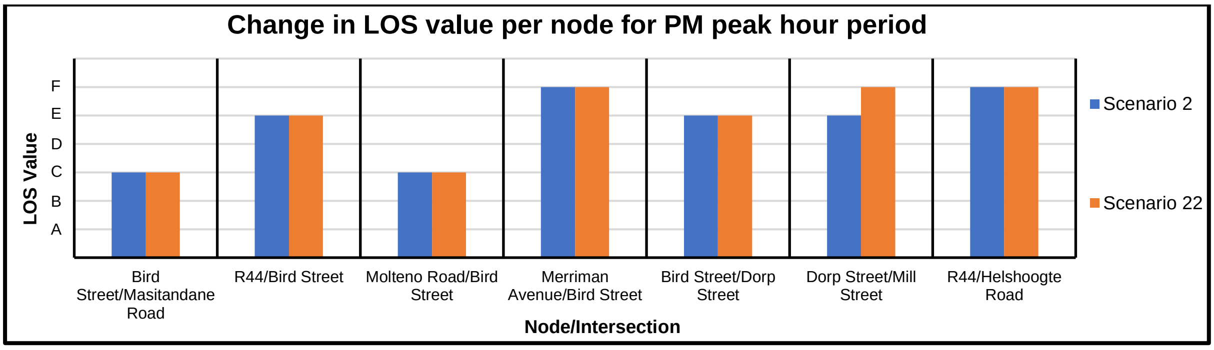

Figure 10.4: Impact of jaywalking activities on the LOS per node during PM peak period

From **Figure 10.3** and **Figure 10.4**, the LOS has remained mostly the same, with a few exceptions. For the AM peak hour period, the average LOS of the Merriman Avenue/Bird Street intersection improves from LOS E to LOS D. For the PM peak hour period, the average LOS of the Dorp Street/Mill Street intersection declines from LOS E to LOS F.

10.3 Impact of Current Signal Plans vs Optimised Signal Plans

In this section, the results collected for Scenario 1 (current signal plan: AM peak) are compared with the results collected for Scenario 3 (optimised signal plans: AM peak) and the results collected for Scenario 2 (current signal plans: PM peak) are compared with the results collected for Scenario 4 (optimised signal plans: PM peak). It is compared to determine the impact of the optimisation of the current signal plans on the vehicle travel time measurement and node evaluation results.

10.3.1 Vehicle Travel Time Measurement Results

Vehicle travel time measurement results were obtained from the model for Scenarios 1 to 4, as illustrated by **Figure 10.5** and **Figure 10.6**. The same conditions apply for **Figure 10.5** and **Figure 10.6** as for **Figure 10.1** and **Figure 10.2**.

From **Figure 10.5**, an decrease in the number of vehicles (22 and 6 vehicles) was identified for two (Masitandane Road/Bird Street to R44/Bird Street and Masitandane Road/Bird Street to Merriman Avenue/Bird Street) of the five vehicle travel time measurement sections, while an average increase of 17 vehicles was identified for the rest of the vehicle travel time measurement sections. An average decrease of 1.646 km/h in the average speed was identified for all of the vehicle travel time measurement sections.

From **Figure 10.6**, an increase in the number of vehicles (7 vehicles) was identified for only one (Dorp Street/Mill Street to Merriman Avenue/Bird Street) of the five vehicle travel time measurement sections, while an average decrease of 9 vehicles was identified for the rest of the vehicle travel time measurement sections. From the same figure, an increase in the average speed (0.01 and 0.66 km/h) was identified for two (Merriman Avenue/Bird Street to Molteno Road/Bird Street and Dorp Street/Mill Street to Merriman Avenue/Bird Street) of the five vehicle travel time measurement sections, while an average decrease of 1.58 km/h was identified for the rest of the vehicle travel time measurement sections.

From **Figure 10.5** and **Figure 10.6**, it was identified that the impact of optimising the signal plans was minimal. To develop a better understanding of how the optimisation of the current signal plans affected the volume and average speed measured between two points in the network, two measurement road sections experiencing major traffic problems were investigated in more detail. The two sections are: Masitandane Road/Bird Street to Merriman Avenue/Bird Street (Sections 1 and 2) and more specifically Masitandane Road/Bird Street to R44/Bird Street (Section 1).

AM peak hour period - Inbound

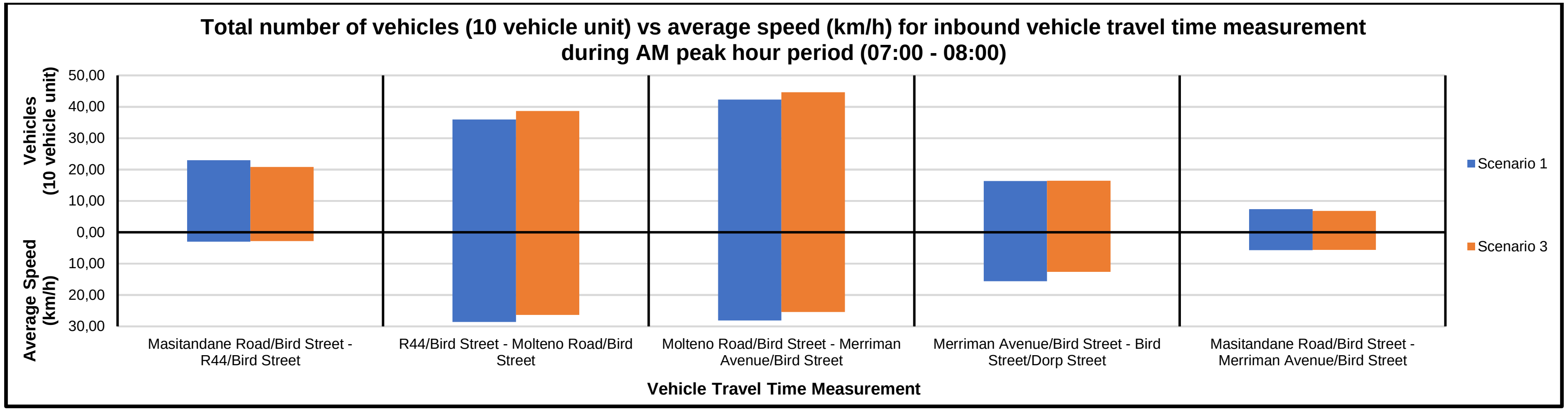

Figure 10.5: Impact of the optimisation of signal plans on the number of vehicles and average speed during AM peak period – inbound

PM peak hour period - Outbound

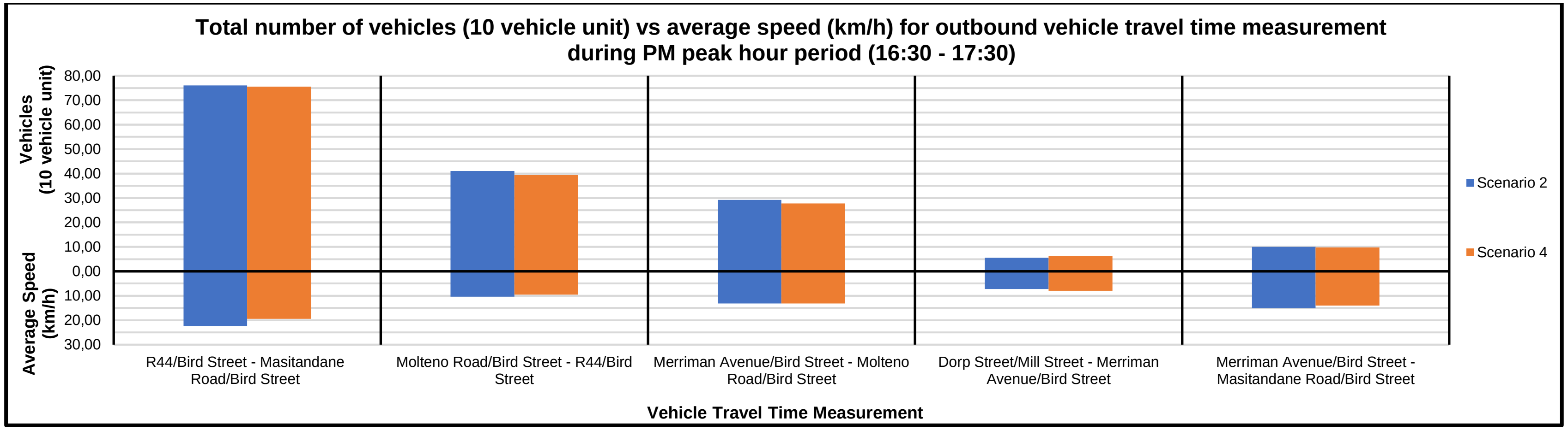

Figure 10.6: Impact of the optimisation of signal plans on the number of vehicles and average speed during the PM peak period – outbound

From the vehicle travel time measurement results of Scenarios 1 to 4 (illustrated by **Figure 10.5** and **Figure 10.6**), it was identified that during the AM peak hour, the volume and average speed for the two sections had decreased by 4% and 3% (maximum impact) between Scenario 1 and 3. For the PM peak hour period, the volume had increased at most by 1% and the average speed had decreased by 6% (maximum impact) between Scenario 2 and 4.

10.3.2 Node Evaluation Results

From the node evaluation results obtained at the seven nodes/intersections within the network for Scenarios 1 to 4, the LOS results were compared to identify the impact of the optimisation of signal plans implemented within the network on the overall LOS of each node. The results can be seen in **Figure 10.7** and **Figure 10.8**.

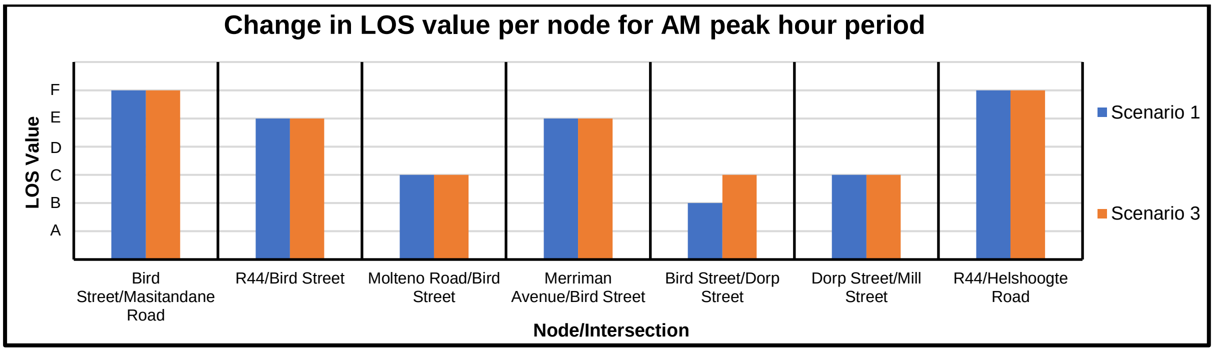

Figure 10.7: Impact of the optimisation of signal plans on the LOS per node during AM peak period

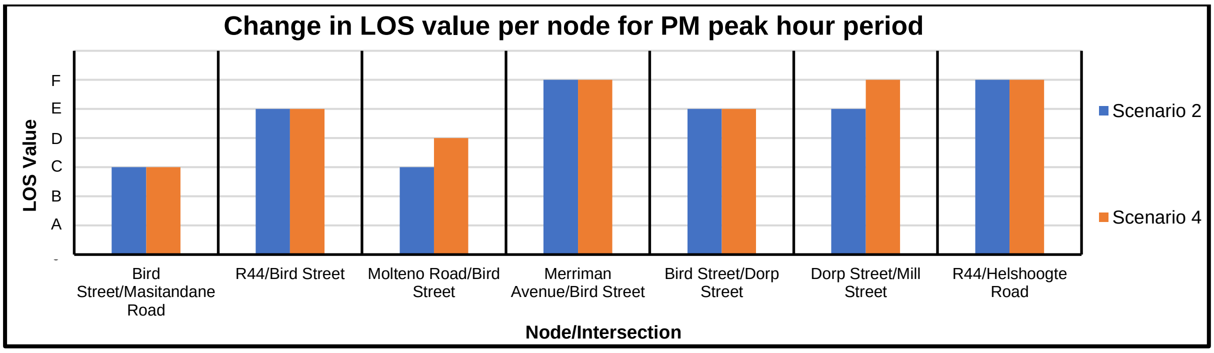

Figure 10.8: Impact of the optimisation of signal plans on the LOS per node during PM peak period

From **Figure 10.7** and **Figure 10.8**, the LOS remained mostly the same, with a few exceptions. For the AM peak hour period, the average LOS of the Bird Street/Dorp Street intersection declined from a LOS B to a LOS C. For the PM peak hour period, the average LOS of the Molteno Road/Bird Street intersection and the Dorp Street/Mill Street intersection declined from a LOS C to a LOS D (Molteno Road/Bird Street intersection) and from a LOS E to a LOS F (Dorp Street/Mill Street intersection). From the vehicle travel time measurement and node evaluation results it is clear that the timings of the current signal plans implemented within the network are closely optimised since the optimisation thereof does not have a big impact on the traffic operations.

10.4 Impact of Functional Classification on Traffic Movement

In this section, the vehicle travel time measurement, node evaluation and vehicle network performance evaluation results of the redesigned condition scenario categories (Scenario category B: unrealistic conditions and Scenario categories C to E: realistic conditions) are compared to Scenario category A (current design condition) as well as to each other. The comparison is made to determine the impact of the correct implementation of functional classification and redesigning of the road network according to the requirements of the functional classification system.

10.4.1 Vehicle Travel Time Measurement Results

Vehicle travel time measurement results were obtained from the model for Scenario categories A to E (Scenario category A: current design condition and Scenario categories B to E: redesigned condition), as illustrated by **Figure 10.9** and **Figure 10.10**.

AM peak hour period - Inbound

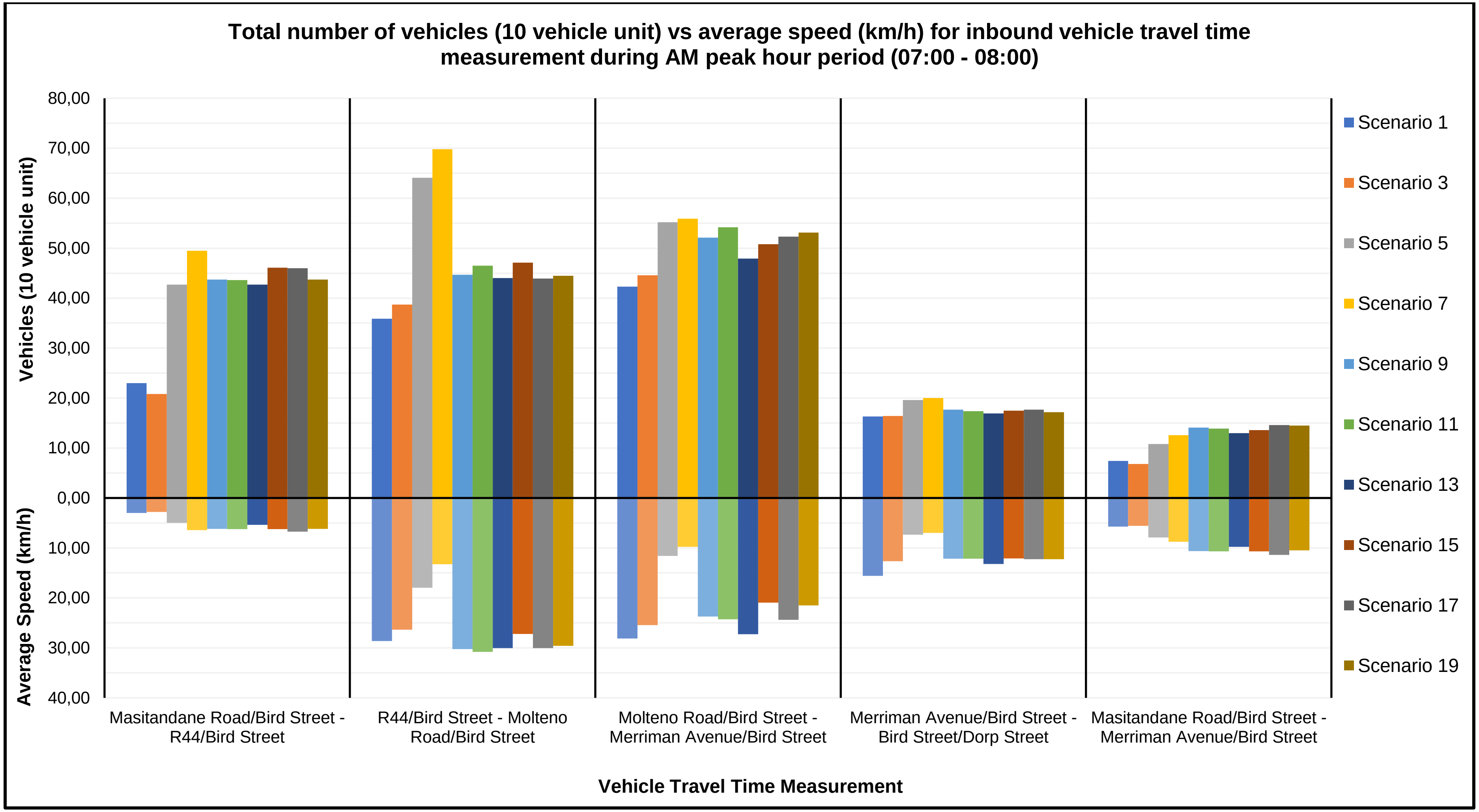

Figure 10.9: Impact of functional classification during AM peak hour period - inbound

PM peak hour period - Outbound

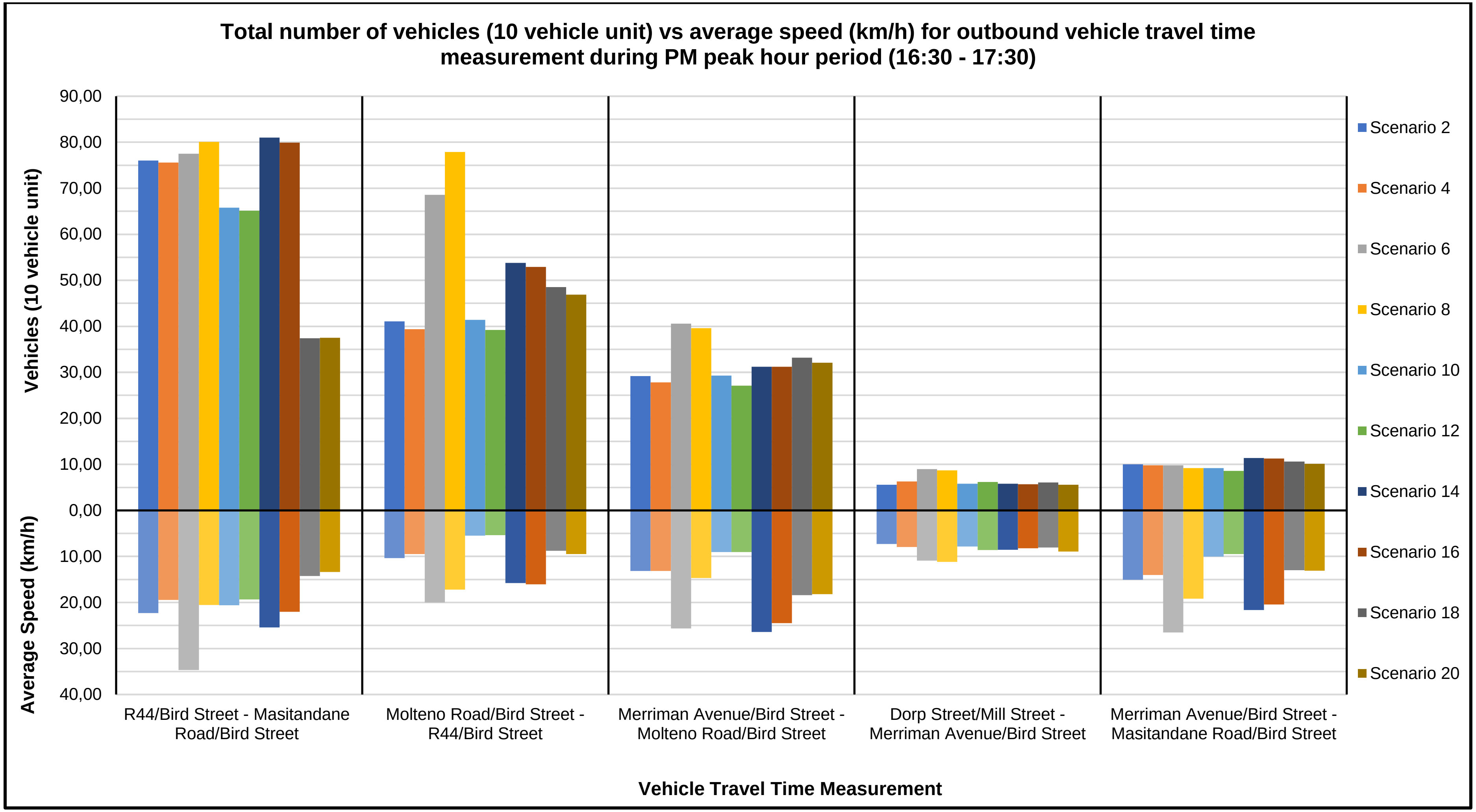

Figure 10.10: Impact of functional classification during PM peak hour period - outbound

From the two figures, it can be seen that the impact of reclassification and redesign of the road network in the context of the functional classification system, has shown general improvements. For the redesigned condition scenarios, during the AM peak hour, an average volume increase of 106% and speed increase of 106% was identified and during the PM peak hour, an average volume increase of 34% and speed increase of 121% was identified.

To develop a better understanding of how the reclassification and redesigning of the road network affected the volume and average speed measured between two points in the network, the change in volume and average speed were investigated in more detail for two road sections experiencing major traffic problems. The two sections are: Masitandane Road/Bird Street to Merriman Avenue/Bird Street (Sections 1 and 2) and more specifically Masitandane Road/Bird Street to R44/Bird Street (Section 1).

From the vehicle travel time measurement results of the redesigned condition scenarios for the two sections respectively, the maximum improvement for the realistic and unrealistic redesigned condition scenarios were determined. The maximum improvement of the unrealistic scenarios was compared with the maximum improvement of the realistic scenarios, for the AM and PM peak hour period respectively. The maximum improvement results can be seen in **Table 10.1** below.

Table 10.1: % change in volume and average speed for unrealistic and realistic conditions

Parameters	AM		PM	
	Unrealistic	Realistic	Unrealistic	Realistic
Volume	120%	114%	6%	17%
Average speed	118%	131%	113%	69%

From **Table 10.1**, it was deduced that for the AM peak hour period, unrealistic conditions produced the maximum volume improvements (120%), whereas realistic conditions produced the maximum average speed improvements (131%). However, for the PM peak hour period, realistic conditions produced the maximum volume improvements (17%), whereas unrealistic conditions produced the maximum average speed improvements (113%).

10.4.2 Node Evaluation Results

Node evaluation results were obtained from the model at seven nodes (intersections) within the road network, for Scenario categories A to E (Scenarios 1 to 20). The average results over the entire network (average of the seven nodes) were calculated. It was used to calculate the percentage change between the current condition scenarios (Scenarios 1 and 2) and each of the redesigned condition scenarios (unrealistic scenarios: Scenarios 5 to 8 and realistic condition scenarios: Scenarios 9 to 20). The percentage change results of each redesigned condition scenario can be seen in **Table 10.2** and **Table 10.3** below.

Table 10.2: % change for redesigned condition scenarios - AM peak hour period

Evaluation Parameters	Scenarios compared with Scenario 1							
	5	7	9	11	13	15	17	19
Queue length (m)	250%	282%	-1%	16%	29%	-4%	5%	1%
Queue length (Max) (m)	65%	85%	0%	5%	6%	-1%	1%	-1%
Vehicles (All) (No of vehs)	13%	17%	10%	12%	10%	13%	9%	10%
Vehicle delay (All) (s)	41%	37%	-4%	0%	-2%	-9%	-1%	-1%
Stopped delay (All) (s)	58%	53%	-3%	2%	2%	-8%	1%	1%
Stops (All)	44%	34%	12%	18%	0%	-4%	12%	13%
Fuel consumption (Litres)	30%	24%	2%	6%	-2%	-8%	3%	3%
Emissions CO (grams)	30%	24%	2%	6%	-2%	-8%	3%	3%
Emissions NOx (grams)	30%	24%	2%	6%	-2%	-8%	3%	3%
Emissions VOC (grams)	30%	24%	2%	6%	-2%	-8%	3%	3%

Table 10.3: % change for redesigned condition scenarios - PM peak hour period

Evaluation Parameters	Scenarios compared with Scenario 2							
	6	8	10	12	14	16	18	20
Queue length (m)	19%	-11%	40%	40%	-14%	-15%	-11%	-8%
Queue length (Max) (m)	-5%	-10%	18%	17%	-11%	-9%	-5%	-3%
Vehicles (All) (No of vehs)	9%	13%	-3%	-2%	5%	6%	0%	1%
Vehicle delay (All) (s)	10%	-3%	25%	25%	-8%	-8%	-1%	0%
Stopped delay (All) (s)	6%	-10%	30%	29%	-11%	-10%	0%	1%
Stops (All)	31%	18%	26%	28%	3%	0%	10%	11%
Fuel consumption (Litres)	20%	10%	20%	22%	0%	-2%	4%	5%
Emissions CO (grams)	20%	10%	20%	22%	0%	-2%	4%	5%
Emissions NOx (grams)	20%	10%	20%	22%	0%	-2%	4%	5%
Emissions VOC (grams)	20%	10%	20%	22%	0%	-2%	4%	5%

The impact on each evaluation parameter per scenario was indicated with a colour scale from red (negative impact) to green (positive impact), for the AM and PM peak hour period in **Table 10.2** and **Table 10.3**. The colour scale was used to aid in the identification of the overall best scenario, based on the impact on each evaluation parameter. From **Table 10.2** and **Table 10.3**, it can be seen that the overall performance was identified to be the best for Scenarios 15 and 16 (auxiliary/right turn lane access managed concept, optimised signal plans scenarios).

10.4.3 Vehicle Network Performance Evaluation Results

Vehicle network performance evaluation results were obtained from the model for Scenario categories A to E. The average results over the entire network were calculated. It was used to calculate the percentage change between the current condition scenarios (Scenarios 1 and 2) and each of the redesigned condition scenarios (unrealistic scenarios: Scenarios 5 to 8 and realistic condition scenarios: Scenarios 9 to 20). The percentage change results of each redesigned condition scenario can be seen in **Table 10.4** and **Table 10.5**.

Table 10.4: % change for redesigned condition scenarios - AM peak hour period

Evaluation Parameters	Scenarios compared with Scenario 1							
	5	7	9	11	13	15	17	19
Delay (avg) (s)	-4%	-13%	-8%	-12%	-9%	-17%	-9%	-15%
Stops (avg)	14%	8%	27%	27%	-4%	-7%	25%	24%
Speed (avg) (km/h)	4%	18%	15%	22%	16%	32%	17%	26%
Delay stopped (avg) (s)	-8%	-18%	-18%	-23%	-11%	-21%	-19%	-26%
Distance (total) (km)	8%	14%	9%	12%	9%	14%	10%	11%
Travel time (total) (s)	5%	-3%	-5%	-8%	-6%	-14%	-6%	-12%
Delay (total) (s)	5%	-7%	-9%	-13%	-10%	-21%	-10%	-18%
Stops (total)	25%	15%	27%	25%	-5%	-11%	24%	19%
Delay stopped (total) (s)	0%	-13%	-19%	-24%	-12%	-25%	-20%	-29%
Vehicles (arrived)	14%	18%	6%	8%	5%	9%	6%	8%
Delay (latent) (s)	-15%	-29%	-25%	-31%	-24%	-37%	-27%	-29%
Demand (latent)	-15%	-29%	-25%	-31%	-25%	-37%	-27%	-29%

Table 10.5: % change for redesigned condition scenarios - PM peak hour period

Evaluation Parameters	Scenarios compared with Scenario 2							
	6	8	10	12	14	16	18	20
Delay (avg) (s)	-8%	-11%	6%	4%	-6%	-7%	0%	-2%
Stops (avg)	-7%	-8%	9%	6%	-1%	-2%	0%	3%
Speed (avg) (km/h)	11%	15%	-7%	-4%	13%	14%	3%	6%
Delay stopped (avg) (s)	-9%	-13%	4%	2%	-8%	-10%	-2%	-5%
Distance (total) (km)	1%	5%	-3%	-1%	2%	4%	0%	2%
Travel time (total) (s)	-9%	-9%	4%	3%	-9%	-9%	-3%	-3%
Delay (total) (s)	-10%	-11%	8%	6%	-10%	-11%	-2%	-3%
Stops (total)	-9%	-9%	10%	7%	-6%	-6%	-1%	2%
Delay stopped (total) (s)	-11%	-13%	5%	3%	-12%	-14%	-4%	-6%
Vehicles (arrived)	9%	13%	-3%	-2%	2%	4%	0%	1%
Delay (latent) (s)	6%	-17%	7%	1%	3%	-6%	5%	-4%
Demand (latent)	5%	-17%	7%	1%	3%	-6%	4%	-3%

The impact on each evaluation parameter per scenario was indicated with a colour scale, for the AM and PM peak hour period in **Table 10.4** and **Table 10.5**. From **Table 10.4** and **Table 10.5**, it can be seen that the overall performance was best for Scenarios 15 (auxiliary/right turn lane access managed concept, optimised signal plans scenario) and 8 (unrealistic, optimised signal plans scenario). However, Scenario 8 was classified as an unrealistic scenario and cannot be applied in the current network, therefore, the impact was determined for the realistic redesigned condition scenarios by excluding the unrealistic condition scenarios. The results of the realistic condition scenarios can be seen in **Table 10.6** below. From **Table 10.6**, it can be seen that the overall performance of Scenario 16 (auxiliary/right turn lane access managed concept, optimised signal plans scenario) was the best.

Table 10.6: % change for redesigned condition scenarios (excluding unrealistic scenarios) - PM peak period

Evaluation Parameters	**Scenarios compared with Scenario 2**					
	10	**12**	**14**	**16**	**18**	**20**
Delay (avg) (s)	6%	4%	-6%	-7%	0%	-2%
Stops (avg)	9%	6%	-1%	-2%	0%	3%
Speed (avg) (km/h)	-7%	-4%	13%	14%	3%	6%
Delay stopped (avg) (s)	4%	2%	-8%	-10%	-2%	-5%
Distance (total) (km)	-3%	-1%	2%	4%	0%	2%
Travel time (total) (s)	4%	3%	-9%	-9%	-3%	-3%
Delay (total) (s)	8%	6%	-10%	-11%	-2%	-3%
Stops (total)	10%	7%	-6%	-6%	-1%	2%
Delay stopped (total) (s)	5%	3%	-12%	-14%	-4%	-6%
Vehicles (arrived)	-3%	-2%	2%	4%	0%	1%
Delay (latent) (s)	7%	1%	3%	-6%	5%	-4%
Demand (latent)	7%	1%	3%	-6%	4%	-3%

10.5 Functional Classification versus Without Jaywalking

From the results discussed in **Section 10.2** (impact of jaywalking activities within the network) and **Section 10.4** (impact of functional classification on traffic movement), the impact of the best functional classification scenario category versus the without jaywalking scenario category will be compared for two vehicle travel time measurement road sections experiencing major traffic problems (Masitandane Road/Bird Street to R44/Bird Street and Masitandane Road/Bird Street to Merriman Avenue/Bird Street). For the functional classification scenario category, the scenario category identified to have the most positive impact on the network's traffic operations (Scenario category D: auxiliary/right turn lane access managed concept, optimised signal plans scenario category) was used as the scenario category for comparison.

The percentage change in volume and in average speed between the current condition scenarios and the two compared scenario categories (functional classification and without jaywalking scenario categories) were determined and compared to each other in order to identify how much of an impact each of them had on the current traffic problems identified in the study area. The percentage change in volume and in average speed results of the functional classification versus without jaywalking activities are illustrated in **Figure 10.11** and **Figure 10.12** below.

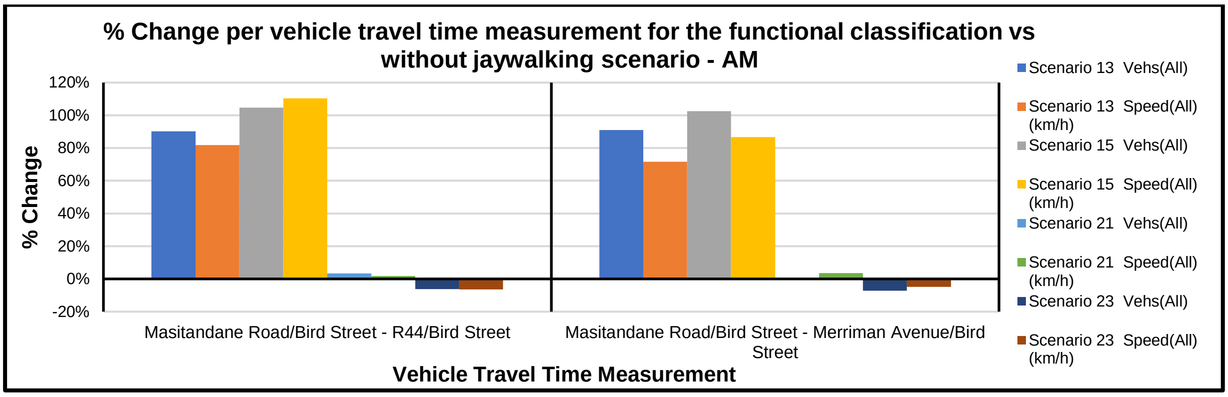

Figure 10.11: Impact of functional classification vs jaywalking activities - AM

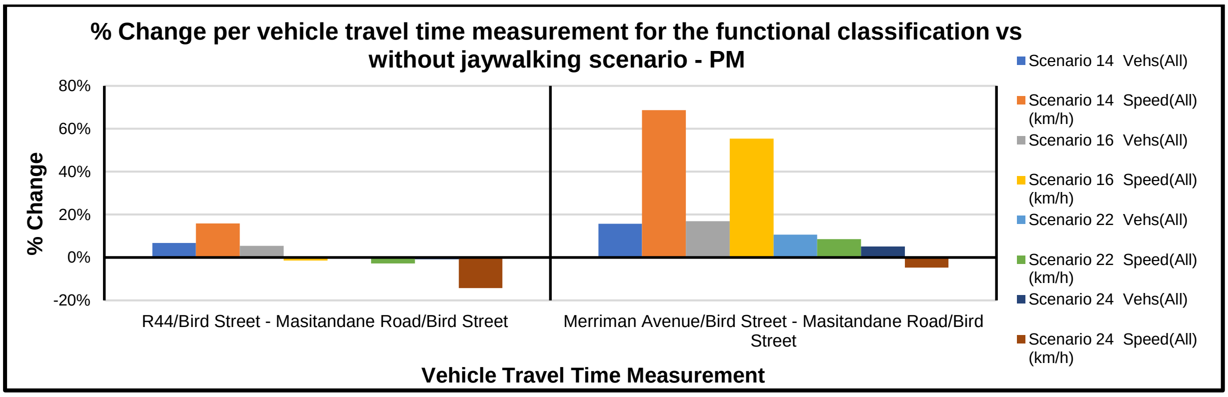

Figure 10.12: Impact of functional classification vs jaywalking activities - PM

From **Figure 10.11** and **Figure 10.12**, it can be seen that the percentage change in volume and in average speed for the functional classification scenarios (Scenarios 13 and 15) are much higher than the percentage change in volume and in average speed for the without jaywalking scenarios (Scenarios 21 and 23). For the AM peak hour period, the comparative observations were identified to be similar for both vehicle travel time measurements (road sections). For the PM peak hour period, the impact variance between the two scenario categories, for the two vehicle travel time measurements, were identified to be less than for the AM peak hour period, but it was still clear that the functional classification scenarios had a higher percentage change in the volume and average speed.

Overall, for both the AM and PM peak hour period, it was observed that the functional classification scenario category had a greater impact on the traffic operations in the study area than the “without jaywalking” scenario category.

10.6 Economic Impact

The economic impact of the best performing realistic scenario category (Scenario category D) was determined. The economic impact was based on the total average network travel time savings as well as the reduction in the average fuel consumption, as discussed below:

10.6.1 Travel Time

From the vehicle network performance evaluation results, the overall average travel time per vehicle was calculated for Scenario categories A (Scenarios 1 and 2) and D (Scenarios 13 to 16). The change in travel time between the two scenario categories was determined and multiplied with the number of vehicles for each scenario of Scenario category D. Thereby, the overall total travel time savings for Scenario category D were calculated. According to the PayScale (2019), the average hourly salary in the Cape Town region, as on 18/08/2019, was given as R53.10 per hour. This average hourly rate was used to calculate the total peak hour travel time cost savings per year. The results of the total savings in rand per year for the AM and PM peak hour period, based on the travel time difference, can be seen in **Table 10.7**.

Table 10.7: Travel time cost savings per year

	Travel time cost savings per year			
	AM		**PM**	
	Scenario 1 vs 13	**Scenario 1 vs 15**	**Scenario 2 vs 14**	**Scenario 2 vs 16**
Change in travel time per vehicle (s/veh) per peak hour	46.23	88.06	52.57	56.73
Vehicles in network	9121	9428	10458	10589
Total change in travel time (h) per peak hour	117	231	153	167
Total travel time cost savings per year per peak hour (21.67 working days per month)	R1 617 395.34	R3 184 357.03	R2 108 709.65	R2 304 247.72

10.6.2 Fuel Consumption

The average fuel consumption per vehicle per node/intersection was determined for Scenario categories A and D from the node evaluation results. Vissim calculates the fuel consumption by using the TRANSYT 7-F model (PTV AG, 2018). The change in fuel consumption between the two scenario categories was determined and multiplied with the total number of vehicles counted at the nodes/intersections (obtained from the node evaluation results), for each scenario of Scenario category D. Thereby, the change in the total fuel consumption was determined. On 07/08/2019, the average cost of fuel was identified to be R14.54 (average price of petrol (R15.28) and diesel (R13.79)) (AA, 2019). Therefore, the average cost of fuel was used to calculate the total peak hour fuel consumption savings per year. The results of the total savings in rand per year for the AM and PM peak hour period, based on the fuel consumption difference, can be seen in **Table 10.8**.

Table 10.8: Fuel cost savings per year

	Fuel cost savings per year			
	AM		PM	
	Scenario 1 vs 13	Scenario 1 vs 15	Scenario 2 vs 14	Scenario 2 vs 16
Average fuel consumption savings per vehicle (L/veh) per peak hour	0.058	0.107	- 0.004	0.013
Vehicles	13792	14249	13972	14213
Total average fuel consumption savings (L) per peak hour	797.03	1519.30	- 54.76	190.62
Total fuel consumption savings per year per peak hour (21.67 working days per month)	R3 012 517.75	R5 742 455.51	- R206 960.76	R720 488.50

10.6.3 Results

The total cost savings per peak hour period based on the travel time and fuel consumption savings are summarised in **Table 10.9**.

Table 10.9: Total cost savings per year

	Total cost savings per year			
	AM		PM	
	Scenario 1 vs 13	Scenario 1 vs 15	Scenario 2 vs 14	Scenario 2 vs 16
Travel time	R 1 617 395.34	R 3 184 357.03	R 2 108 709.65	R 2 304 247.72
Fuel	R 3 012 517.75	R 5 742 455.51	- R 206 960.76	R 720 488.50
Total	R 4 629 913.09	R 8 926 812.54	R 1 901 748.90	R 3 024 736.22

From **Table 10.9**, it can be seen that the total peak hour cost savings for the two optimised signal plans scenarios (Scenarios 15 and 16) resulted in the highest savings per year for the AM and PM peak hour period respectively. Therefore, the economic impact of redesigning the road network according to the functional classification system and optimisation of the signal plans, resulted in a total cost saving of R11 951 548.76 per year.

10.7 Impact on Emissions

The average CO, NOx, and VOC emissions per vehicle per node/intersection were determined for Scenario categories A and D from the node evaluation results. Vissim calculates the fuel consumption by using the TRANSYT 7-F model together with data on emissions gathered by the Oak Ridge National Laboratory of the U.S. Department of energy (PTV AG, 2018). According to the Vissim manual, the data refers to a typical North American vehicle fleet and does not differentiate between individual vehicle types. The change in emissions between the two scenario categories was determined and multiplied with the total number of vehicles counted at the nodes/intersections (obtained from the node evaluation results), for each scenario of Scenario category D. Thereby, the change in the total CO, NOx, and VOC emissions, per node, was determined and added together to obtain the total change in emissions of all the nodes within the network. The results of the total change in emissions can be seen in **Table 10.10** below.

Table 10.10: Total emissions savings per year (kg)

Emissions	Total emissions savings per year (kg)			
	AM		PM	
	Scenario 1 vs 13	Scenario 1 vs 15	Scenario 2 vs 14	Scenario 2 vs 16
CO	3826.23	7295.35	-262.86	915.08
NOx	744.43	1419.39	-51.12	178.06
VOC	886.76	1690.76	-60.91	212.08

From **Table 10.10**, it can be seen that the total emissions savings for the two optimised signal plans scenarios (Scenarios 15 and 16), resulted in the highest savings per year for the AM and PM peak hour period respectively. Therefore, the impact of the functional classification system and optimisation of the signal plans proved to be more environmentally friendly in reducing the carbon footprint.

10.8 Conclusion

In **Chapter 10**, results obtained from the model were used to determine the impact of the techniques incorporated into the scenarios. The impact of jaywalking, optimised signal plans and redesigning the road according to functional classification rules was determined. The impact of redesigning the road network according to functional classification rules and the impact of jaywalking was compared in order to identify which one contributed the most to the current traffic operations observed in the study area. From the results it was identified that jaywalking activities and the timing of the current signal plans implemented in the network were not the main cause of the current traffic congestion in the study area, in fact the impact of functional classification of the road network was greater.

From the functional classification comparison results, the best scenario category was identified to be Scenario category D. Scenario category D was designed according to an auxiliary-lane (right turn lane) access managed concept in line with the standards identified by the literature. Changes to the current road network were made to intersection and property accesses, auxiliary lanes, parking and pedestrian crossings. For the best scenario category, the economic impact as well as its impact on the emissions were determined. It was concluded that the economic impact could result in a total cost saving of R11 951 548.76 per year and the impact on the emissions were found to be more environmentally friendly, due to a reduction in the carbon footprint.

CHAPTER 11 : CONCLUSIONS AND RECOMMENDATIONS

11.1 Summary of Findings

In **Section 11.1**, the findings of each component of the study are summarised.

Chapter 5 : Vehicle Movement Data Analysis

- Worst traffic condition periods (AM and PM peak hour period).
  - AM: 07:00 to 08:00
  - PM: 16:30 to 17:30
- During the AM peak period, the direction of the main traffic stream was inbound (in the direction of Stellenbosch central) and during the PM peak period, the main traffic stream was outbound (in the opposite direction of Stellenbosch central).

Chapter 6 : Traffic Volumes Analysis

- The traffic volume growth rate per annum for the AM and PM peak hour period was identified to be 4% and 5% respectively.
- The vehicle composition at the main vehicle input points consisted out of three mode categories, namely light vehicles, busses and heavy vehicles. The percentage of the bus mode was identified to range between 0% and 1.4% and the percentage of the heavy vehicles was identified to range between 0% and 3.6%.
- In the PM peak hour period, the vehicle input volume of three of the seven signalised intersection approach groups, exceeded the capacity of those specific approach groups, after calibration.

Chapter 7 : Functional Classification

- For the current designed condition, all three sections of Bird Street were classified as a Class 4a road.
- For the current operating condition, Sections 1 and 2 were classified as a Class 3 road and Section 3 as a Class 4a road.
- This discrepancy in the classification of the design and operating condition highlights the traffic progression problem along Bird Street. The function and operation of Sections 1 and 2 are mobility and for Section 3, activity, but Sections 1 to 3 are designed for access.

Chapter 8 : Scenario Development

- Six scenario categories were developed based on the two classification conditions.
  - Scenarios 1 and 6 were based on the current designed conditions (Class 4a).

  - Scenarios 2, 3, 4 and 5 were based on the current operating conditions (Sections 1 and 2: Class 3 and Section 3: Class 4a).
- Each category consists out of four scenarios:
  - AM peak hour period:
    - Current signal plans scenario
    - Optimised signal plans scenario
  - PM peak hour period:
    - Current signal plans scenario
    - Optimised signal plans scenario

Chapter 9 : Microscopic Traffic Modelling

- The original five runs were adequate to obtain accurate results from the model, with a negligible maximum expected error.
- The microscopic traffic model was deemed sufficiently accurate.
- The routes and volumes remained consistent for all the scenarios.

Chapter 10 : Microscopic Traffic Modelling Results

- The optimisation of the current signal plans implemented within the network did not have a big impact on the traffic operations.
- There was no significant difference in the results of the unrealistic and the best realistic scenario category.
- From the node and vehicle network performance evaluation results, Scenario category D was identified as the best overall scenario category since it has the most positive impact on the network's traffic operations.
- It was found that jaywalking activities were not the main cause of the current traffic congestion in the study area, in fact the impact of functional classification of the road network was greater.
- The implementation of roundabouts in a Class 3 road was identified as inappropriate, due to its negative impact on the traffic operations.
- The economic impact of redesigning the road network according to the functional classification system and optimisation of the signal plans, resulted in total cost savings of R11 951 548.76 per year.
- The implementation of the functional classification system and optimisation of the signal plans proved to be more environmentally friendly by reducing the carbon footprint.

Achievements of research objectives

For the study, different research objectives were identified in **Section 1.3** (**Chapter 1**). The goal of the project was to achieve these objectives. In **Table 11.1** below, it is indicated whether the objectives were achieved with the relevant chapters in which these objectives were met.

Table 11.1: Indication if the objectives identified for the study were achieved

Objective	Objective achieved	Relevant chapters
1. Investigate the road classification and access management techniques for different road types.	√	**Chapter 2**
2. Investigate the different types of intersections, intersection control techniques and their impact on specific road networks.	√	**Chapter 2**
3. Quantify traffic patterns along Bird Street through collected traffic data.	√	**Chapter 4** **Chapter 5** **Chapter 6**
4. Analyse data to determine the functional classification of the road according to design and according to operations and compare the two.	√	**Chapter 7**
5. Develop and model different scenarios to identify the main cause of the poor traffic operations and whether there is a discrepancy between the actual and intended road classification of Bird Street.	√	**Chapter 8** **Chapter 9** **Chapter 10**
6. Recommend any improvements to the current situation in terms of the findings of the different scenarios.	X[5]	**Chapter 11**

11.2 Conclusions

The aim of this research was to investigate the relationship between the design and actual operational needs of roads in order to establish if a discrepancy in the design of the road and its functional classification has an impact on traffic movement. This was applied to a case study along Bird Street in Stellenbosch. From the results obtained for the different scenarios, it was concluded that the main cause of the current traffic conditions along Bird Street was

[5] Will be achieved at the end of **Section 11.2** and **Section 11.3**.

outdated functional classification and access management of the road section, compared to the needs of the current operating conditions.

The conclusion was developed based on the impacts identified from four comparison groups. Firstly, the impact of jaywalking activities was determined to identify whether this had any impact on the current traffic conditions. It was concluded that jaywalking activities in fact had a minor impact on the traffic movement. Secondly, the impact of the optimisation of the current signal plans implemented at signalised intersections in the network was determined in order to identify whether the current signal plans function optimally and whether it contributed to the current poor traffic state. It was concluded that the optimisation of the current implemented signal plans, only had a minor impact on the current traffic conditions.

Thirdly, the impact of the functional classification and access management techniques, identified by the literature, was determined based on two conditions, unrealistic and realistic conditions. The unrealistic redesign entailed forced closure of all roads that did not fall in the correct access spacing requirements. The realistic design entailed the following modifications to the base scenario:

- Realistic 1 - Left-in left-out access managed concept - marginal intersection.
- Realistic 2 - Auxiliary/right turn lane access managed concept.
- Realistic 3 - Realistic 1 with modification to Bell Road (Access movements at the Bell Road/Bird Street intersection were modified).

From the unrealistic and the three realistic conditions scenario categories results, no major variance was identified between the unrealistic condition scenario category and the best realistic condition scenario category results. Therefore, it was concluded that by redesigning outdated road networks, in a realistic context and according to the standards identified by the literature, the same outcome can be achieved as in an unrealistic context.

Finally, the results of the best functional classification scenario category were compared with the results of the "without jaywalking" scenario category, in order to identify the cause of the current traffic congestion identified along Bird Street. From the results, it was concluded that the functional classification scenario category had a greater impact on the traffic operations in the study area, than the "without jaywalking" scenario category. It was also concluded that the functional classification and access management did not only improve the traffic operations, it can also contribute to economic growth and to a reduction in the carbon footprint.

For the realistic condition scenarios, the scenario category which includes the two roundabouts (Scenario category C), was identified as the worst condition scenario category, based on the node and vehicle network performance evaluation results. It was identified to be even worse than the current condition scenario category. Based on the results of Scenario category E (scenario with a slip lane), improvement in the results was identified between Scenario category C and E. Therefore, it was concluded that roundabouts were not appropriate for implementation in a Class 3 road.

Overall, it was concluded that the main cause of the current traffic congestion along Bird Street was the outdated functional classification and access management. The study also demonstrated the importance of the functional classification and access management of roads, not only based on the conditions of the study area, but also in general to other similar situations around the world.

11.3 Recommendations

This study identified the importance of applying access management rules according to the correct functional classification of roads. It is recommended that road networks be designed according to a functional classification and access management system. Various design components should be taken into account, including the application of auxiliary lanes, number of accesses per property, rat-run control, flow interferences, signal plans and pedestrian activities control. More specific recommendations were developed, as discussed below.

Firstly, it is recommended that Bird Street (between Masitandane Road/Bird Street and Merriman Avenue/Bird Street) should be classified as a mobility road (Class 3). The number of possible vehicle flow interruptions, by way of pedestrians and accesses, should be managed along this section. Secondly, it is recommended that the right turn movements should be accommodated by way of right turn/auxiliary lanes, to avoid flow interruptions. Interruptions by pedestrian jaywalking activities should be controlled by implementing better pedestrian facilities, which will require future research. Thirdly, it is recommended that the current implemented signal plans should be reviewed, as well as the implementation of other area traffic control techniques.

Finally, it is recommended that the number of accesses per property should be reviewed and should be limited to only one access per property, reducing the number of possible flow interruption points. Road access to Bird Street, which accommodates rat run traffic, should be redesigned by implementing measures to restrict such activities. Therefore, two intersections (Bird Street/Papegaairand Road and Bird Street/Drukkers Road), which accommodates rat run traffic, should be redesigned by restricting such activities.

Since it was concluded that the functional classification and access management system had a major impact on the traffic operations of Bird Street, it is recommended that the functional classification and access management techniques identified by the literature, should be the basis of the design or redesign of new or existing road networks. It is very important to classify and design a road section, exclusively on the basis of its function to function optimally, as identified by the literature.

In **Section 11.2** and **Section 11.3**, improvements to the current situation of the traffic operations in the study area, in terms of the findings of the different scenarios, were recommended. Thereby the last objective was achieved.

11.4 Future Research

For the study, different aspects were not researched, since the required level of detail was not within the scope of the study. Therefore, future research is recommended for the following aspects:

- Management of pedestrian movement activities, more specifically jaywalking activities.
- Measures to increase the safety of approaching auxiliary lanes with no offset.
- Measures to increase the effectiveness of the application and usage of auxiliary lanes.
- Impact of different area traffic control techniques in the area and how they correlate with each other.
- Identify rat-run routes in the study area.
- Validation guidelines for microscopic traffic models, within the context of South African road networks and conditions.

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APPENDIX A : STUDY AREA INFORMATION

Satellite image map of study area:

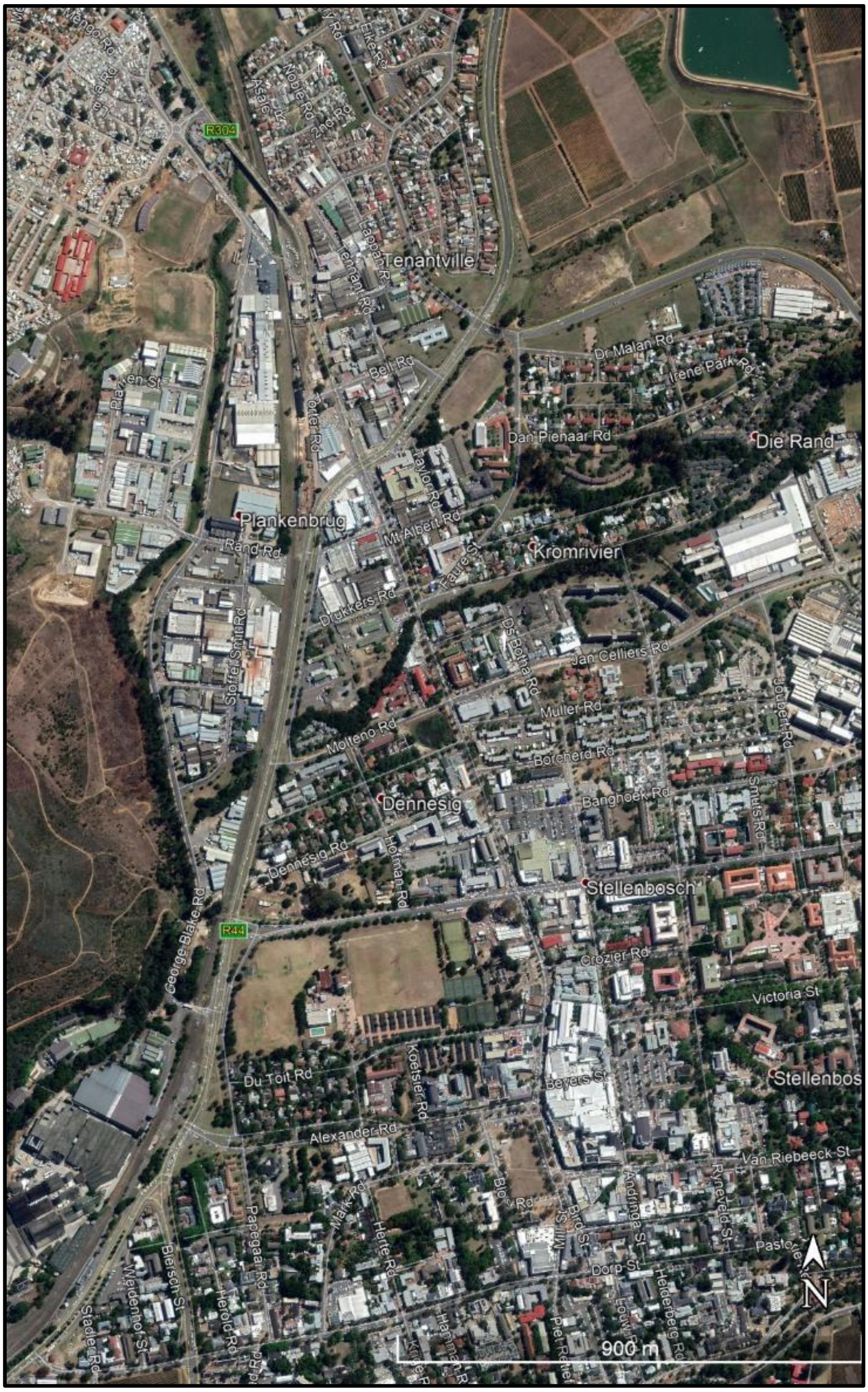

Figure A.1: Satellite image map of the study area (Google Earth Pro, 2019)

Detailed map – Section 1:

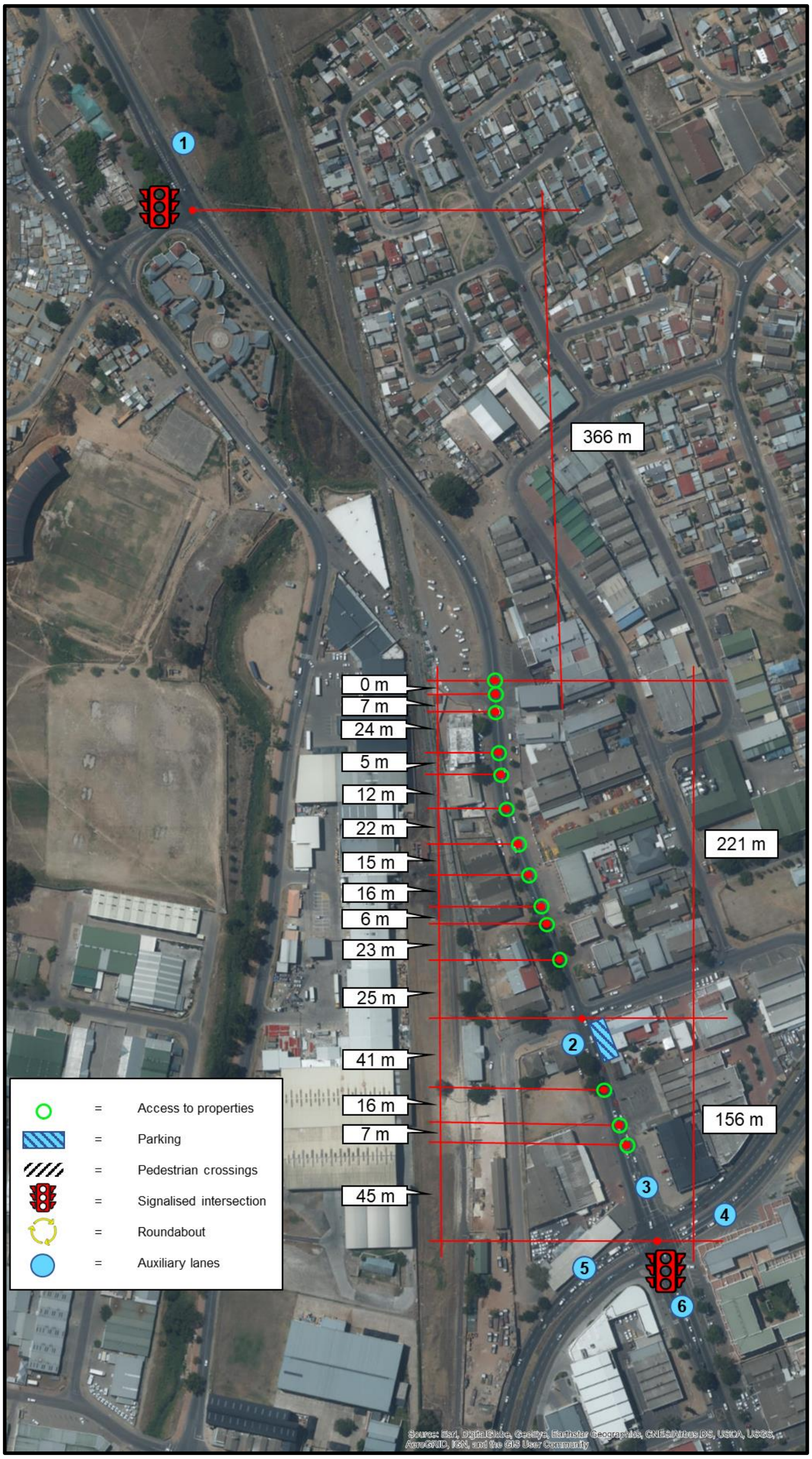

Figure A.2: Detailed map – Section 1 (USGS LandsatLook, 2019)

Detailed map – Section 2:

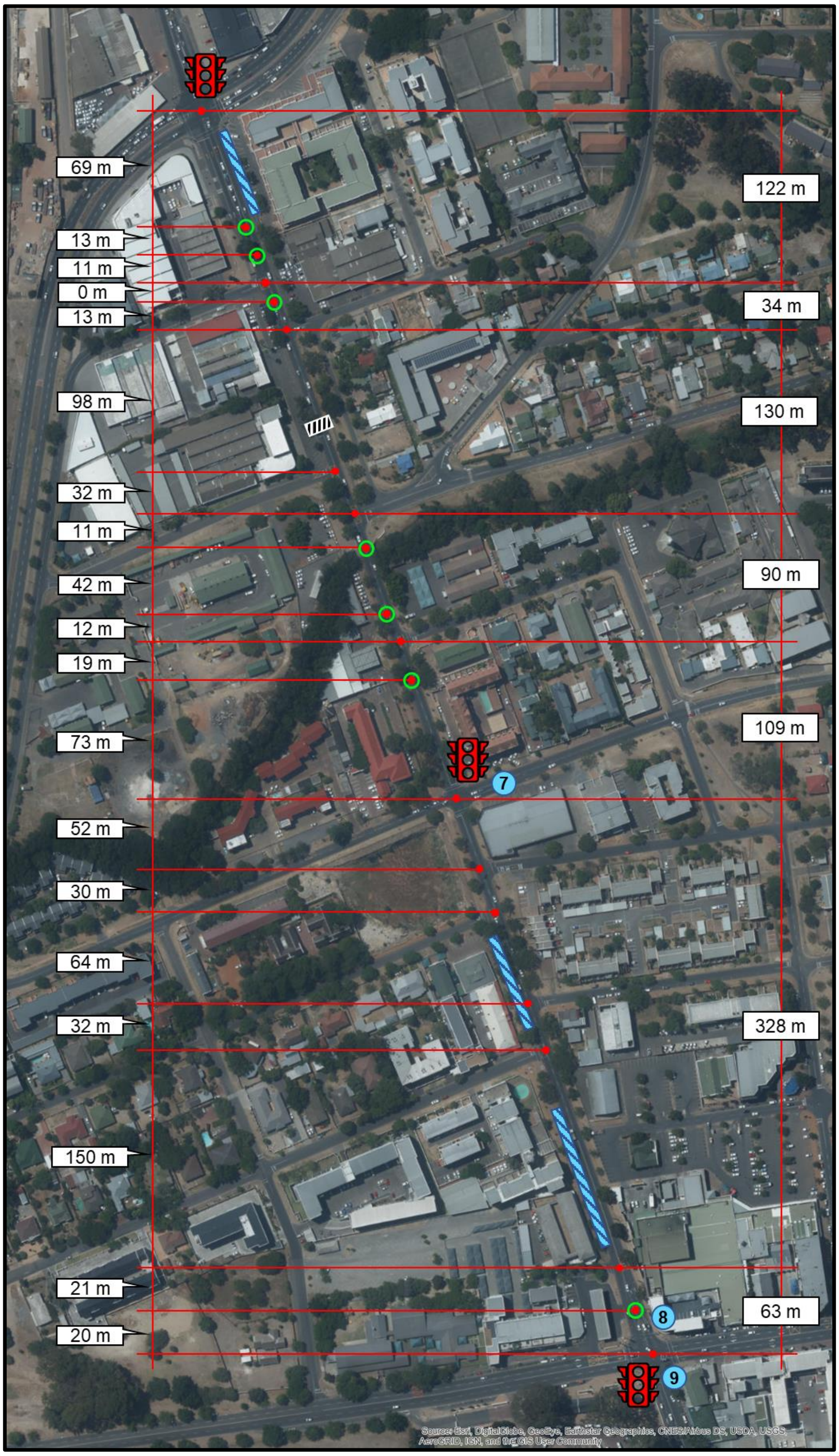

Figure A.3: Detailed map – Section 2 (USGS LandsatLook, 2019)

Detailed map – Section 3:

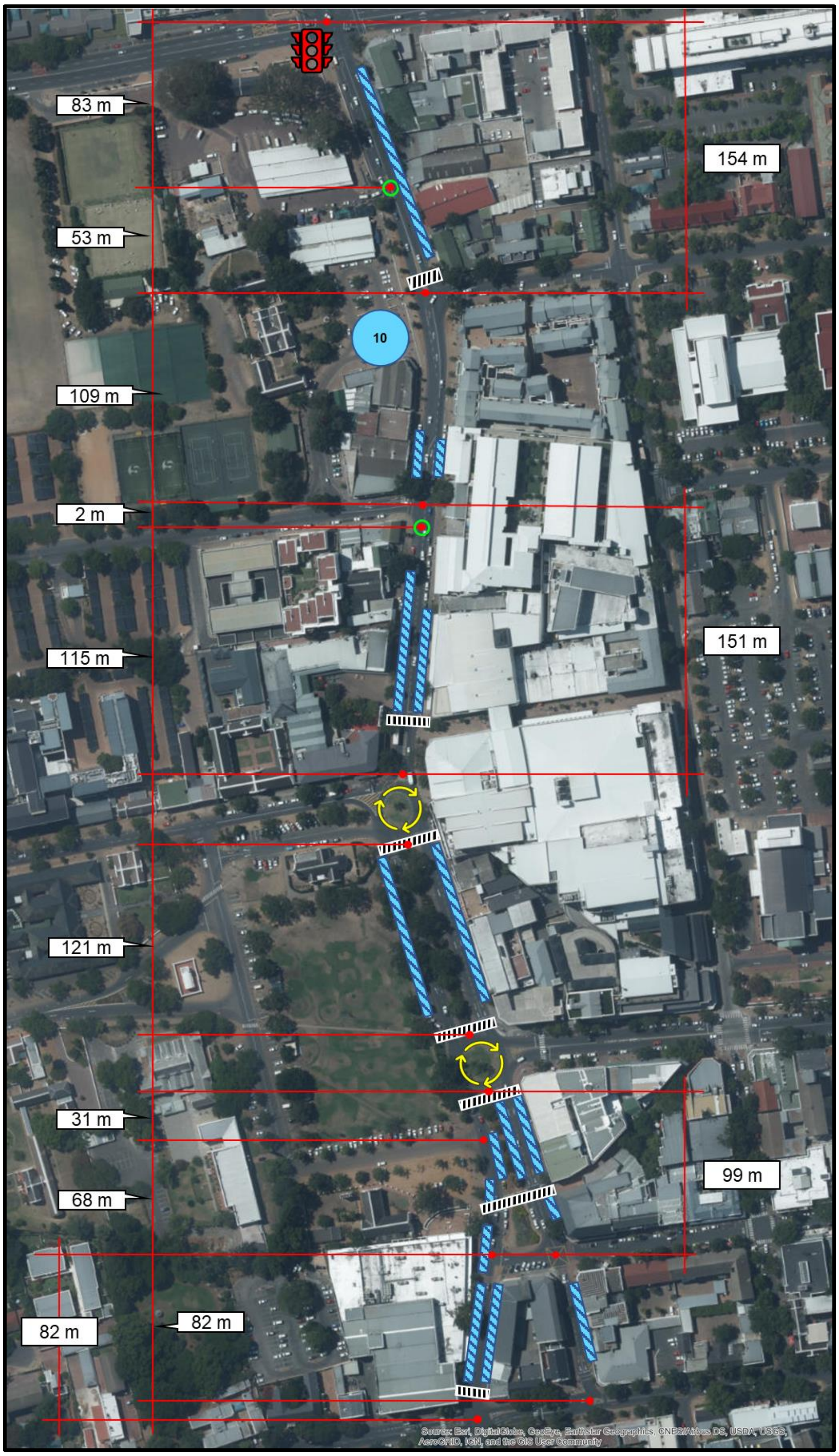

Figure A.4: Detailed map – Section 3 (USGS LandsatLook, 2019)

<u>Study area information table:</u>

Section 1:

Table A.1: Study area information – Section 1

Type	Observed
Type of area (rural or urban)	Urban
Intersection spacings	**Figure A.2**
Any accesses to properties	Yes - **Figure A.2**
Parking in the area	Yes - **Figure A.2**
Speed limit	60 km/h
Typical cross section	
Number of lanes	One
Lanes divided or undivided	Undivided
Kerbed	Yes
Median at pedestrian crossing	No
Boulevard	No
CBD one-way	No
Roadway / lane width	3.3 - 3.5 m lanes
Road reserve width	20 - 30 m
Public transport stops and pedestrian crossings	No
Pedestrian footways (constructed)	Yes
Cycle lanes	No
Traffic calming measures	No
Land use information	Commercial
Length of auxiliary lanes	**Figure A.2** and **Table A.2**
Intersection control type	
Roundabouts	No
Priority control	Yes
Signal control	Yes
Intersection type	**Table 7.4**

Table A.2: Auxiliary lane length (m)

<table>
<tr><th rowspan="2">Auxiliary lane</th><th colspan="3">Length (m)</th></tr>
<tr><th>Left</th><th colspan="2">Right</th></tr>
<tr><td>1</td><td>-</td><td colspan="2">92</td></tr>
<tr><td>2</td><td>-</td><td colspan="2">66</td></tr>
<tr><td>3</td><td>-</td><td>122</td><td>73</td></tr>
<tr><td>4</td><td>-</td><td colspan="2">67</td></tr>
<tr><td>5</td><td>84</td><td colspan="2">104</td></tr>
<tr><td>6</td><td>63</td><td>76</td><td>70</td></tr>
</table>

Section 2:

Table A.3: Study area information – Section 2

Type	Observed
Type of area (rural or urban)	Urban
Intersection spacings	**Figure A.3**
Any accesses to properties	Yes - **Figure A.3**
Parking in the area	Yes - **Figure A.3**
Speed limit	60 km/h
Typical cross section	
Number of lanes	One
Lanes divided or undivided	Undivided
Kerbed	Yes
Median at pedestrian crossing	No
Boulevard	No
CBD one-way	No
Roadway / lane width	3.3 - 3.5 m lanes
Road reserve width	20 - 30 m
Public transport stops and pedestrian crossings	Public transport stops - No Pedestrian crossing - Yes
Pedestrian footways (constructed)	Yes
Cycle lanes	No
Traffic calming measures	No
Land use information	Commercial
Length of auxiliary lanes	**Figure A.3** and **Table A.4**
Intersection control type	
Roundabouts	No
Priority control	Yes
Signal control	Yes
Intersection type	**Table 7.8**

Table A.4: Auxiliary lane length (m)

Auxiliary lane	Length (m)	
	Left	Right
7	48	-
8	65	37
9	-	80

Section 3:

Table A.5: Study area information – Section 3

Type	Observed
Type of area (rural or urban)	Urban
Intersection spacings	**Figure A.4**
Any accesses to properties	Yes - **Figure A.4**
Parking in the area	Yes - **Figure A.4**
Speed limit	60 km/h
Typical cross section	
Number of lanes	One
Lanes divided or undivided	Mostly Divided
Kerbed	Yes
Median at pedestrian crossing	No
Boulevard	No
CBD one-way	No
Roadway / lane width	3.3 - 3.5 m lanes
Road reserve width	20 - 30 m
Public transport stops and pedestrian crossings	Public transport stops - No Pedestrian crossing - Yes
Pedestrian footways (constructed)	Yes
Cycle lanes	No
Traffic calming measures	No
Land use information	Commercial
Length of auxiliary lanes	**Figure A.4** and **Table A.6**
Intersection control type	
Roundabouts	Yes
Priority control	Yes
Signal control	Yes
Intersection type	**Table 7.11**

Table A.6: Auxiliary lane length (m)

Auxiliary lane	Length (m)	
	Left	Right
10	-	60

APPENDIX B : REQUIREMENTS AND FEATURES

Table B.1: Urban Access Management Requirements and Features (COTO, 2012b)

Basic Function	Description		REQUIREMENTS					TYPICAL FEATURES (use appropriate context sensitive standards for design)								
	Class No (U_)	Class name	Design typology	Route no.	Intersection spacing	Access to property	Parking	Speed km/h	Inter-section control	Typical cross section	Roadway / lane width	Road reserve width	Public transport stops and ped. xing.	Pedestrian footways (constructed)	Cycle lanes	Traffic Calming
Mobility	1	Principal arterial	Freeway	Yes (M/R/N)	2,4 km (1.6 km - 3.6 km)	not allowed	No	100-120	Interchange	4 / 6 / 8 lane freeway	3.3 - 3.7 m lanes	60 - 120 m (60 m)	No	No	No	No
	2	Major arterial	Highway	Yes (M/R)	800 m (± 15%)	Not allowed*/**	No	80	Co-ordinated traffic signal, Interchange	4 / 6 lane divided, kerbed	3.3 - 3.6 m lanes	38 - 62 m (40 m)	Yes at inter-sections	Off road	Yes – widen roadway	No
	3	Minor arterial	Main road	Yes (M)	600 m (± 20%)	Not allowed*/**	No	70	Co-ordinated traffic signal, roundabout	4 lane divided or undivided, kerbed	3.3 - 3.5 m lanes	25 - 40 m (30 m)	Yes at inter-sections	Yes	Yes – widen roadway	No
Access / Activity	4a	Collector street, commercial	Commercial major collector	No (A for temp. routing)	> 150 m	Yes (larger properties)	Yes if conditions allow	60	Traffic signal, roundabout or priority	4 lane, median at ped. xing., boulevard, CBD one-way		20 - 40 m (25 m)	Yes at inter-sections or mid block	Yes	Yes, widen road or on verge	Median for peds, curved roadway
	4b	Collector street, residential	Residential minor collector	No	> 150 m	Yes	Yes if appropriate	50	Roundabout, mini-circle or priority	2 / 3 lane undivided	6 - 9m roadway, < 3.3 m lanes	16 - 30 m (20 m)	Yes anywhere	Yes	Yes, on road or verge	Raised ped, median, narrow lanes
	5a	Local street, commercial	Commercial access street	No		Yes	Yes if conditions allow	40	Priority	2 lane plus parking		15 – 25 m (22 m)	If applicable, anywhere	Normally yes	Use roadway	Raised ped. crossing
	5b	Local street, residential	Local residential street	No		Yes	Yes on verge	40	Mini-circle, priority or none	1 / 2 lane mountable kerbs	3.0 - 5.5 m roadway (two way)	10 - 16 m (14 m)	If applicable, anywhere	Not normally, pedestrians can use roadway	Use roadway	Yes, but should not be necessary
	6a	Walkway, non-motorized priority	Pedestrian priority	No	500 m maximum	Yes	Yes if parking lot or woonerf	15	None, pedestrians have right of way	Surfaced			If applicable, anywhere	Yes or use roadway	Rare	Yes
	6b	Walkway, non-motorized only	Pedestrian only	No	500 m maximum	Yes	No vehicles	peds. 80 m / minute	None, pedestrian signal	Block paving		6 m		Yes	Yes	

** Access to properties sufficiently large to warrant a private intersection / interchange can be considered if access spacing requirement met and there is no future need for a public road.*

*** Partial and marginal access at reduced spacing allowed to relieve congestion, reduce excessive travel distances or remove the need for a full intersection*

APPENDIX C : SCENARIOS

C1. Scenarios 1 to 4

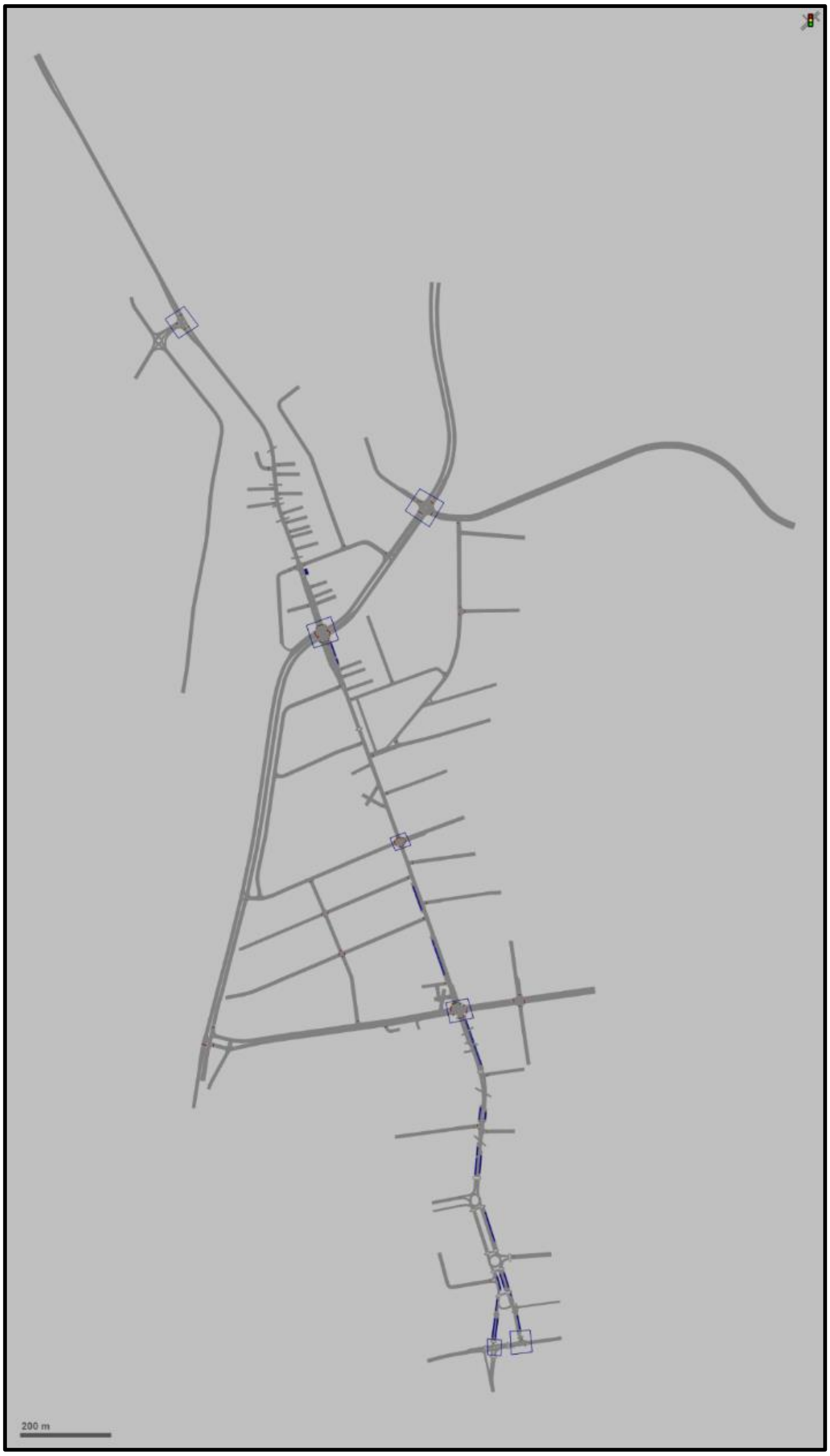

Figure C.1: Scenario category A (Scenarios 1 to 4)

C2. Scenarios 5 to 8

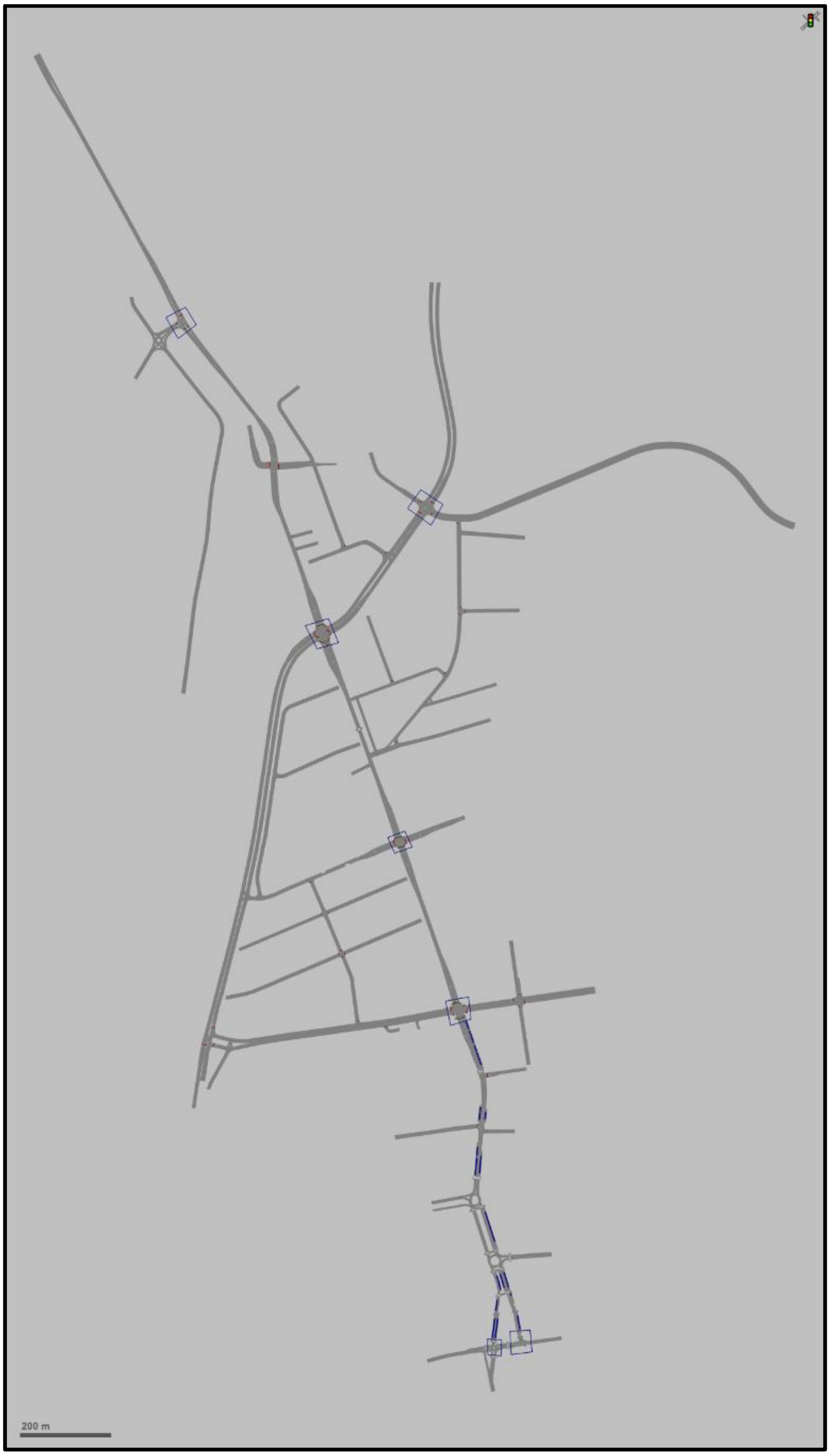

Figure C.2: Scenario category B (Scenarios 5 to 8)

C3. Scenarios 9 to 12

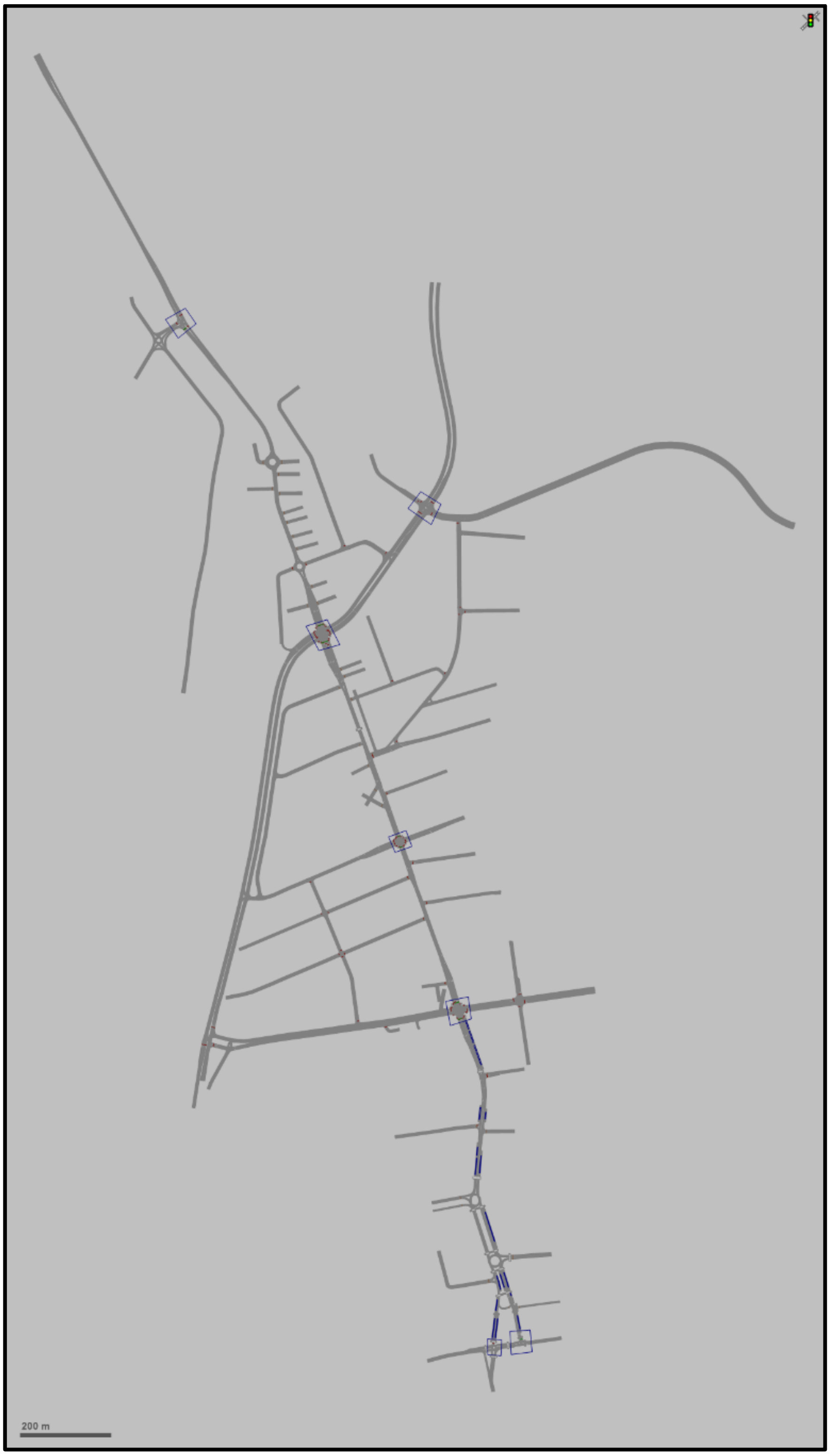

Figure C.3: Scenario category C (Scenarios 9 to 12)

C4. Scenarios 13 to 16

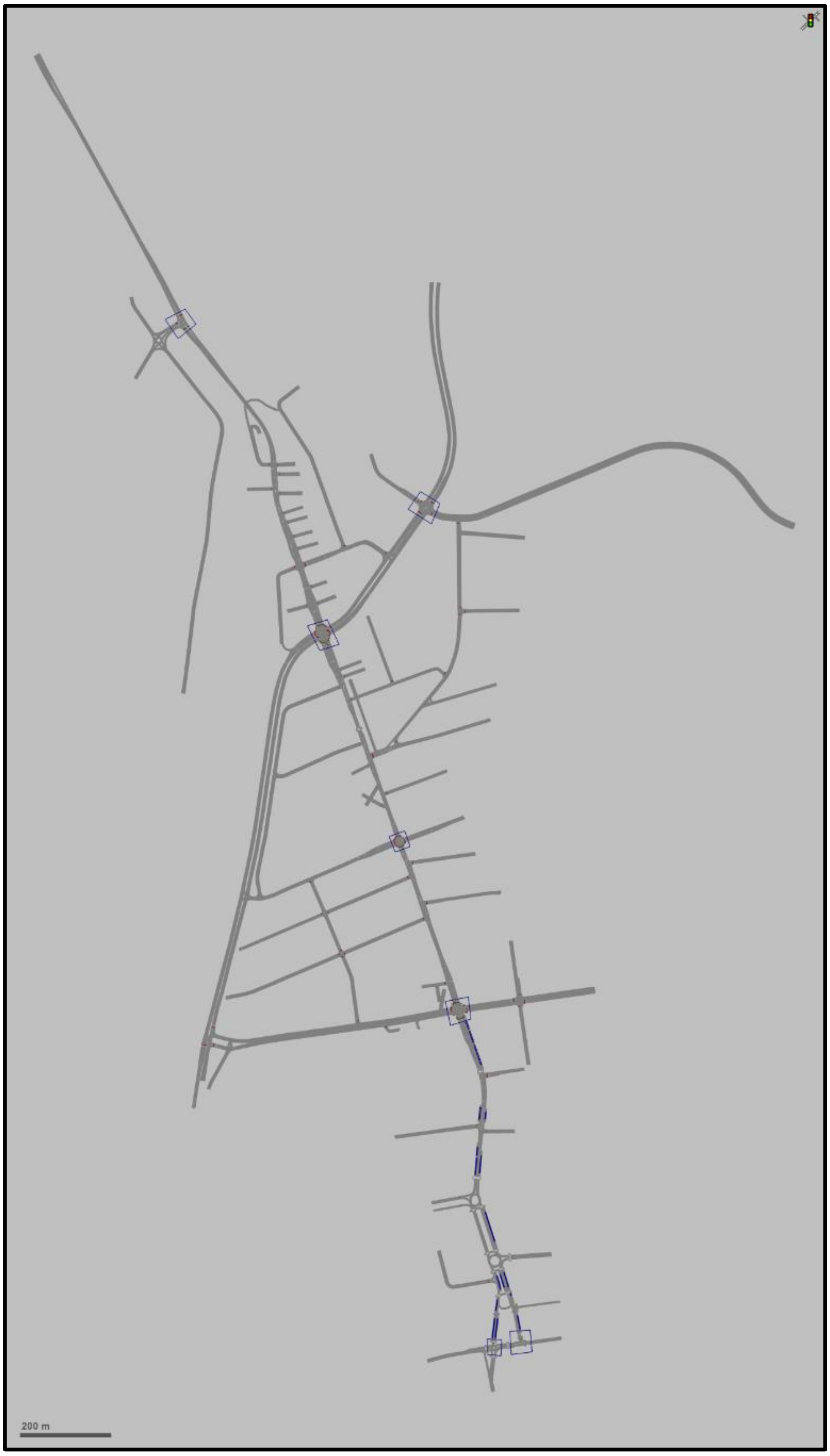

Figure C.4: Scenario category D (Scenarios 13 to 16)

C5. Scenarios 17 to 20

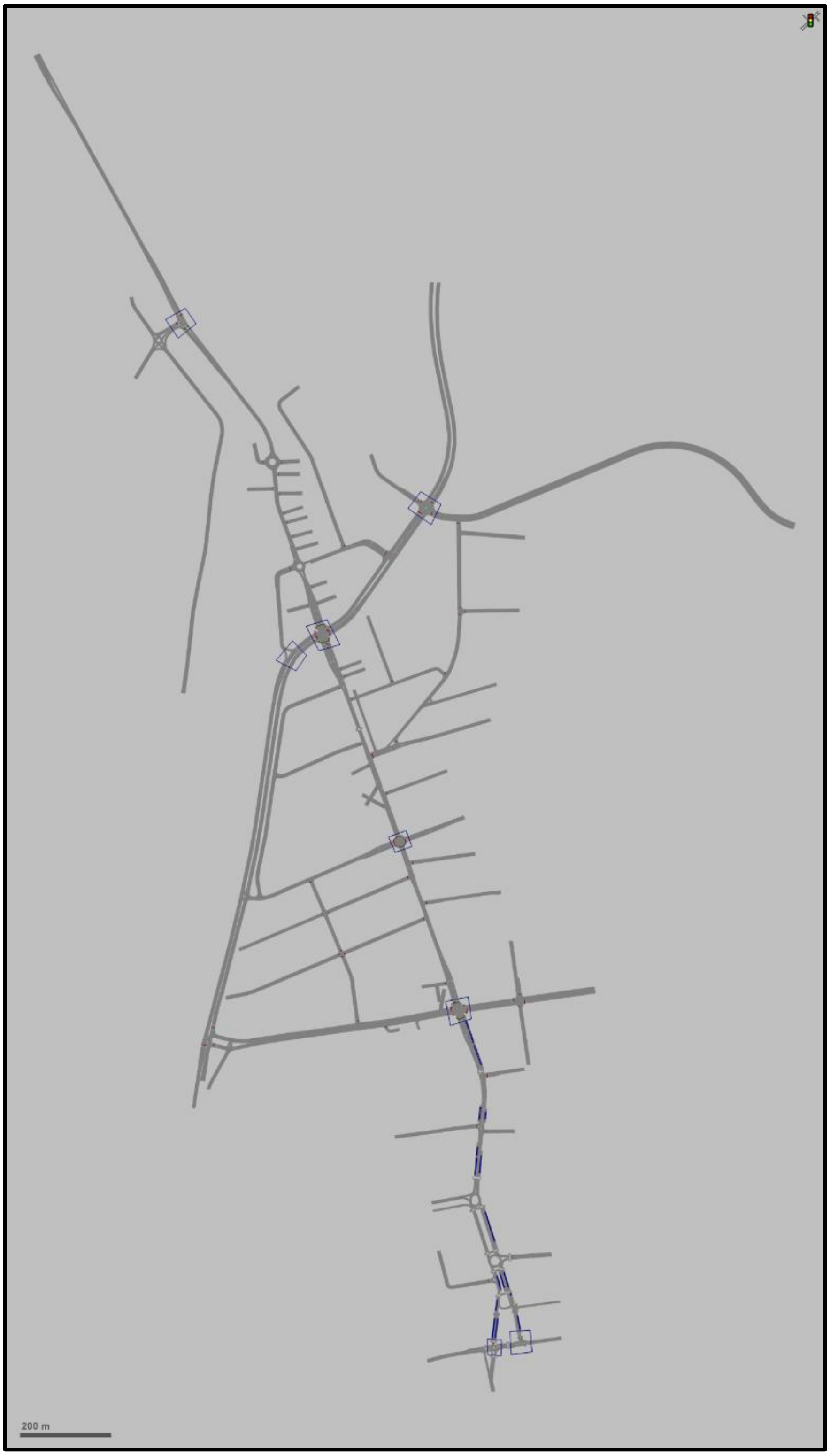

Figure C.5: Scenario category E (Scenarios 17 to 20)

C6. Scenarios 21 to 24

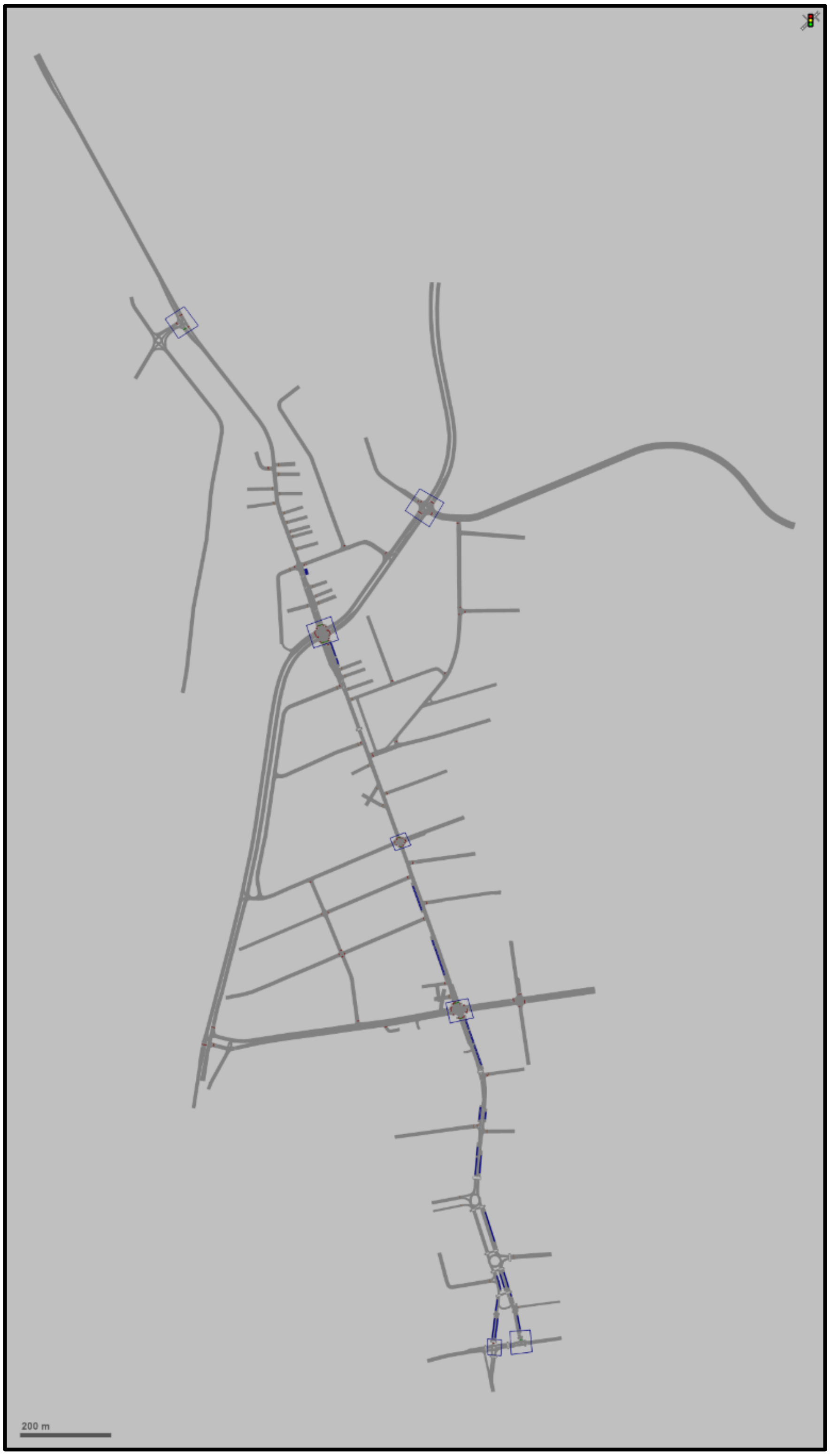

Figure C.6: Scenario category F (Scenarios 21 to 24)

C7. Requirements

The following standards/requirements were adapted from the TRH26 Manual (2012b).

C7.1 Intersection and Access Spacing

Table C.1: Minimum spacing requirements for full intersections on mobility roads (COTO, 2012b)

Class	Urban signals (*)	Urban roundabouts and priority (*)
Class 3	600 m ± 20%	600 m ± 20%

(*) These values can be halved for the leg of T-junctions and for one-way streets.

Table C.2: Minimum spacing recommendations for intersections on access streets (COTO, 2012b)

Class	Urban signals	Urban roundabouts and priority
Class 4a	200 – 300 m	200 – 300 m

Table C.3: Minimum access separation for class U3 roads (COTO, 2012b)

Intersection / access configuration	Class 3
Right-turn lanes not required at any of the intersections	125 – 150 m
Right-turn lanes required at one intersection only	125 – 150 m
Right-turn lanes required in series at both intersections*	200 – 250 m
Service station upstream of intersection**	100 – 125 m
Service station downstream of intersection***	125 – 150 m

* The separation requirements for this configuration can be reduced in situations where the right-turn lanes at the two intersections can be provided in parallel rather than in series.

** The requirements are only applicable when no bus stop is required between the access and the intersection. Otherwise, the separation applicable for accesses downstream from an intersection must be applied.

*** The separation provides for a bus stop downstream of the intersection. Where a bus stop is not required (now or in the future), the upstream spacing may be used.

C7.2 Auxiliary Lanes

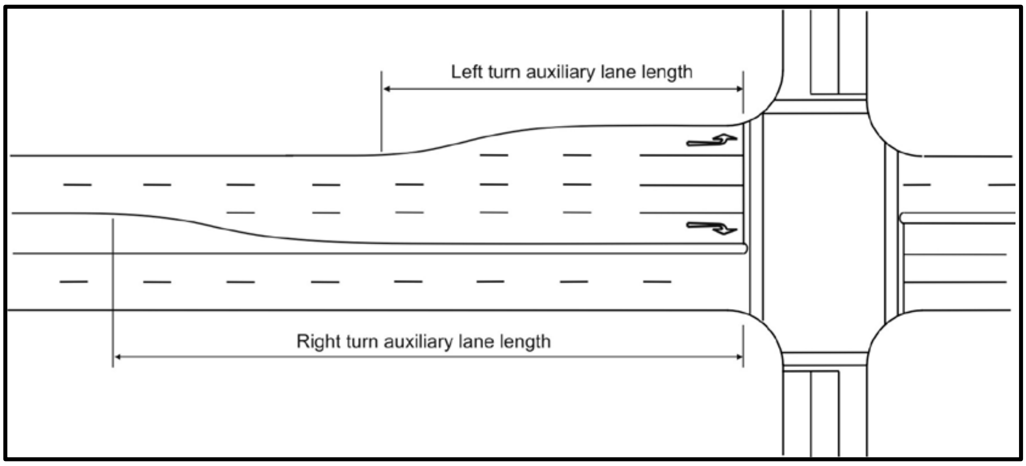

Figure C.7: Auxiliary turning lanes (COTO, 2014)

Table C.4: Auxiliary turning lane lengths at signalised intersections (COTO, 2014)

Description	Left turn lane	Right-turn lane lengths (m) for right-turn flow rates of:								
Right-turn flow rate		**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
Urban Class 3 Roads	85	90	105	120	135	150	165	180	195	210
Urban Class 4 Roads	65	80	95	110	125	140	155	170	185	195

1) Right-turn flow rate in units of veh/h per lane

2) Turning lane lengths include approach taper

APPENDIX D : DATA MEASUREMENTS PARAMETERS DEFENITIONS

For each of the four data collection/evaluation measurements, the definitions (as defined by Vissim) of the parameters identified for each measurement, will be defined in **Section D1** to **D4** below.

D1. Data Collection Measurements

Number of vehicles - Count of vehicles of the data collection measurement in the time interval.

D2. Node Evaluation

Queue length (m) – In each time step, the current queue length is measured, and the arithmetic mean is thus calculated per time interval.

Queue length (Max) (m) – In each time step, the current queue length is measured, and the maximum is thus calculated per time interval.

Vehicles (All) – Total Number of vehicles.

LOS value – Level-of-service as numerical value (1 to 6) as computed by the associated LOS scheme. Value 1 corresponds to LOS 'A', 6 to LOS 'F'.

Vehicle delay (All) (s) – The delay of a vehicle in leaving a travel time measurement is obtained by subtracting the theoretical (ideal) travel time from the actual travel time. The theoretical travel time is the travel time which could be achieved if there were no other vehicles and/or no signal controls or other reasons for stops. Reduced speed areas are taken into account. The actual travel time does not include any passenger service times of PT vehicles at line stops and no parking time in real parking lots. The delay due to braking before a PT stop and/or the subsequent acceleration after a public transport (PT) stop are part of the delay.

Stopped delay (All) (s) – Stopped delay per vehicle in seconds without stops at PT stops and in parking lots.

Stops (All) – Number of vehicle stops per vehicle without stops at PT stops and in parking lots.

Emissions CO (grams) – Quantity of carbon monoxide.

Emissions NOx (grams) – Quantity of nitrogen oxides.

Emissions VOC (grams) – Quantity of volatile organic compounds.

D3. Vehicle Network Performance Evaluation

Delay (avg) (s) – Total delay / (total number of vehicles (veh) in the network + total number of vehicles that have arrived).

Stops (avg) – Total number of stops / (total number of veh in the network + total number of veh that have arrived).

Speed (avg) (km/h) – Total distance (1) / Total travel time (2).

Delay stopped (avg) (s) – Average standstill time per vehicle. (Total standstill time / (total number of veh in the network + total number of veh that have arrived)).

Distance (total) (1) (km) – Total distance of all vehicles that are in the network or have already left it.

Travel time (total) (2) (s) – Total travel time of vehicles traveling within the network or that have already left the network.

Delay (total) (s) – Total delay of all vehicles that are in the network or have already left it. The delay of a vehicle in a time step is the part of the time step that must also be used because the actual speed is less than the desired speed. For the calculation, the quotient is obtained by subtracting the actual distance travelled in this time step and desired speed from the duration of the time step. The following are taken into account: (1) Passenger service times, (2) Stop times at stop signs, (3) Stop Delay. The following are not taken into account: (1) Stop times of buses/trains at PT stops.

Stops (total) – Total number of stops of all vehicles that are in the network or have already arrived. The following are not taken into account: (1) Scheduled stops at PT stops, (2) Stop in parking lots A stop is counted if the speed of the vehicle at the end of the previous time step was greater than 0 and is 0 at the end of the current time step.

Delay stopped (total) (s) – Total standstill time of all vehicles that are in the network or have already arrived. Standstill time = time in which the vehicle is stationary (speed = 0) The following are not taken into account: (1) Stop times of buses/trains at PT stops, (2) Parking times, regardless of parking lot type

Vehicles (arrived) – Total number of vehicles which have already reached their destination and have left the network before the end of the simulation.

Delay (latent) (s) – Total delay of vehicles that cannot be used (immediately). Total waiting time of vehicles from input flows and parking lots that were not used at their actual start time in the network. This value may also include the waiting time of vehicles that enter the network before the end of the simulation.

Demand (latent) – Number of vehicles that could not be used from input flows and parking lots. Number of vehicles that were not allowed to enter the network from input flows and parking lots until the end of the simulation. These vehicles are not counted as vehicles in the Vehicle active (vehicles in the network at the end of the simulation) network.

D4. Vehicle Travel Time Measurements

Vehicles (All) – Number of vehicles recorded between two points in the network.

Travel time (All) (s) – Average travel time of vehicles between two points in the network.

Distance travelled (All) (m) – Total distance travelled between two points in the network.