# ECONOMIC EVALUATION OF A FULLY INTEGRATED INTELLIGENT TRANSPORTATION SYSTEM IN STELLENBOSCH USING THE TOPS-BC TOOL

by

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## DECLARATION

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## ABSTRACT

Transportation plays a fundamental part in the social and economic functioning of a society, since it permits the movement of individuals and products to their destination. A reliable transportation system significantly affects the economic vitality of a nation and its capacity to make use of its natural assets. Cities have considerably improved their transportation system in order to ensure the availability of transport facilities.

Transport issues, specifically, traffic congestion and road safety cannot be solved by the construction of new road infrastructure, which in themselves have high time and cost implications. For this reason, various components of Intelligent Transportation Systems (ITS) are considered as innovative alternative solutions. The objective of ITS is to improve road traffic conditions using modern technology, which empowers transportation management and operations to ensure road safety and efficiency using existing road infrastructure.

ITS may not totally eradicate traffic congestion in Stellenbosch, but provide a fundamental parts that can yield more operational effectiveness from the current transportation network. It is a challenge to estimate the impacts of the ITS applied to the Stellenbosch transportation networks, because benefits from ITS deployments in the greater South Africa are poorly studied and understood as these technologies are still fairly new.

Stellenbosch currently has no formalised public transport system. The informal minibus taxi services mainly cater for the low-income residential areas and farm workers. Like various urban communities in South Africa, Stellenbosch still battles with the remnants of apartheid's spatial arranging structures and racial isolation, which created spatial disparities of access for various races. Poor communities exist on the edges of the urban areas and force them into long commutes to work and school, while pedestrian facilities and/or public transport are inadequate. Stellenbosch also caters for the mobility of a large student population, tourists and business entities, resulting in major traffic congestion problems.

The objective of this study is to provide an understanding of suitable ITS applications for Stellenbosch, by quantifying the benefits and costs that will result from the deployment of specific components of integrated ITS and operational strategies in Stellenbosch. There are different procedures to determine Benefit-Cost (B/C) ratios, but this thesis makes use of the Tool for Operations Benefit/Cost (TOPS-BC) that was developed by the Federal Highway Administration (FHWA) of the United States of America (USA). TOPS-BC is a spreadsheet-

based tool intended to help practitioners in evaluating the advantages of operations or ventures.

The B/C evaluation in this thesis compared ITS operations and deployment scenarios to a more conventional scenario that contain no ITS operation and deployment. TOPS-BC was intended to assess the particular benefits and costs of ITS deployments based on observed, real–world benefits and costs. It was used to gauge benefits, incorporating changes in travel time, travel time reliability, number and severity of accidents, vehicle emissions, fuel usage, and other essential measures.

The ITS facilities that constitute the Stellenbosch ITS deployment were identified from information provided by the local Stellenbosch Municipality Transportation and Planning Department. Data was extracted from the Stellenbosch mobility study, which was carried out in 2010.

To achieve the research objective two scenarios were tested. Firstly, to estimate the ITS deployment benefits in Stellenbosch, the following ITS operational strategies were analysed with TOPS-BC:

- Arterial Traffic Management System
- Parking Management System which is an application of En-Route Multimodal Traveller Information System

Secondly, the construction of the Stellenbosch Western Scenic Bypass was proposed as a traditional transportation strategy. This was evaluated and compared with abovementioned ITS operations strategies.

The overall B/C results indicate that the deployment of the proposed ITS strategies of the Stellenbosch Arterial Management System and the Stellenbosch Parking Management System yielded higher B/C ratio, compared to that of Stellenbosch Western Scenic Bypass.

Based on the assumptions of the research, it will be more beneficial for Stellenbosch Municipality to deploy these ITS strategies, than to have a roadway bypassing Stellenbosch.

## OPSOMMING

Vervoer is 'n noodsaaklike komponent in die maatskaplike en ekonomiese ontwikkeling van 'n gemeenskap, aangesien dit die beweging van mense en goedere na hul bestemming neem. Betroubare vervoerstelsels het 'n beduidende impak op die ekonomiese lewenskragtigheid van 'n land en op sy vermoë om van sy natuurlike hulpbronne gebruik te maak. Tans, met die groei van die bevolking wêreldwyd, het stede aansienlike verbetering in hul vervoerstelsels gemaak om die beskikbaarheid van vervoer fasiliteite te verseker.

Sekere vervoerprobleme, in die besonder verkeersopeenhopings en padveiligheid, kan nie uitsluitlik opgelos word deur die voorsiening van meer padinfrastruktuur nie, wat op sigself 'n hoë koste en tyd implikasies inhou. Om hierdie rede, word verskeie Intelligente Vervoer Systeme (IVS) beskou as innoverende alternatiewe oplossings. Die doel van IVS is om padverkeer toestande met behulp van moderne tegnologie te verbeter, en so vervoerbestuur en bedrywighede te bemagtig wat probeer om padveiligheid en doeltreffendheid te verbeter met behulp van bestaande padinfrastruktuur.

Alhoewel, IVS nie heeltemal verkeersopeenhopings in Stellenbosch uitroei nie, is hulle noodsaaklike komponente wat kan help om meer operasionele doeltreffendheid uit die bestaande vervoerstelsel te benut. Daar bestaan egter 'n uitdaging om die impak van die IVS te skat, wat toegepas word op die Stellenbosch vervoernetwerke, want voordele as gevolg van die IVS toepassing in die groter Suid-Afrika bly ‘n swak bestudeerde vak en die verstaan van hierdie tegnologie is nog redelik nuut.

Stellenbosch het tans geen formele openbare vervoerstelsel nie, behalwe vir die informele taxidienste, wat hoofsaaklik voorsiening maak vir die lae-inkomste woonbuurte en plaaswerkers. Soos die meeste ander stede in Suid-Afrika, sukkel Stellenbosch steeds met die oorblyfsels van apartheid se ruimtelike beplanning en rasse-segregasie wat ruimtelike ongelykhede van toegang vir verskillende rassegroepe geskep het, deurdat arm gemeenskappe aan die buitewyke van stedelike gebiede geplaas was en gedwing was om in 'n lang pendel na werk en skool , terwyl daar geen veilige voetganger fasiliteite of doeltreffende openbare vervoer verskaf was nie. Stellenbosch het 'n groot student bevolking asook 'n gereelde instroming van toeriste en sake-entiteite, wat lei tot groot verkeersopeenhopings probleme.

Die doel van hierdie studie is om 'n beter begrip van die mees geskikte IVS toepassing in Stelelnbosch te leen deur die voordeel en koste wat as gevolg van die implementering van 'n

geïntegreerde IVS en bedrywighede strategieë in Stellenbosch te kwantifiseer. Daar is verskeie metodes om voordeel/koste (v/k) verhoudings te bepaal, maar hierdie tesis sal gebruik maak van die *Tool for Operations Benefit/Cost (TOPS-BC)* sagteware wat ontwikkel is deur die *Federal Highway Administration (FHWA)* van die Verenigde State van Amerika (VSA). TOPS-BC is 'n sigblad-gebaseerde instrument wat ontwerp is om die industrie te help met die beoordeling van die voordele van projekte vir bedrywighede.

Die voordeel-koste analise (v/k) wat in hierdie tesis gebruik word sal die bedrywighede en IVS ontplooiing opsies met ‘n meer tradisionele geval vergelyk wat geen bedrywighede en IVS ontplooiing bevat nie. TOPS-BC is ontwerp om die spesifieke voordele en koste van ontplooide IVS te baseer op waargenome, werklike wêreld koste en voordeel. TOPS-BC is 'n analise-instrument wat gebruik word om voordele, insluitend veranderinge in reistyd, reistyd betroubaarheid, aantal en erns van ongelukke, voertuigemissies, brandstof gebruik en ander belangrike maatreëls te skat.

Die IVS fasiliteite wat die ontplooiing van IVS in Stellenbosch uitmaak is geïdentifiseer met die hulp van inligting vanaf die plaaslike Stellenbosch Munisipaliteit se Vervoer en Beplanning Departement. Data vanuit die Stellenbosch Mobiliteit Studie, wat in 2010 verwerk was, was ook gebruik in hierdie studie.

Om die navorsing doelwitte te bereik en akkuraat die voordele van die IVS ontplooiing in Stellenbosch te bepaal, word die volgende verskillende IVS en strategieë ontplooiing ontleed met behulp van TOPS-BC:

- Hoofpad vervoerbestuurstelsel
- Parkeerbestuurstelsel wat ‘n deel uitmaak van die roete multimodale reisiger informasie stelsel

Laastens, is 'n tradisionele vervoerverbetering geëvalueer en vergelyk met bogenoemde IVS strategieë. Die algehele v/k resultate dui daarop aan dat die ontplooiing van die voorgestelde IVS strategieë binne die Stellenbosch Arteriële Bestuur Sisteem en die Stellenbosch Parkering Bestuur Sisteem sal na verwagting die hoogste voordeel/ kosteverhouding lewer, in vergelyking met dié van die Stellenbosch Westerse Toerisme Verbypad.

Dit sal dus meer voordelig wees vir Stellenbosch om hierdie IVS strategieë te ontplooi, as om 'n Stellenbosch verbypad te bou, by die oorweging van die behoefte om die vervoer opeenhoping in Stellenbosch te verminder.

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My sincerest thanks to the following:

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| | |
|---|---|
| APTS | Advanced Public Transportation Systems |
| ATIS | Advanced Traveller Information System |
| ATMS | Advanced Traffic Management System |
| BRT | Bus Rapid Transit |
| CCTV | Closed Circuit Cameras |
| CoCT | City of Cape Town |
| CVO | Commercial Vehicle Operation |
| DoT | Department of Transport |
| ETC | Electronic Toll Collection |
| FMS | Freeway Management System |
| IRT | Integrated Rapid Transit |
| ITS | Intelligent Transportation Systems |
| PWOB | Present Worth of Benefits |
| PWOC | Present Worth of Costs |
| SANRAL | South African National Road Agency Limited |
| TMC | Traffic Management Centre |
| TOPS-BC | Tool for Operations Benefit/Cost Analysis |
| USDoTFHWA | United States (of America) Department of Transport Federal Highway Administration |

# 1. Introduction

## 1.1. Overview

Transportation is an essential component in the social and economic functioning of a society, since it allows the movement of people and goods to their destination. A reliable transportation system has a significant impact on the economic vitality of a country and on its ability to make use of its natural resources. With the growth of the population and wealth worldwide, cities have considerably improved their transportation system in order to ensure the availability of transport facilities. Challenges still exist, resulting in an imbalance between the ever-growing demand and the slow increase in transport system supply.

Certain transport problems, in particular, traffic congestion and road safety, cannot solely be solved by the construction of more road infrastructures, which in themselves have high cost and time implications. In response to this dilemma and rapid development in technology, several information and communication technologies known as Intelligent Transportation Systems (ITS) are being applied worldwide in order to provide innovative solutions. The objective of ITS is to improve road traffic conditions using modern technology, which is empowering to transportation management and operations who seek to ensure road safety and efficiency using existing road infrastructure.

Stellenbosch was selected for this research to represent the small urban area (due its complex transportation situation) to perform a course economic analysis of an integrated ITS System in the Western Cape Province. Various scenarios were considered to represent the deployment of ITS operations in Stellenbosch. These different cases were evaluated in order to quantify the cost and the benefits of the deployment. This was compared to a traditional road construction strategy.

Stellenbosch currently has no formalized public transport system, except for the informal minibus taxi services, which mainly caters to the low-income residential areas and farm workers. Like various urban communities in South Africa, Stellenbosch still battles with the remaining parts of apartheid's spatial arranging and racial isolation which created spatial disparities of access for various racial gatherings. This left poor communities on the edges of urban areas and forced them into long commutes to work and school, while no safe pedestrian facilities or effective public transport was offered.  Stellenbosch also caters to a large student population and a frequent influx of tourists and business entities, resulting in major traffic congestion problems.

ITS may not eradicate traffic congestion in Stellenbosch, but they are essential components that can help to squeeze more operational efficiency out of the existing transportation system.

There is a challenge in estimating the impacts of ITS operations applied to the Stellenbosch transportation networks, because benefits due to ITS deployment in the greater South Africa remain poorly studied and understood as these technologies are still fairly new.

### 1.2. Problem Statement

The objective of this study is to provide an understanding of the ITS application within the Stellenbosch context, by conducting an economic evaluation of the applicable ITS strategies in Stellenbosch and compare with traditional new road construction strategy. Benefits and costs that will result from the deployment of integrated ITS strategies in Stellenbosch will be quantified to determine the appropriate ITS deployment that make sense from an economic perspective and compared to the benefit-cost (B/C) analysis building of a bypass.

There are various methodologies to ascertain B/C ratios. This thesis will make use of the Tool for Operations Benefit/ Cost (TOPS-BC) that was developed by the Federal Highway Administration (FHWA) of the United States of America (USA). TOPS-BC is a spreadsheet-based tool designed to assist practitioners in assessing the benefits of operations projects.

The B/C evaluation employed in this thesis will compare ITS deployment to more conventional road construction that contain no ITS deployments. TOPS-BC was intended to assess the particular benefits and costs of ITS deployments based on observed, real–world advantages and expenses. TOPS-BC is an investigation tool used to gauge benefits, incorporating changes in travel time, travel time reliability, number and seriousness of accidents, vehicle emissions, fuel usage, and other essential measures and costs.

The ITS facilities that constitute the Stellenbosch ITS deployment were identified with the information provided by the local Stellenbosch municipality transportation and planning department. Data on traffic movements and delays were extracted from the Stellenbosch mobility study, which was carried out in 2010.

To achieve the research objectives and estimate the ITS deployment benefits in Stellenbosch, the following ITS strategies were analysed with TOPS-BC:

- Arterial Traffic Management System

- Parking Management System (an application of En-Route Multimodal Traveller Information System)

A traditional road construction was also evaluated and compared with abovementioned ITS strategies. The two B/C ratios were then compared to understand application of ITS in Stellenbosch.

### 1.3. Outline of Study

Chapter 1 provides an overview of the challenges experienced in transportation facilities in South Africa, in particular Stellenbosch, which forms part of the research problem. This chapter also discusses the objectives that are required for this thesis and states the outline that was followed to carry out the research project.

Chapter 2 discusses the status of ITS in South Africa and Stellenbosch, which will form the background of this research study. This chapter discuss various benefit-cost analysis principles, basic ITS elements, ITS strategies, and their likely benefits.

Chapter 3 presents and explains the methods used to gather and manipulate the information used in this research study together with the procedures used to conduct the economic evaluation for the different ITS deployments and conventional traditional road building strategy using TPS-BC.

Chapter 4 details the findings of the research study. This chapter discusses the results obtained from the TOPS-BC analysis.

Chapter 5 completes the study by discussing the conclusions and recommendations for future research work.

A list of references that aided this research study as well as the appendices that formed part of this thesis, are provided.

# 2. Literature Study

## 2.1. Status Quo: Stellenbosch

### 2.1.1. Demographic and Socio-Economic Position

Stellenbosch is a town situated in the Western Cape Province of South Africa, located approximately 50 kilometres, east of Cape Town. Stellenbosch was the second town founded in South Africa by European settlers. Many of the buildings and road system in Stellenbosch dates back to the 19th century, making Stellenbosch an important heritage site for South Africa. Stellenbosch experiences a high growth, because of its prestige as a national as well as an international tourist destination, a sought after residential and retirement town, the South African wine making centre, a popular zone for business head offices and the influence of a fast expanding university (Van der Merwe, 2004).

Stellenbosch's Municipal Area consists of Stellenbosch, Klapmuts, Pniel, Franschhoek and Pniel, and covers an overall area of 831 km$^2$, which also forms part of the Cape Winelands District Municipality. Figure 2-1 provides an illustration of the Stellenbosch Municipal location.

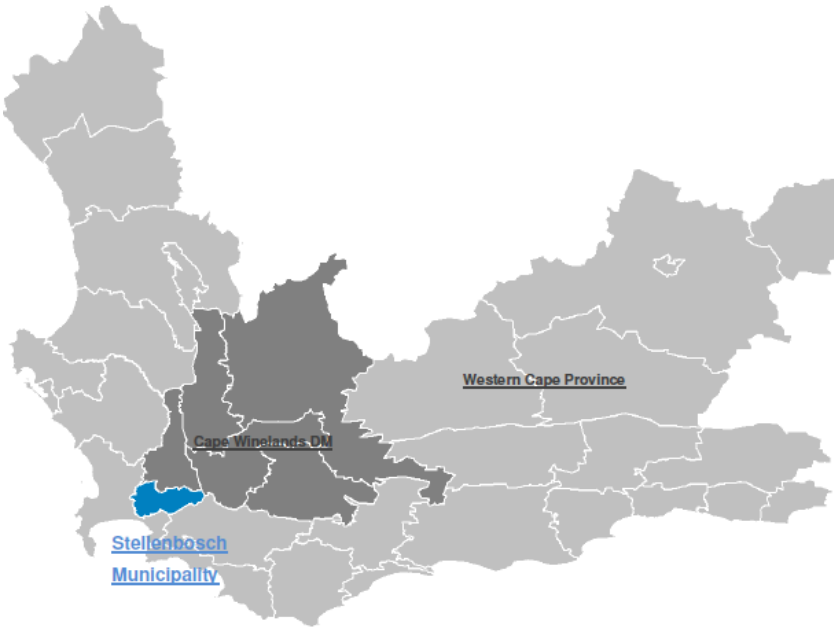



**Figure 2-1: Stellenbosch Municipal Area (Vela VKE, 2011)**

The demographic and socio-economic statistics of the Stellenbosch region shows that the area experiences a population growth rate of 2.7% and that only 37% of the population contribute to the GDP. The student population does not directly contribute to the GDP, which places economic pressure on the fragment of the population who do directly contribute. This leads to financial constraints, which can deter investment in the region (CNdV Africa, 2010a).

## 2.2. Stellenbosch Transportation System

The National Land Transport Act (NLTA), Act 5 of 2009, requires that district and local authorities compile a package of plans to give effect to the requirements and provisions of the NLTA. In November 2007, the Minister of Transport published in the Government Gazette No. 30506, the minimum requirements and regulations for the preparations of Integrated Transport Plans (ITP's). The Municipality of Stellenbosch appointed Vela VKE Engineers in 2010, to compile a Comprehensive Integrated Transport Plan (CITP) for the Stellenbosch municipal area. It was completed in 2011 with 2009 as base year for data.

### 2.2.1. Public Transportation System

#### *2.2.1.1. Minibus Taxi*

Minibus Taxi services are provided by licenced and unlicensed 15 seater vehicles operating from ten different minibus facilities, of which only two are formal minibus facilities, one at Bergzicht and one at Lanquedoc taxi ranks. Three minibus taxi associations currently operating in the region are the Stellenbosch, Kayamandi and Franschhoek Taxi Associations (Vela VKE, 2011). Figure 2-2 provides an illustration of the taxi ranks in the Stellenbosch area.


**Figure 2-2: Location of taxi ranks within the Stellenbosch Municipal Area (Vela VKE, 2011)**

Arup Transport Planning (2007) reported that minibus taxi services cover mostly the low income residential areas and farm workers. On any particular weekday, about 100 taxis can be found operating on 27 different routes, carrying approximately 7500 passengers on 940 vehicle trips. The majority of taxi service users are commuters, evident during the morning peak hour between 07:00 and 08:00 when one third of the daily passengers are making use of the taxi services.

It has further been accounted for that around 78% of motorised trips made by low income residents are by means of public transport, mainly minibus taxis. Kayamandi, Idas Valley and Cloetesville are low-income neighbourhoods on the northern edge of Stellenbosch. Inhabitants of these areas make extensive use of public and non-motorised transport such as walking (Vela VKE, 2011).

Minibus taxi vehicles currently do not meet the requisite standards for universal access and user-friendliness, resulting in disabled persons not being able to make use of the services. The offered taxi services are permitted to function on specific routes, but do not operate on a fixed schedule and there is no formal system for collecting fare. Taxi services are the primary mode of public transport for commuters in the Stellenbosch area (Vela VKE, 2011).

#### *2.2.1.2. Golden Arrow Bus*

Golden Arrow Bus Service (GABS) started a new bus service in January 2015 between Stellenbosch, Somerset West and Strand, which operates from Mondays to Fridays. This bus route operates twice daily, starting in Strand at 06:30 and ending in Stellenbosch at 07:30. In the afternoon, the bus service starts in Stellenbosch at 16:50 and ends in Strand at 17:40 (GABS, 2012). The route description can be seen in Figure 2-3.


**Figure 2-3: Golden Arrow Bus Route for Stellenbosch Area (GABS, 2012)**

#### *2.2.1.3. Passenger Rail*

There are currently seven railway stations operating within the Stellenbosch area. These are Klapmuts, Muldersvlei, Koelenhof, Du Toit, Stellenbosch, Vlottenburg and Lynedoch (Vela VKE, 2011).

Metrorail is the current operator of the passenger railway system and is a branch the Passenger Rail Agency of South Africa (PRASA), which offers a scheduled service to passengers. Metrorail offers its service to a number of locations within the Stellenbosch region via its northern line, which starts from Cape Town and proceeds to Bellville, via Goodwood. From Bellville passengers have an option to travel to Stellenbosch via Eerste River or via Muldersvlei (Metrorail, 2007).

### 2.2.2. Private Transportation

#### *2.2.2.1. Major Road Network*

A network of Provincial Main Roads including the R44, R310, R304, R101 and R45 as well as a network of Municipal Roads.

#### *2.2.2.2. Levels of Congestion on Major Road Network*

Ercan (2013) stated that increases in population, number of vehicles and vehicle miles travelled (VMTs) are general causes of traffic congestion. Congestion has a number of negative impacts on society.

Sinclair et al., 2012 argued that saturated traffic flows are economically costly, making significant contributions to production loss, economic inadequacy of commercial entities and challenges in service delivery in an area. They likewise contended that traffic congestion directly affects the psychosocial soundness of a population, which is connected to an increased level of transport related anxiety, depression, aggression and disaffection.

Pienaar (1981) described that vehicle operation costs increase significantly during periods of congestion and that the situation is exaggerated by the accelerating and decelerating actions required during stop-start driving. It was furthermore found that traffic associated gas-form and particulate pollutants increase as a result of congestion. Respiratory illnesses in children in particular have directly resulted from traffic congestion pollution (Carslaw et al., 2006).

Stellenbosch is a university town where traffic flow is negatively affected by the movement of students. A study compiled by Stellenbosch municipalities in the Stellenbosch Transportation Master Plan showed that Stellenbosch is in dire need of mobility (Vela VKE, 2011). A survey conducted at the main campus of the University of Stellenbosch (US) amongst students and personnel showed that the number of students attending the university has increased over the last decade. At the time of the survey in 2010, approximately 21 000 students were enrolled at the University. Of those who attended class on campus it was found that roughly:

- 7 000 (33%) live in or near the core campus
- 7 000 (33%) live in Stellenbosch town or immediate surrounding area,
- 7 000 (33%) live in surrounding towns or the Cape Metro

Table 2-1 summarises the outcome of the survey and indicate that a high proportion of students travel to campus by car with only 22% using non-motorised modes of travel (NMT), despite the fact that approximately 14 000 students live in the town of Stellenbosch.

Of those who do use NMT modes, preferred walking over cycling due to a lack of cycling facilities and negative preceptions on cyclists safety.

**Table 2-1: Main Mode of Travel to and from Stellenbosch University (Vela VKE, 2011)**

| Main Mode of Travel to and from Stellenbosch University | Students (%) | Personnel (%) |
|---|---|---|
| **Car** | 52 | 86 |
| **Motor Cycle** | 1 | 1 |
| **Combination (Mainly Public Transport & Walking)** | 25 | 6 |
| **Bicycle** | 3 | 4 |
| **Walking** | 19 | 3 |

Currently the majority of Stellenbosch's main road intersections are congested, especially during the morning peak hours. Stellenbosch is experiencing an average growth rate in vehicles of 6.2% per year compared to the Western Cape Province annual growth rate of 3.7%. If this growth rate continues in the coming years the traffic volumes will triple, which will worsen the traffic problem in the town (Sinclair et al., 2012). Table 2-2 shows the existing and estimated traffic volumes for the major roads in Stellenbosch.

**Table 2-2: Average Annual Traffic (AADT) volumes on the selected roads of Stellenbosch in 2009 (Sinclair et al., 2012)**

| Counting Station | Light Vehicles (LV) | | Heavy Vehicles (HV) | Future Light Vehicles (FLV) | Future Heavy Vehicles (FHV) |
|---|---|---|---|---|---|
| | Observed 2000 | Observed 2009 | Observed 2009 | Projected 2030 | Projected 2030 |
| R44 Blaauwklippen | 20510 | 35406 | 1266 | 73224 | 3213 |
| R44 Cloetesville | 12928 | 19339 | 1106 | 39995 | 2 824 |
| R304 Kayamandi | 14151 | 18247 | 867 | 37737 | 2 203 |
| R310 Polkadraai | 13641 | 19207 | 1216 | 39722 | 4 360 |
| Helshoogte | 5358 | 6893 | 373 | 14256 | 1 131 |

Figure 2-4 illustrates the traffic volumes double in 9 years along the major roads of Stellenbosch, as reported by Sinclair et al., (2012).

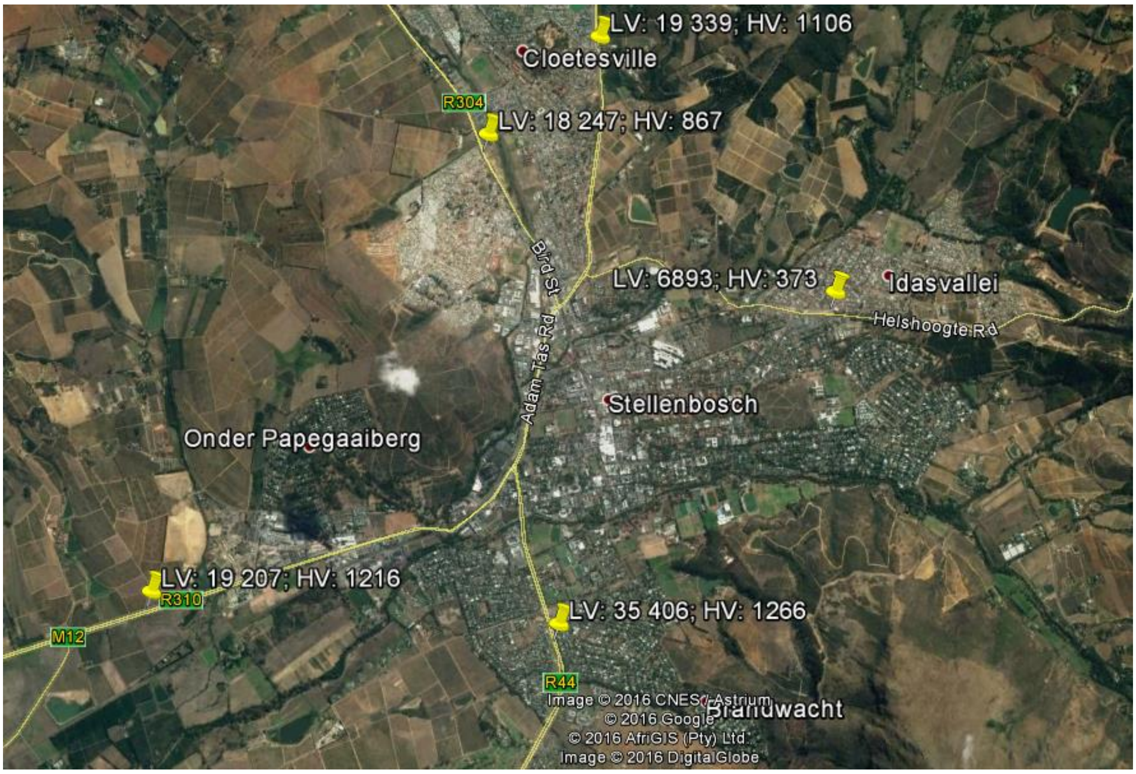



**Figure 2-4: Average Annual Daily Traffic for Major Roads in Stellenbosch in 2009 (Sinclair et al., 2012)**

High accident rates are also found along these high volume congested major routes as illustrated in Figure 2-5.

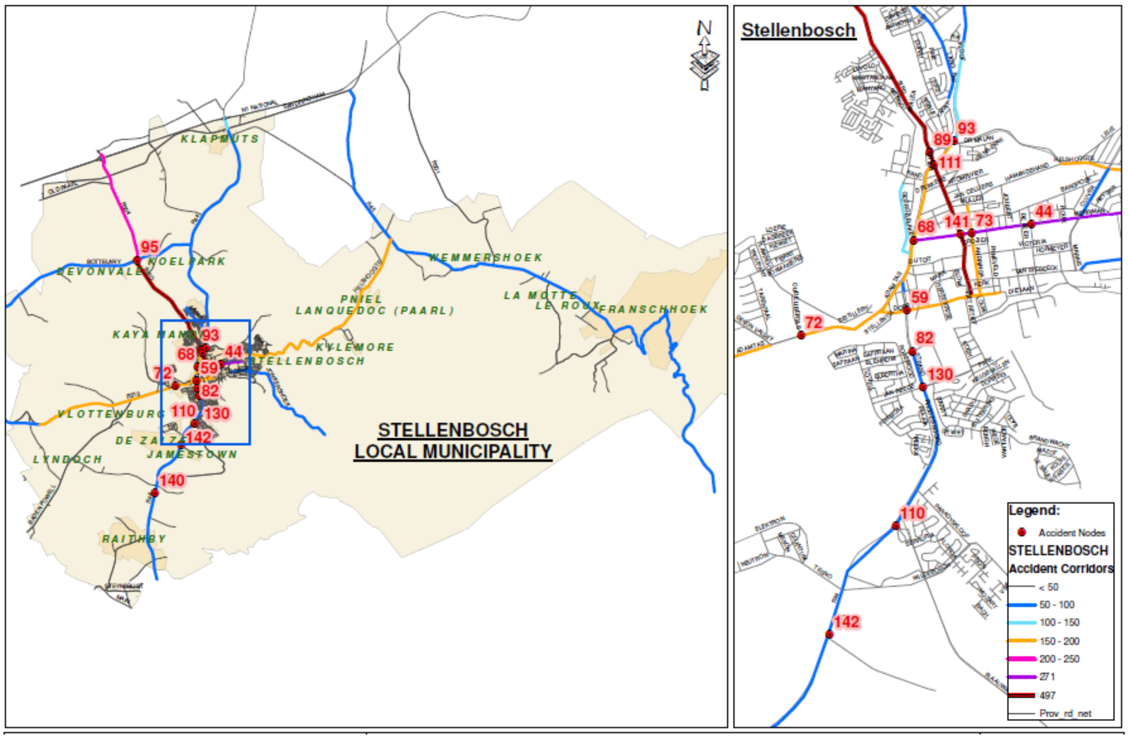



**Figure 2-5: Accident Locations in Stellenbosch (Vela VKE, 2011)**

The increase in the numbers of vehicles on Stellenbosch road networks can be attributed to inadequate and unreliable public transport, hence many travellers prefer to use private vehicles to Stellenbosch. A large number of people visit the town of Stellenbosch for tourism, research, business and conferences while others pass through on their way to other towns.

Traffic signals along the main congested routes in Stellenbosch are not part of an integrated system. Traffic signals are operating in isolation. Traffic volumes were expected to double by 2009 and have dire effects for the main routes in and around Stellenbosch. Some feasible solutions were proposed in the Stellenbosch Transportation Master Plan to alleviate the problems of the Stellenbosch Transportation System. These solutions included the construction of a western bypass to alleviate traffic on the R44 and R310, construction of new parking areas and promotion of the NMT and development of a Public Transportation System (Vela VKE, 2010).

#### *2.2.2.3. Parking in Stellenbosch*

Future anticipated traffic volumes for the town of Stellenbosch indicate that volumes in 2009 can triple by 2030. This traffic growth will have negative effects on traffic mobility and will worsen the current parking shortage in Stellenbosch, for business, education and tourism.

Table 2-3 presents the parking shortfall experienced in Stellenbosch.

**Table 2-3: Stellenbosch Parking Shortfall (Vela VKE, 2010)**

| Class | Total | Rate (%) | Parking Spaces |
|---|---|---|---|
| **Personnel** | 1872 | 82.06 | 1536 |
| **Students** | 14000 | 43.25 | 6055 |
| **Parking Demand** | | | 9591 |
| **Parking Spaces Available** | | | 1844 |
| **Theoretical Parking Shortfall** | | | 5747 |
| **Timeshare Adjustment (40%)** | | | 3448 |

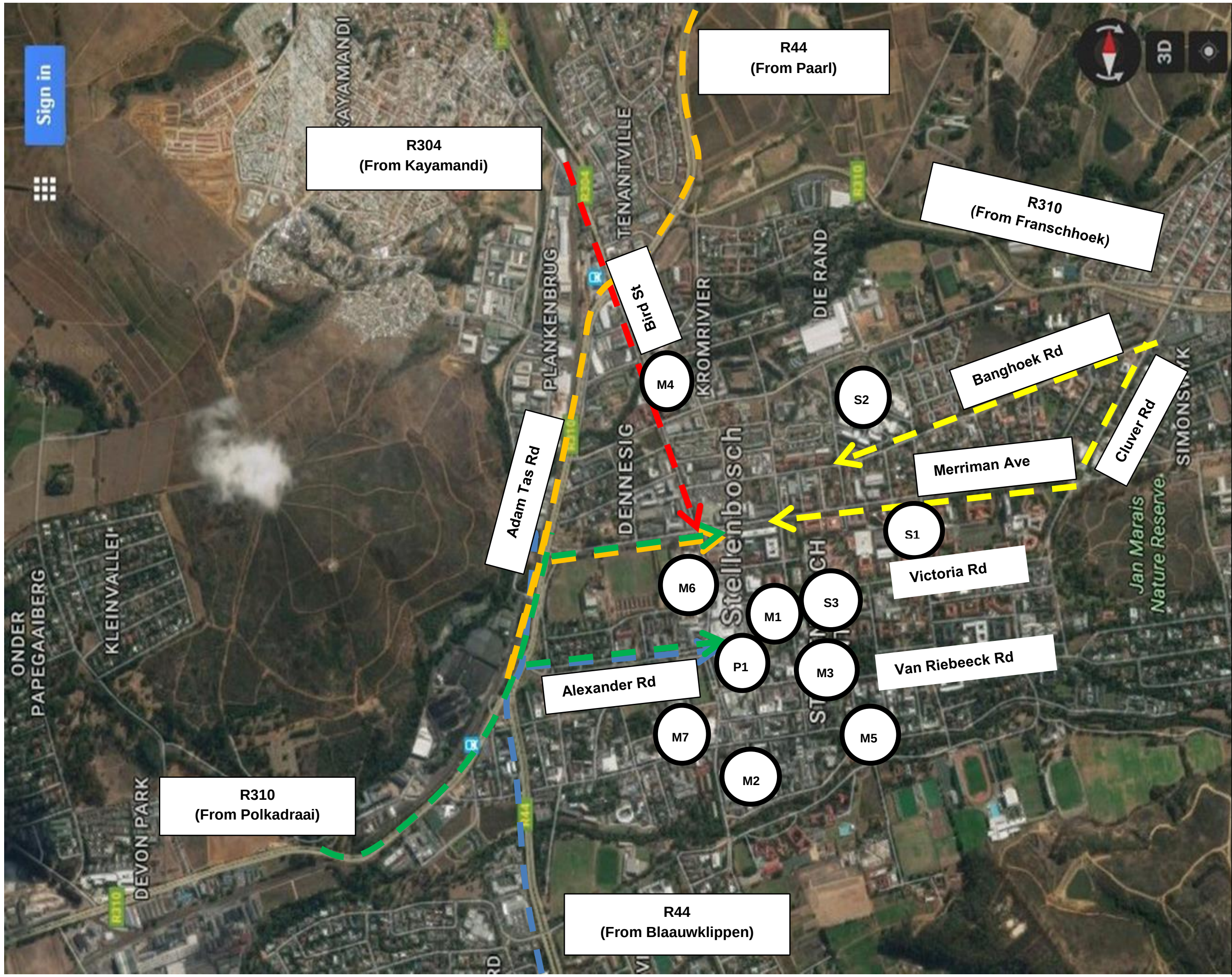
The parking facilities of Stellenbosch are composed of controlled parking by the Stellenbosch Municipality and controlled parking by the University of Stellenbosch.

Table 2-4 presents the parking facilities currently available in the Stellenbosch area.

**Table 2-4: Parking Facilities in the Stellenbosch Area in 2009 (Stellenbosch Vela VKE, 2010)**

| Parking Facility Name | Parking Key | Capacity | Average Utilisation (%) | Average Duration of Stay (Hour) |
|---|---|---|---|---|
| **Eikestad** | M1 | 293 | 75 | 1h00 |
| **Stelcor** | M2 | 206 | 84 | 2h45 |
| **Bloemhof** | M3 | 179 | 87 | 5h00 |
| **Stelmark** | M4 | NA | NA | NA |
| **Noordwal** | M5 | NA | NA | NA |
| **Aandklas** | M6 | 78 | 50 | 1h45 |
| **Checkers** | M7 | NA | NA | NA |
| **Neelsie** | S1 | 155 | 92 | 3h15 |
| **Engineering** | S2 | NA | NA | NA |
| **Sasol Art Museum** | S3 | NA | NA | NA |
| **Eikestad Underground** | P1 | NA | NA | NA |

Figure 2-6 presents an illustration of the current parking locations in Stellenbosch.




| Parking Key | Parking Facility Names |
|---|---|
| M1 | Eikestad |
| M2 | Stelcor |
| M3 | Bloemhof |
| M4 | Stelmark |
| M5 | Noordwal |
| M6 | Aandklas |
| M7 | Checkers |
| S1 | Neelsie |
| S2 | Engineering |
| S3 | Sasol Art Museum |
| P1 | Eikestad Underground |
| **Legend** | |
| ○ | Parking Facility |
| S | Stellenbosch University Parking |
| M | Municipality Parking |
| P | Private |
| SCALE 1:50 000 | |

**Figure 2-6: Current Parking Facilities in Stellenbosch (Vela VKE, 2010)**

During the last decade, parking management worldwide is considered a solution to reduce traffic congestion during the peak hours by avoiding loss in traveller time while using the road capacity in search of available parking (TRH 26, 2012).

On-street parking significantly affects road safety as well as the capacity of the street. The Access Management Manual (TRB, 2003), indicated that banning of on-street parking could prompt a 30% increase in traffic flow and 20% to 40% reduction in impacts.

In a literature review on the effects on-street parking have on accidents, Paul Box (TRB, 2001) found that kerb parking, if permitted, contributes unduly to accidents, varying from approximately 40% of total accidents in two-way major streets, to 70% on local avenues. Higher extents occurred for one-way avenues.

Traffic congestion and road safety influence the everyday lives of Stellenbosch inhabitants and visitors and constitute the main transport difficulties that need to be addressed to develop a future that is sustainable.

In addition to these transportation problems, there are poor traffic management, lack of proper and safe public transport, inadequate provision of NMT. Stellenbosch can recognize the key segments of a future transport framework for its inhabitants from these problems and issues.

Stellenbosch requires an integrated transportation system that makes sufficient provision for all its road users and successfully addresses their requirements for accessibility, mobility and safety. This must be accomplished through responsible planning to establish a system that is financially proficient, socially stable and environmentally sustainable (Sinclair et al., 2012).

## 2.3. Intelligent Transportation Systems (ITS)

### 2.3.1. ITS Definition

The U.S. Federal Highway Administration (2012) defines intelligent Transportation Systems (ITS) as follows:

“The application of advanced sensor, computer, electronics and communication technologies and management strategies, in an integrated manner, to increase the safety and efficiency of the surface transportation system”.

Intelligent Transportation Systems (ITS) contain a broad choice of systems and methodologies that are implemented as stand-alone applications or as enhancements to existing transportation techniques or facilities.

Challenges have previously been reported with consolidating ITS into the planning procedures of transport divisions, mostly on the grounds that ITS has frequently been characterised as an ensemble of support features as opposed to an arrangement of transportation strategies governed by particular objectives (US Federal Highway Administration, 1998).

One major contribution to sustainable transportation development is the application of Intelligent Transportation Systems (ITS) across transportation departments worldwide. ITS helps mitigate problems such as traffic congestion, air quality, and safety without constructing additional roads (Bekiaris & Nakanishi, 2004).

### 2.3.2. Sustainable Transportation Development

Improvements in transportation systems have resulted in direct advancement of economic growth as well as increased in social developments, due to greater mobility and better accessibility to people, resources and the market place.

There is however a concern that improved transportation systems will have associated costs (economic, social and environment) for current and future generations, and that accounting for each of these entities is needed for sustainable transport development (Zuidgeest, 2005).

Vanderschuren (2006) presented the following concept of integrating economic, social and environmental sustainability, as can be seen in Figure 2-7.

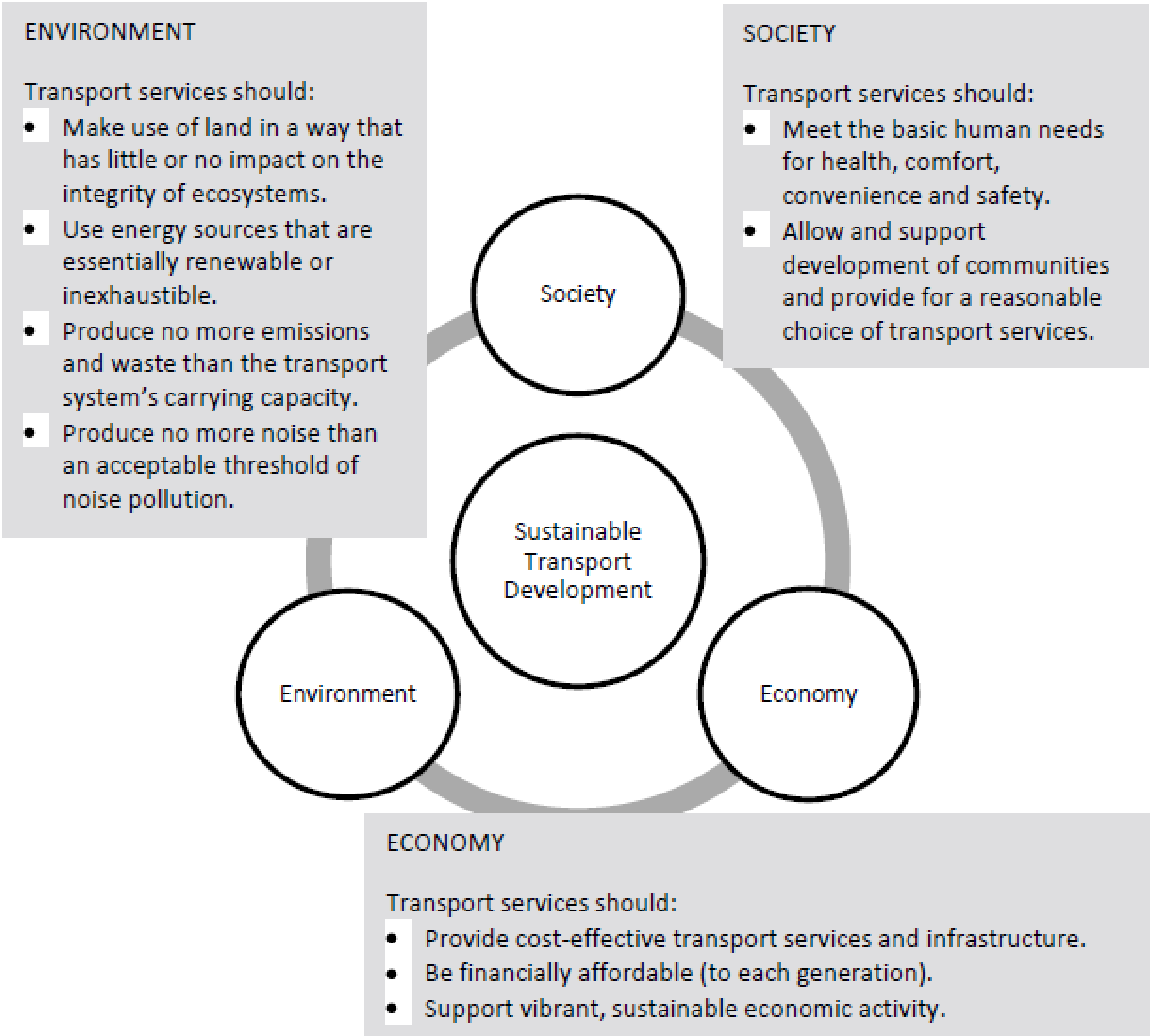



**Figure 2-7: Concept of Sustainable Transport Development (Vanderschuren, 2006)**

Black (2010) argued that the concept of sustainable transport development has various indicators which need to be accounted for, these are the effects on fossil fuel (petroleum), reserves, global atmosphere, local air quality, noise pollution, level of mobility, congestion rate and mortality rates (fatalities and crashes).

### 2.3.3. Objectives of ITS Measures

ITS measures are empowering advancements, applications, systems or services that are executed in order to infer anticipated transportation related advantages. The following six main goals are crucial for ITS measures (Mitretek System, 2001):

- Safety

One of the fundamental goals of any ITS implementation is to offer a safe voyaging environment while persistently attempting to improve the system's performance. World Health Organisation (2004) reported that crashes are responsible for almost 1 million fatalities annually and approximately 70 million injuries.

Ercan (2013) argued that each crash costs a significant amount of money to society. Accidents and fatalities are undesirable, but are at times unavoidable occurrences, which is why different ITS measures endeavour to diminish the threat of crash incidents. This is conceivable by reducing the threat of crash occurrences and minimising the likelihood of a fatality event.

Typical indicators used to gauge safety performance include the injury crash rate, fatality crash rate and general crash rate. Crash rates are typically described as accidents per annum, crashes per 10 000 populace or accidents per million vehicle kilometres travelled.

- Mobility

ITS measures also strive to enhance mobility and reliability by diminishing delay and travel time. Delay can be described by different formats, subject to the sort of transport system being assessed. A typical expression for transport scheme is seconds or minutes of delay per vehicle, though for the users of such a system it is person-hours.

Delay in freight deliveries can be described as the time passed scheduled arrival time of the delivery. Moreover, delay can likewise be measured by observing the quantity of stops that drivers need to make prior to and after a specific strategy is implemented.

Variability in travel time depicts the irregularity in travel time from an origin to a destination in a system, which would ordinarily incorporate any mode transfers or stops in transit (en-route). This measure is relevant for inter-modal movement of merchandise (cargo) and for individual travel. Decreasing the travel time variability enhances the expected arrival time reliability that organizations or individuals use to plan and programme choices. By reducing incident delay, ITS techniques can reduce travel time variability in transportation systems.

- Efficiency

Various ITS segments strive to enhance the competence and performance of existing services and use of right-of-way in order to address the issues of mobility, while reducing the need to extend facilities or build new ones. This is conceivable by enhancing the current (effective) limit of the transportation system. Effective capacity is defined as the “maximum potential rate at which persons or vehicles may traverse a link, node or network under a representative composite of roadway conditions," including "weather, incidents and variation in traffic demand patterns" (McGurrin and Wunderlich, 1999).

The Highway Capacity Manual describes capacity as the "maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a given point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions" (TRB, 2000).

Capacity is measured under prevailing facility conditions, for example, desirable weather and road surface conditions, without any incidents aggravating the system, while effective capacity can vary depending on these facility conditions, as well as the utilization of operational and management strategies. Throughput can be portrayed as the quantity of vehicles, merchandise or vehicles navigating through a roadway section or system per unit time.

Expanding effective capacity will cause increases in throughput. It can likewise reveal the maximum number of travellers that the transportation network can accommodate, contingent upon specific conditions. Throughput is less challenging to quantify than effective capacity and can be accordingly used as a substitute measure when assessing the performance of an ITS technique. Local conditions will however affect local capacities and throughput.

- Productivity

The usage of ITS methodologies frequently decreases operational expenses and takes into consideration enhancements in productivity. Moreover, ITS alternatives may have lessened procurement and life cycle costs when contrasted with traditional transportation enhancement methodologies, i.e. new road construction. Productivity can similarly be measured as a cost saving that result from the deployment of ITS techniques. Cost savings can furthermore be viewed as the evaluation of cost savings amongst ITS and conventional transportation improvements.

- Energy and Environment

ITS services can make significant contributions towards the energy effects and quality of air mainly for non-accessible locations. In most instances, benefits for the environment can only be assessed after investigation and simulation is performed. The difficulties related to local measurement contains the minor effects of singular projects and vast quantities of exogenous variables such as contributions from non-mobile sources, weather and the time-evolving nature of ozone pollution.

- Customer Satisfaction

The development of many ITS programmes and projects is intentional to serve the public and to ensure that the end user's expectations are met or even surpassed. Measures of customer satisfaction describe the difference between expectations of users and experiences relative to a product or service. The vital question in an evaluation for customer satisfaction is, "Does the product deliver sufficient value (or benefits) in exchange for the customer's investment, whether the investment is measured in money or time?"

Typical results reported in assessing the impact of consumer satisfaction with an item or service involve awareness of the item, item usage, expectations of item benefit(s), reaction (conduct change or decision-making), accomplishing of advantages and valuation of worth. It is challenging to gauge satisfaction directly, however measures connected with satisfaction is evident for increased travel by various modes, and the estimation of service, and additionally the bulk of compliments as well as grievances received by the product or service supplier.

In addition, it is necessary to evaluate the satisfaction of the transportation system manager or supplier. For example, numerous ITS techniques are deployed to improve the coordination between various partners in the transportation segment. In such ventures, it is crucial to assess the satisfaction of the transport supplier, with a specific end goal to ensure the best utilization of limited financing. One approach to evaluate the execution of such a venture is to survey transport suppliers before and after the venture, with a specific end goal to determine whether coordination improved.

### 2.3.4. ITS Elements and User Services

ITS is an extensive field, that can range from control of traffic lights to incident management, from enforcement to information for passengers and from assistance for drivers to enforcement of intelligent speed limit. Applications for ITS are summarised within a compilation of interconnected services for its various users. The different user services considers the perspective of the user when characterising benefits of the ITS strategy.

An ITS user could be the general populace or a system operator, depending on the type of application. Standardization can allow packages of the various user services grouped together within the following classifications:

#### *2.3.4.1. Advanced Traveller Information Systems (ATIS)*

Advanced Traveller Information System (ATIS) is as an encapsulation of multi-modal motorway-based private and commercial travel. The traveller information system aims to provide accurate information on the conditions of traffic, in order to assist travellers and fleet managers to adjust their times, modes of travel, delivery and routes (PIARC, 2011), through the following initiatives:

- Collection of data using technologies such as GPS installed enabled in the vehicles
- Provision of variable road sign messages for real-time communication of the expected traffic conditions (bottleneck, congestion, accidents and alternative route information during the road maintenance and closure)
- Provision of websites and smart phone applications to provide a colour-coded network map showing congestion levels and incidents on the highway

ATIS therefore offers travel-related information to users of various transport systems, to aid in decision making on choices of routes, travel time estimates, and to evade congestion. Figure 2-8 provides an illustration of an advanced traveller information system.

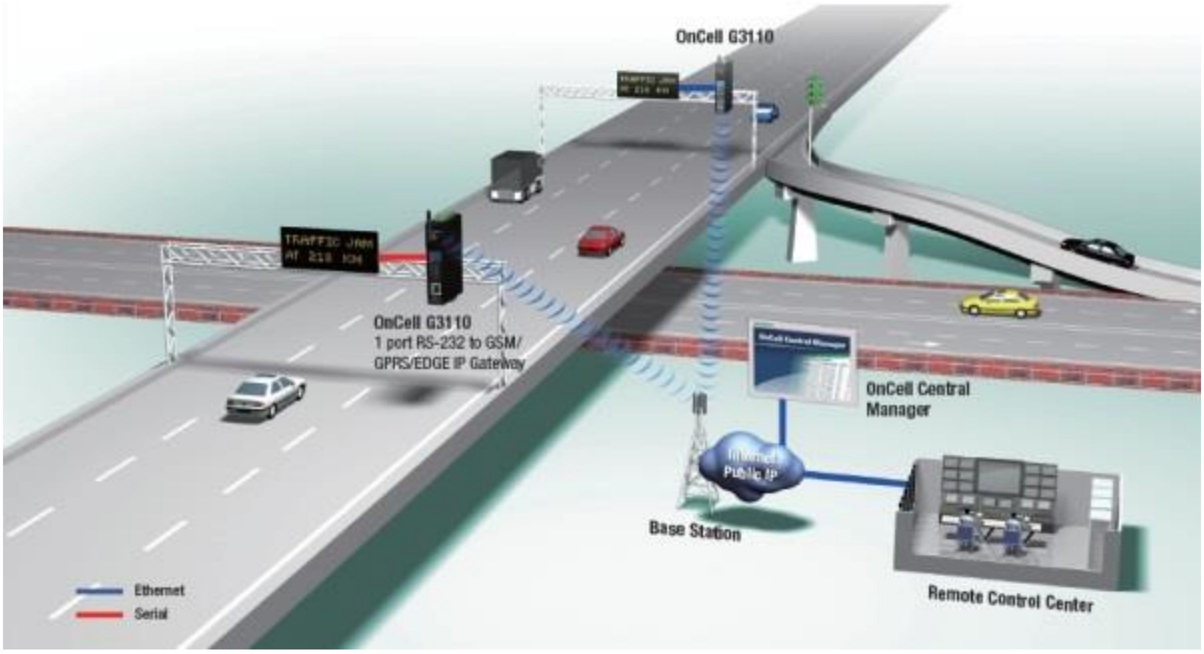



**Figure 2-8: Illustration of an Advanced Traveller Information System (MOXA, 2012)**

### 2.3.4.2. *Advanced Transportation Management System (ATMS)*

Advanced Transportation Management System (ATMS) comprises of appropriate ITS applications that focus on the devices of traffic control, for instance, ramp metering, traffic signals and variable (dynamic) communication signs on the roadway that offers drivers messaging in real-time, with regard to traffic or the status of the roadway. ATMS is offered to various road users to ensure safe, efficient and optimal usage of the capacity of the inter-urban and urban transport networks. In order to provide these systems, authorities dedicate funds to provide a traffic management centre that can manage traffic (PIARC, 2011).

These centres are typically known as Traffic Management Centres (TMCs) and Traffic Control Centres (TCCs) that depend on modern technology tools to link sensors and roadside devices, motor vehicle probes, message signs, cameras and other equipment to generate an integrated outlook of the flow of traffic and to detect incidents or other potential harm on the roadway (Ezell, 2010). TMCs and TCCs are responsible for generating vital sources of statistics that when processed can inform and advise road users. Figure 2-9 provides an illustration of the various components that make up the advanced traffic management system.

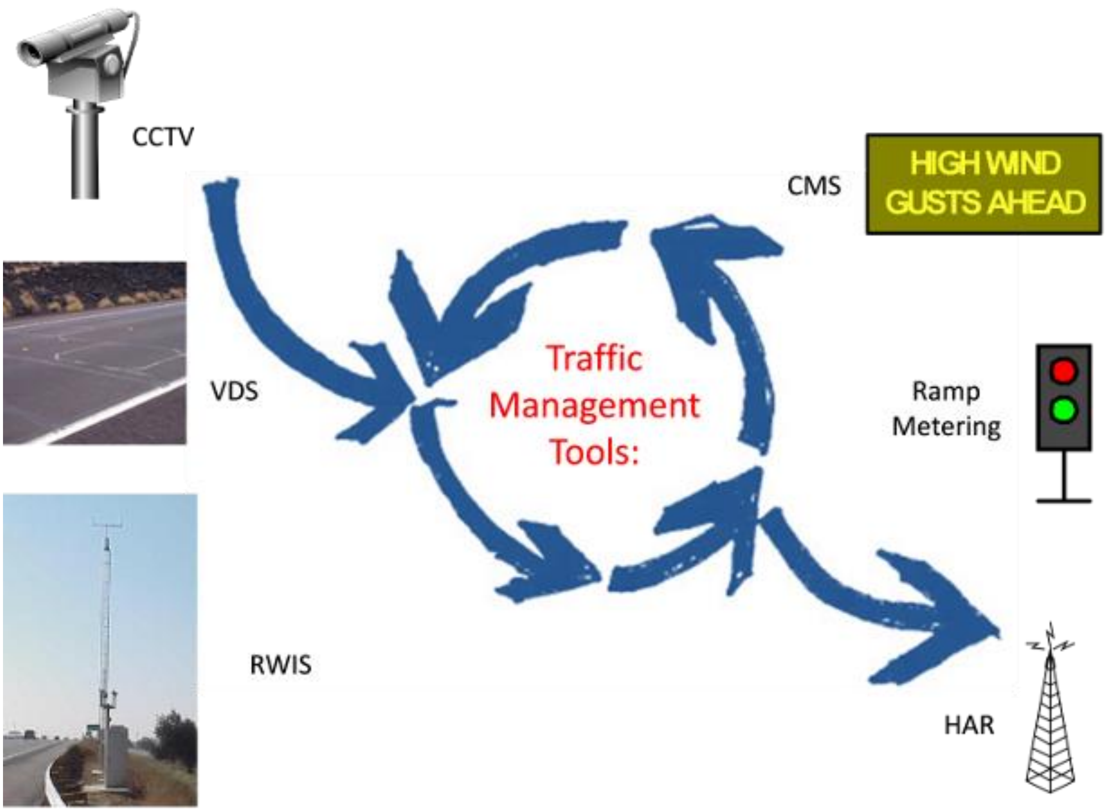



**Figure 2-9: Various Components of the Advanced Transportation Management System (AHMCT, 2012)**

The ATMS thus guarantees traffic control in urban regions, coordination of various traffic signals to reduce delays and control traffic queues. Long distance traffic management (including cross-border travel), traffic flow and demand management, guidance for re-routing, warnings systems for adverse weather, incidents detections and response, as well as law enforcement are also possible through the provision of ATMS (PIARC, 2011).

#### *2.3.4.3. ITS-Enabled Transportation Pricing Systems*

Funding for transportation systems worldwide is often collected through ITS initiatives. One such application is the electronic toll collection (ETC) system, also known globally as "charging of road users," which require drivers to pay fees automatically via a Dedicated Short Range Communication (DSRC) enabled device positioned on the vehicle's windshield. Countries such as Japan and Australia, have applied a single national standard electronic toll collection system, removing the necessity, as in the United States, to transport multiple ETC tags when travelling on cross-country trips, since numerous operators of freeway ETC systems is challenged with operability (Ezell, 2010).

Figure 2-10 illustrates an example of an electronic toll collection information system.


**Figure 2-10: Illustration of Electronic Toll Collection information Systems (DVRPC, n.d.)**

A growing number of cities have applied a pricing scheme for traffic congestion, particularly requiring fees for entering urban centres, typically at peak hours. This is implemented as a strategy to minimise congestion and generate resources that can fund public transport investments and simultaneously reduce environmental impacts of automobiles (Ezell, 2010). In Stockholm, a pricing scheme for congestion provided a number of positive results. It has been reported that traffic decreased by twenty percent in the first month of implementation, since most road users opted for public transport instead. Furthermore, a net revenue of $120 million was generated.

Fee based express lanes is another application of ATMS, which is basically a high-occupancy toll lane (or HOT lane), i.e. is a sort of movement lane or roadway that is accessible to high-occupancy vehicles and other excluded vehicles without charge; different vehicles being required to pay a variable expense that is balanced in light of interest. Unlike on toll roadways, drivers have a choice to utilize general-purpose lanes, on which an expense is not charged. Express toll lanes, which are less common and operate along comparative lines, however do not relieve high-occupancy vehicles.

A vehicle distance travelled tax, alluded to as a VMT tax, VMT fee, mileage-based charge, or road user fee, is a strategy of charging drivers based on the distance they have travelled. In metricated countries such as South Africa, this concept of distance travelled is referred to as vehicle kilometres travelled (VKT). It has been proposed in different states in the United States as a feature of ATMS and elsewhere as an infrastructure funding instrument to supplement the fuel tax (A New Framework for Transportation, National Surface Transportation Infrastructure Financing Commission Final Report, 2009), which has been producing billions less in income every year because of progressively fuel efficient vehicles.

Variable parking fees is another application of ATMS, which is a subset of ITS enabled pricing and its concept is still under experimentation in overseas countries.

#### *2.3.4.4. Advanced Public Transportation Systems (APTS)*

Advanced Public Transportation Systems (APTS) comprise of applications that facilitate public transportation vehicles, whether rail or bus, to regularly communicate their current location to the public, through automatic vehicle location devices. APTS assist administrators of traffic operations to produce a real-time outlook of the present status of assets in the public transportation system (U.S. Federal Highway Administration, 1999).

APTS furthermore assist the public transportation system to provide a more appealing choice for travellers by offering them improved visibility into the status of arrival and departure of trains and buses. APTS offering “next train” or “next bus” communications are gradually increasing worldwide, from USA, to France, Japan, and elsewhere. Figure 2-11 depicts typical components of an advanced public transport system.

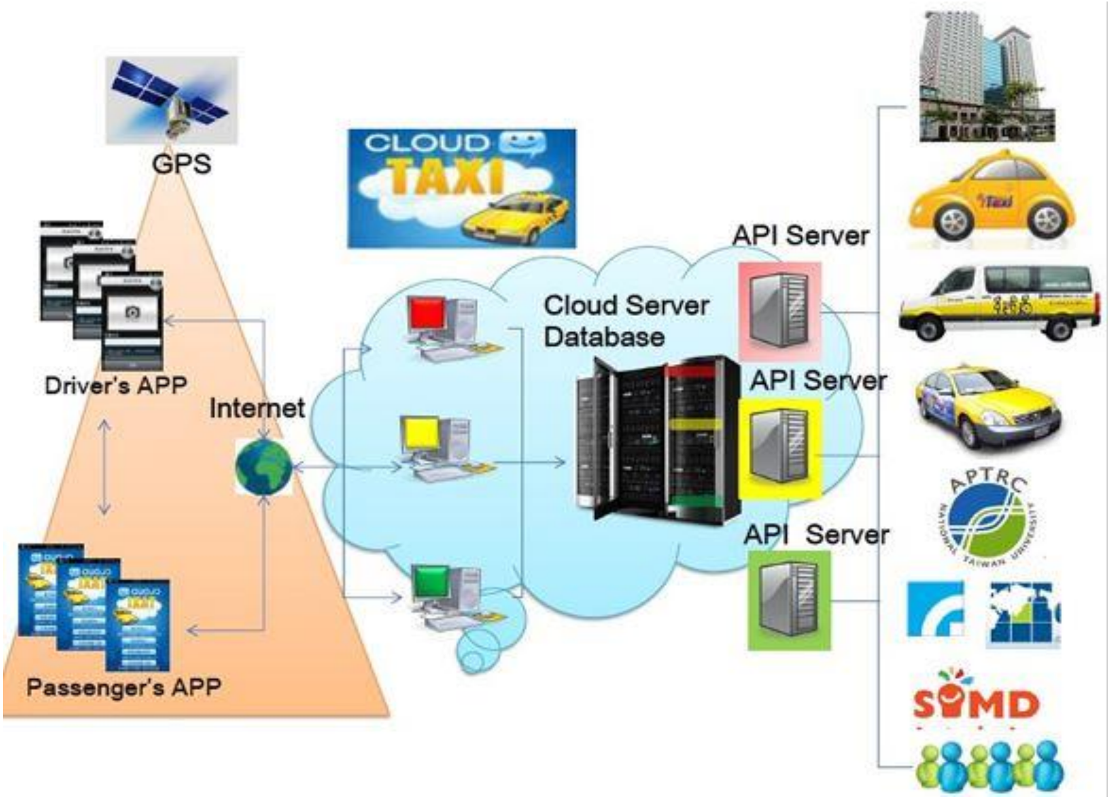



**Figure 2-11: Components of an Advanced Public Transportation System (ITA Taiwan, n.d)**

### *2.3.4.5. Vehicle-to-Infrastructure Integration (VII) and Vehicle-to-Vehicle (V2V) Integration*

Vehicle-to-infrastructure integration is the model for a broadly integrated intelligent transport system, known as the connected vehicle. Japan, Australia, USA and various European countries have implemented and enabled a communication facility that supports VII messaging for different vehicle safety applications and transport communications. (Ezell, 2010).

Connected vehicles foresees that DSRC-enabled sensors or tags, if widely implement in motor vehicles, freeways, and in intersection or roadside devices, would allow the basic components of the transport system to communicate intelligently with one another, offering an extensive range of paybacks, as can be seen in Figure 2-12.

These applications would be adaptive signal timing, warning notices for lane departures, dynamic re-directing of traffic through variable message signs, customized identification of roadway dangers (potholes) and warning notices for speeds when moving toward road curves (Ezell, 2010).

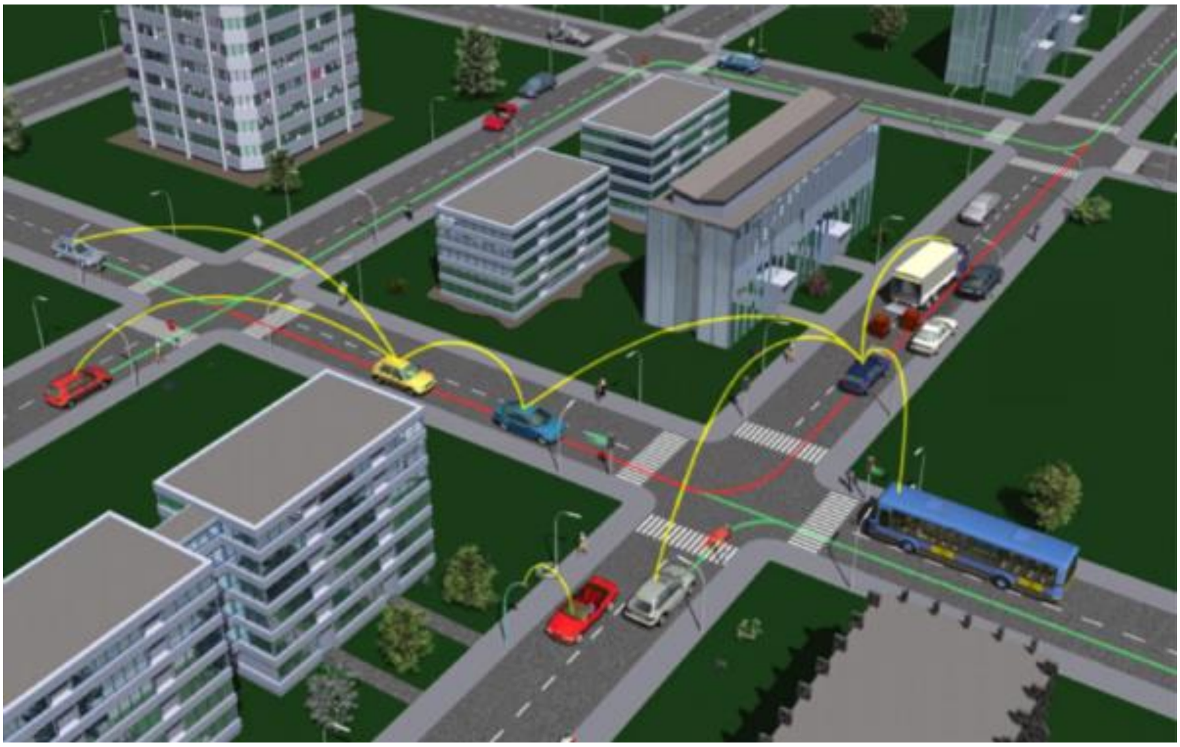


**Figure 2-12: Cooperative Vehicles to Infrastructure Integration and Vehicles to Vehicles Integration (Bush, 2013)**

If the connected vehicle product consolidates vehicle-to-vehicle and vehicle-to-infrastructure integration into a joined platform, various additional ITS applications would be empowered.

#### *2.3.4.6. Commercial Vehicles Operations (CVO)*

Commercial Vehicles Operations (CVO) addresses the needs for credential enforcement, as well as safety enforcement in order to ensure that the fleet management system complies with transportation laws and regulations. CVO makes use of a set of roadside sensors and back-end systems that capture commercial vehicle information, such as license plate numbers, over height and weight, and checks the associated data against third party databases, such as permitting systems and commercial vehicle registration systems (Kapsch, n.d.).

CVO makes use of the Automatic Vehicles Location (AVL), which assists vehicle operators to operate and manage loads and fleets more efficiently, by offering benefits in both economics and logistics. Figure 2-13 provides an illustration of an automatic vehicle location system.


**Figure 2-13: Illustration of Automatic Vehicle Location System (Kapsch n.d.)**

## 2.4. Benefits of ITS Implementation

ITS serves the interest of the general society, by offering considerable improvements towards improved traffic management, reduction in carbon emission, increased safety, environmental preservation and increased economic value. The following section provides an overview of the benefits of ITS, internationally as well as locally.

### 2.4.1. International Studies

The European Commission report (2013) projected the total influence of road safety-related traffic information systems to yield an average decrease of 1.8% in injuries and a reduction of 2.7% in fatalities, when considering different types of road crashes.

In 2005, an evaluation was performed on an ITS deployment in Tucson, Arizona, which consisted of 35 applications consisting of Variable Message Signs (VMS), highway advisory radio (HAR), a cellular and network-based traveller information system. The study anticipated that traffic congestion will reduce by 6% and that a 70% reduction will be possible for incident-related delays on highways. It was furthermore found that travel times would be reduced within the studied road network by seven hours per year (Ezell (2010). Nielson (2003) reported that VMS reduce travel time by 22% in London and between 7% and 18% in Turin.

The provision of real-time traffic data to traffic signal lights in the USA can significantly improve traffic flow as reported by Ezell (2010), by decreasing travel time by 25%, decreasing stops by 40%, reducing fuel consumption by 10% and reducing emissions by 22%. In general ITS is expected to decrease traffic congestion by 20% or more.

(Bunch et al 2011) reported that re-timing a traffic signal system for the period of a two-phase project in Oakland County, Michigan lead to a reduction in carbon monoxide levels between 1.7% and 2.5%, a decrease in nitrogen oxide levels between 1.9% and 3.5% and a decrease in hydrocarbon levels between 2.7% and 4.2%

In USA, 86% of the drivers reacting to the traffic enforcing cameras admitted that their speed reduction was as a result of the visibility of the speed cameras. Drivers (77%) furthermore recognised that the computerized speed enforcement system enhanced road safety (Federal Highway Administration, 2006).

### 2.4.2. South African Studies

Mkhize and Thomas (2005) investigated the effects of ITS (e-mobility) on freeways in eThekweni. An incorporated system, which comprised of managing incidents, offering information on incidents and ramp metering, was implemented and estimated an increase in speed as well as a decline in travel time, from 27% to 32%.

Roux and Bester (2002) examined the effect of the HOV lane on the N2 in Cape Town. The introduction of an HOV lane appears less promising. Even though a considerable reduction in travel time (76%) and a substantial increase in average speeds were reported for the HOV. The highway's throughput reduced significantly by 40%.

De Jongh-Schreuder and Venter (2005) explored a type of ramp metering system, known as an Interchange Control System at the intersection of the two national roads, N1 and N2. The goal was to enhance traffic flows at the junction. A general reduction in time travelled was found from 1% to 19%, while an improvement in throughput, from 2% to 37% was estimated. Following manual alterations to the settings, the reduction in time travelled was between 17% and 46%, while the rise in throughput was between 3% and 54% (Vanderschuren, 2006).

Beer et al., (2005) investigated a Public Transport Priority system for the Soweto-Parktown corridor and found a wide range of results. Private vehicles were estimated to experience a reduction in travel time (20%), as well as the public transportation system. Upgrading of the signal-controlled intersections largely did not significantly improve the LOS. Private vehicles reported an increase in travel times by 8%, while the level of service for public transportation system rose by up to 20%. Precedence for public transport was evident. With the consideration of extending the public transportation services to the Soweto-Parktown area, private vehicles and public transport would have the same LOS as the current state.

Cloete (2002) published the initial estimates of the simulated benefits of Ramp Metering on the N1, in South Africa. A 13% increase in speed and a 28% reduction in travel time was reported. In the developing world, driver behaviour is not necessarily similar to that of drivers in developed countries and therefore estimated effects might not be entirely accurate. For this reason, developed world models cannot be easily transferred to the developing world.

Figure 2-14 to Figure 2-16 provide a summary of the estimated benefits of selected ITS measures for South Africa, as proposed by Vanderschuren (2006).

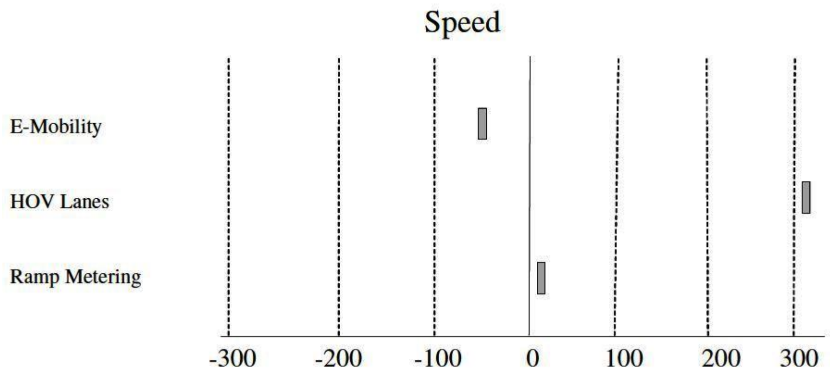



**Figure 2-14: Summary of Estimated ITS Benefits for Speed for South Africa (Vanderschuren, 2006)**

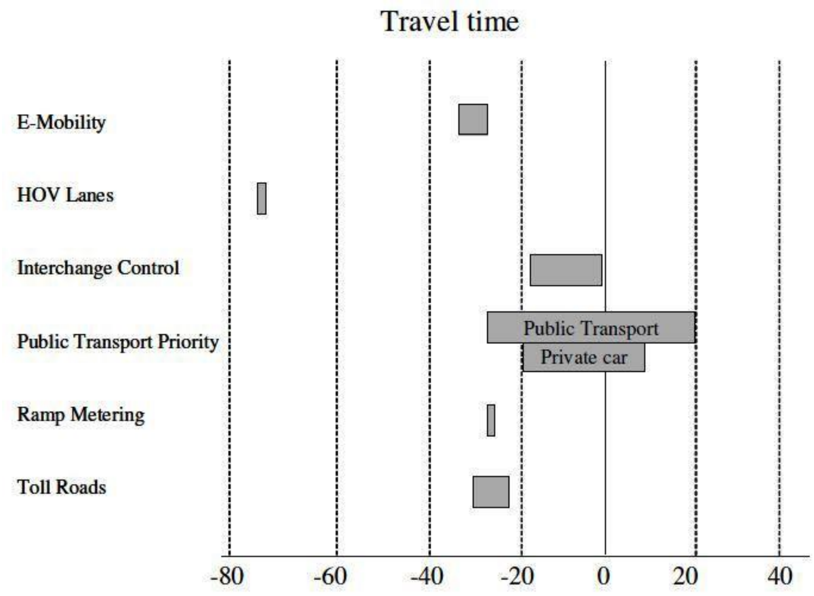



**Figure 2-15: Summary of Estimated ITS Benefits for Travel Time for South Africa (Vanderschuren, 2006)**

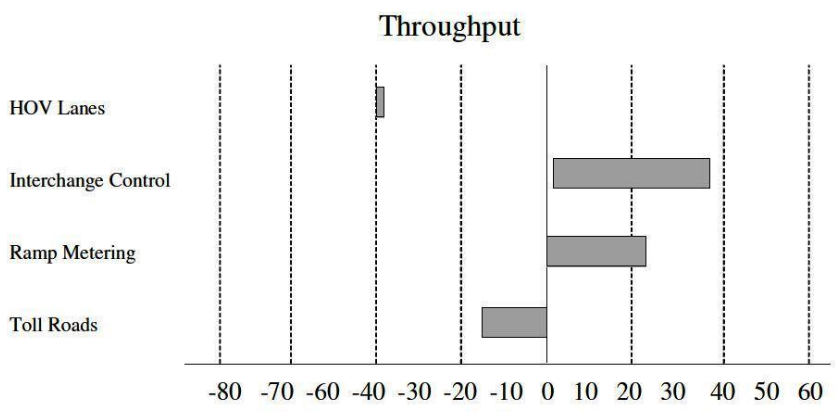



**Figure 2-16: Summary of Estimated ITS Benefits for Throughput for South Africa (Vanderschuren, 2006)**

## 2.5. Challenges in Implementing ITS

Understanding ITS in the South African context and realising that the South African transportation budget is limited is essential for the successful implementation of ITS in South Africa. When considering ITS deployments that have been implemented worldwide, it is evident that ITS initiatives need to be “South Africanised” by ensuring that solutions and approaches promote sustainable transportation development at local and national level in South Africa (Burnett et al., 2000).

The majority of ITS services are confronted with challenges regarding system interdependency, requiring holistic system coordination to implement, acceptance and ownership by the individual road users, whilst operating at an effective magnitude (Ezell, 2010). Marketplaces for ITS services are quite volatile, due to uncertainty and increased risks for new applications. Developments of such service are therefore challenging.

ITS applications are furthermore challenged with an assortment of organisational obstacles, and these institutional complications ultimately decide how the acting organisations, frequently across various authorities, establish and uphold mutual schedule and plans. Organizations regulate how funding priorities are allocated and information is made available to other entities. Moreover, ITS services are often confronted with a lack of proficiency within local and regional transportation departments with respect to the technical tools that are fundamental ITS services and implementation (Ezell, 2010).

ITS technologies lack proper technical standards, causing the integration of ITS services across various institutions to be quite challenging. In South Africa, a lack of mutual ITS architecture and proper technical codes or standards for the technical tools that form the basis of the ITS services are the biggest challenges in implementing ITS services. It is probable to encourage organisational integration through an integrated multimodal transportation system (integration across transportation modes). Consequently, a platform needs to be created for the development of a common ITS architecture (Struwig, 2013).

## 2.6. Benefit – Cost (B/C) Analysis of Intelligent Transportation Systems

### 2.6.1. B/C Analysis Studies

The term B/C analysis is used interchangeably and synonymous with economic evaluation. B/C analysis is a conceptual procedure to determine the viability of investment projects by considering all benefit and cost regardless of whom they accrue to within a country. A benefit is regarded as any gain in the total utility associated with the investment needed to establish a facility, where utility is measured in terms of opportunity costs.

B/C helps decision-makers to decide on implementation of a project. B/C analysis calculates and compares the benefits associated to a project with the costs of implementing the given project. B/C determines whether the project is feasible (provides justification) and compares the project with alternate projects (ranking/priority assignment). It recommends the implementation of the project if the benefits exceed the costs (Bester, 2013).

B/C analysis is one of the fundamental techniques of evaluation in the domain of transportation, since it assists transportation planners to decide which alternative will be cost-effective once it is implemented. B/C analysis for transportation projects attempts to forecast the future changes in MOEs related to a potential project or collection. For many improvement projects, transportation-planning data need to drive the future predictions of benefits are often obtained from travel demand or simulation models, or a variety of analysis tools capable of modelling changes in traffic performance (Bester, 2013).

In order to select the Measure of Effectiveness (MOEs) to use in the B/C analysis, transportation analysts need to capture the comprehensive impacts of their strategy. However, caution should also be applied to avoid double-counting particular benefits. The MOEs selected should be mutually exclusive.

Avineri et al. (2000) lists profile and checklist, scoring, cost-benefit analysis and mathematical programming as the four main methods used for evaluating transportation systems.

Cambridge Systematics (2002) as part of the National Cooperative Highway Research Program (NCHRP), explored the economic, safety and environmental benefits of reduced congestion levels, without taking into account the indirect impacts of industry.

Texas Transportation Institute (TTI) similarly conducted a benefit-cost analysis focusing on ITS projects in 2003 (Stockton & Walton, 2003), but did not study the resultant indirect economic and environmental effects.

U.S. Federal Highway Administration (FHWA) built up a basic leadership instrument named *Surface Transportation Efficiency Analysis Model* (STEAM) that is used by national and local transportation agencies to evaluate infrastructure costs and benefits (U.S. Federal Highway Administration, 2013).

Likewise, U.S. Department of Transportation (DoT) arranged reports about ITS applications in the U.S. regarding *t*heir cost, advantage, and lessons learned with various contextual analyses (U.S. DOT Research and Innovative Technology Administration, 2008; U.S. DOT Research and Innovative Technology Administration, 2011). This database is openly accessible through U.S. DoT's website, which permits clients to filter contextual investigations in terms of their ITS sort, state, infrastructure cost, advantage and so on [http://www.itsbenefits.its.dot.gov/].

The US Federal Highway Administration (2012) also developed and supported the ITS Deployment Analysis System (IDAS) as part of the STEAM model in 2001. IDAS have since been subjected to various redesigns. IDAS, a sketch-planning instrument operating as a travel demand model post-processor, actualises the modular split and traffic assignment steps connected with the conventional traffic demand estimating planning model. IDAS gauges changes in modal, route, and temporal choices of travellers derived from more than 60 sorts of ITS advances. The US Federal Highway Administration does however not support IDAS anymore, as newer programmes have been developed.

The U.S. Federal Highway Administration (FHWA) developed the Tool for Operations Benefit/Cost (TOPS-BC) in parallel with a Desk Reference, to provide guidance by analysing four key capabilities (FHWA, 2012):

- Investigate Impacts – It discusses capacity for users to examine the normal scope of effects connected with past deployments and investigations of numerous ITS systems;

- Research Methods – It discusses screening system to assist users in distinguishing proper apparatuses and techniques when conducting a B/C investigation in view of their evaluation needs;
- Estimate Costs – It suggests a default cost information system to appraise the life-cycle expenses of different ITS methodologies, including capital, substitution (replacement), and ongoing operations and maintenance(O&M) costs; and
- Estimate Benefits – It provides a framework and recommended impact values system for conducting basic B/C investigation for chosen ITS procedures

TOPS-BC covers an extensive list of systems, because of the evolving environment of ITS, where new strategies are continually created and being upgraded. The instrument is intended to be adaptable for simple adjustment and change by experts to address the issues of a specific analysis and is hence favored by different professionals. Indeed, the analysis tool contains capacities intended to support the creation of new analysis techniques within the tool.

TOPS-BC furthermore maintains an internal database of observed benefits and effects for particular methodologies when implemented in different regions in the United States and abroad. This data has been compiled from the ITS Joint Program Office's Benefit Cost Database [http://www.benefitcost.its.dot.gov] and various different sources. Furthermore, input parameters utilized as a part of a few operational analysis instruments are likewise recorded in the database for additional guidance.

This state of the industry tool was thus selected to do the B/C for the research.

### 2.6.2. Measures of Effectiveness (MOEs)

ITS interventions are commonly evaluated according to key performance measures, also known as Measures of Effectiveness (MOEs). MOEs are those metrics that will exhibit changes and help to quantify the benefits.

MOEs applicable to the ITS strategies for benefit-cost analysis are subdivided in the following groups:

- Traditional MOEs
- Emerging MOE
- Hard-to-Quantify MOEs

#### 2.6.2.1. *Traditional MOEs*

Once ITS strategies are implemented the changes that occurred in the transportation system performance represents the benefits or disbenefits of the strategies. The benefits ITS can be estimated with a more quantifiable metric, which can easily convert in monetary values. Traditional MOEs used in ITS B/C analysis derived from measures used in estimating traditional transportation improvement (Bester, 2013). These MOEs usually include:

- User Travel Time Savings

User time saving is a MOE commonly used in B/C analysis of transportation system improvements. User travel time is defined as the net change in the total person hours of travel (PHT), resulting from the implementation of the strategy in the transport system. During analyses, the travel time measured from the PHT is dived into In-Vehicle Travel Time and Out-of-Vehicle Travel Time.

The *in-vehicle travel time* represents the time spend in the mode of transport chose by the user to reach their destination and the *out-of-vehicle travel time* represent the time to access the mode of transport. This approach is generally used in analyses involving transit mode to represent the time to walk to the transit stop, to wait for the transit vehicle and the time of transfer between modes (Allen et al, 2012).

- User Vehicle Operating Costs

The user vehicle operating cost is a performance measure that is commonly used in road improvement project. The estimation of vehicle operating costs is based on simple evaluations applied directly to vehicle miles of travel (VMT). For analyses a static rate of average fuel use (gallon per VMT) is applied to any change in VMT to estimate the net change in fuel use.

User vehicle operating cost is the financial equivalent of road user costs and is traditionally divided into running cost (fuel cost) and time-bound costs, such as non-fuel cost (Bester, 2013).

These two groups of cost are subdivided as follow in Table 2-5:

**Table 2-5: Typical Running Costs and Time-Bound Costs (Bester, 2013)**

| Running Costs | Time Bound Costs |
|---|---|
| Fuel | Depreciation, Interest |
| Tyres | Insurance, Licensing and Permits |
| Engine Oil | Garage and Parking |
| Maintenance and Repair Costs | Drivers and Crew Costs |

- Reduction in Crashes

The reduction in the number and severity of accidents may be one of the main objectives in the planning of the transportation system improvement. ITS strategies have shown significant improvement in reducing the number of accident and severity of vehicles crashes. Strategies that serve to smooth the flow of traffic at difficult merge points such as ramp metering systems, have been observed to directly reduce the risk of crash exposure at these locations.

The benefit valuations applied to a reduction in the number of crashes are often substantial particularly in the case of fatality and injury crashes. These are based on the combination of “actual costs” and “cost to avoid” methods. Actual cost methods capture the actual accountable costs of crash (cost of medical treatment of the victims, the loss of the victim’s wage for the family and any property damage), while cost to avoid estimates the value that individuals would likely pay to avoid being in a severe crash (Bester, 2013).

To estimate the change in crashes attributable to ITS during the B/C analysis, crash rates (crash occurrence per million VMT) are applied to the change in VMT in the transportation network. Different crash rates are applied for different severities of crashes (Verburgh and Farquharson, 1985). Crash severities are divided into:

1. Fatality Crash

A fatal accident is one in which at least one person dies as a result of the accident, immediately or up to a period of six days after the accident.

2. Serious Crash

A serious accident is one in which at least one person is seriously (but not fatally) injured, the injuries being fractures, crushing, concussion, internal injuries, severe cuts and laceration, and severe shock necessitating.

3. Injury Crash

A slight accident is one in which at least one person sustains slight injuries such as cuts, bruises, sprains and slight shock.

4. Property Damage

A property damage only accident is one where no injuries are suffered by occupants. When accurate estimate rates can not be obtained, the following default rates apply (Verburgh and Farquharson, 1985), as detailed in Table 2-6.

**Table 2-6: Accident Rates for Different Types of Roads (Verburgh and Farquharson, 1985)**

| Type of Road | Accident Rate |
|---|---|
| Divided Multi-Lane Highways | 4 |
| Undivided Highways with Paved Shoulders | 43 |
| Two-Lane Highways with Gravel Shoulders | 63 |
| Gravel Roads | 75 |

- Reduction in Emissions

Emission is commonly used for B/C analysis of transportation improvement projects. The addition of emissions estimate in the benefit/cost analysis is particularly important when projects are being prioritised in competition for funding.

Emission is one of the most challenging MOEs to estimate. Many variables are used to determine the appropriate emissions rate. Most emissions estimations are based on application of emission rate on a per VMT basis (Allen et al, 2012). B/C analysis usually includes the following emissions categories, which attract most concern in the local region:

1. Hydrocarbons (reactive organic gases)
2. Nitrous Oxide ($NO_x$)
3. Carbone Monoxide(CO)
4. Carbon Dioxide ($CO_2$)
5. Particulate Matter ($PM_{10}$)
6. Sulphur Dioxide ($SO_2$)

Table 2-7 provides a summary of Traditional Measures of Effectiveness (MOEs).

**Table 2-7: Summary of Traditional Measure of Effectiveness (MOEs)**

| Traditional Measure Of Effectiveness (MOEs) | Components |
|---|---|
| **User Travel Saving** | In vehicle time<br>Out vehicle time |
| **User Vehicle Operating Costs** | Distance VMT<br>Fuel costs<br><br>Nonfuel costs<br>Maintenance costs<br>Insurance<br>Depreciation cost |
| **Crashes**<br><br>Fatality crashes<br>Injury crashes<br>Property damage | Number of Crashes<br>Annual cost<br>Costs to avoid |
| **Emissions** | Distance Vehicle Miles Travel (VMT)<br>Emission Rates<br>Cost of Emssions |

The benefits of ITS are mostly of a secondary nature. Traditional benefits of transport projects are of a primary nature, such as providing a road for travel. Secondary benefits of ITS projects would be to improve reliabilituy. New MOEs must therefore be developed to include secondary effects.

*2.6.2.2. Emerging MOEs*

Several new MEOs have been introduced into B/C analysis, in order to provide more justification for ITS projects. These MEOs include:

- Travel Time Reliability (TTR) of Variability

ITS strategies are often more directly targeted at the underlying causes of nonrecurring congestion such as incidents, weather, construction work zones, special events, and poor operations, and can have substantial success in mitigating the delay caused by these sources.

Average travel time is the primary measure used for B/C analysis of transportation projects. The use of average measure only captures the change in recurring travel time. This is due to the nature of the measure itself and to the measurement methods (Allen et al., 2012).

Travel time reliability measurement seeks to quantify the variability in travel times caused by nonrecurring, as well as recurring congestion sources in order to better estimate the full distribution of travel times experienced by the system users.

It is important that travel time reliability be considered for traditional capacity projects, however, it is often even more critical that this measure be considered for B/C analysis of ITS strategies, since a much higher proportion of the anticipated overall benefit is expected to be derived from these strategies' impacts on reducing nonrecurring congestion (Allen et al., 2012).

Some new methods used for quantifying the travel time reliability benefits within a benefit/cost analysis structure are presented as follow:

1. Measurement of Standard Deviation

For existing deployments where sufficient "before and after" data is available, the impact on travel time reliability may be estimated by comparing the distributions of travel time prior to application of the strategy (the "before" or "without" scenario) with the distribution following the application (the "after" or "with" scenario). The net change in the standard deviation in minutes of travel time may be calculated from the distributions and multiplied with the number of facility users to estimate a temporal measure of travel time reliability savings. A value may be applied to this measure to monetize the benefit for use in the B/C analysis.

2. Measurement of Total Recurring and Non-Recurring Delay

In this method an approach is developed to estimate total delay (combining both recurring and nonrecurring delay), based on the mean recurring travel time and assuming a normal distribution of travel times. The developed analysis method and equation are intended for application in “data poor” situations, where the robustness of either the archived historic traffic data or the modelled predicted traffic data was insufficient to provide meaningful analysis of nonrecurring congestion delay.

The function below, which is intended to be applied to freeway facilities, was estimated by statistically examining the relationship between the total mean travel time delay and the mean recurring travel time estimate (as based on long-term data collected and analysed from multiple regions throughout the nation). An allowance is made for adjustment of the mean recurring travel time estimate to include the addition of an estimate of nonrecurring travel time (SHRP2 L03, 2010).

$$MeanTT = 1.0274 * RecurringMeanTT^{1.2204} \tag{1}$$

The above equation provides a reasonable approximation of the relationship between overall congestion and recurring congestion. The method does produce a measure of total recurring and nonrecurring delay that may be summed for all facilities and users, compared for a baseline and alternative scenario, to identify a net change in the measure.

Furthermore it should be monetised to provide an estimate of travel time reliability in the B/C analysis. However, its application in B/C analysis for ITS strategies is limited, primarily due to the inability to effectively break out recurring travel time from nonrecurring travel time (travel time reliability).

The difficulty in assessing the specific impact that a particular ITS strategies is reducing specific causes of nonrecurring congestion since any change in total mean travel time is only based on changes in mean recurring travel time (SHRP2 L05, 2010).

Figure 2-17 illustrates how recurring travel time measurement differs from actual traveller experiences.

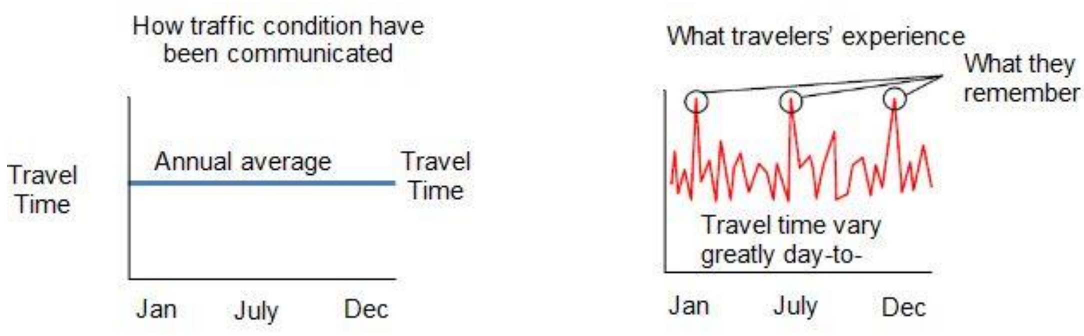



**Figure 2-17: Recurring Travel Time Measurement versus Actual Traveller Experience (US Federal Highway Administration, n.d.)**

Different rates are also estimated based on the length of the analysis period (one-hour, two-hour, three-hour, four-hour, or daily).

- Incident Related Delay (IRD)

The most prevalent example of these methods is the analysis originally developed and implemented as part of the analysis capabilities of the US Federal Highways' IDAS sketch-planning tool. The IDAS incident delay analysis involves the use of look-up tables containing estimates of the amount of incident-related delay likely to be experienced for a facility on a per VMT basis. These rates were predicted based upon long-term monitoring and analysis of annual incident delay experience on a number of national freeway and arterial corridors. These rates are sensitive to several key input factors, including the following:

1. The Number of Facility Lanes:

The incident-related delay rate for roadways with a greater number of lanes is less than for facilities with fewer lanes, assuming other factors are also equal. This is due to the more substantial blockage of capacity caused by similar incidents on roadways with fewer lanes. For example, identical incidents blocking a single lane would reduce capacity by one-half of the available lanes on a two-lane facility, but only reduce capacity by one-quarter of the available lanes on a four-lane facility.

2. The Facility Volume-to-Capacity (V/C) Ratio

The level of base congestion (prior to the occurrence of the incident) is represented by the V/C ratio. Facilities with a higher V/C ratio will have higher incident-related rates associated with them, as it would be expected that incidents on these more congested facilities would cause a quicker breakdown in conditions and a longer time required to allow the incident-related queue to dissipate once the incident was cleared.

These tables can be employed using a look-up function in an analysis to identify the appropriate rate to the VMT estimated for the facility. This estimation would be performed for the baseline scenario (without the improvement) and for an alternative scenario (with the improvement). The amount of incident-related delay would be expected to change if there are any changes in roadway volumes, capacities, or number of lanes as a result of the improvement in the alternative scenario as compared to the baseline scenario.

In addition to changes in incident-related delay forecast due to predicted changes in volume, capacity, or number of lanes, some ITS strategies have been observed to lessen the frequency of incidents or reduce their duration. Strategies such as traffic incident management systems have been observed to reduce incident-related delay by up to 40 percent due to the improved and faster response provided by the enhanced incident detection, verification, and coordinated response.

- Consumer Surplus/Induced Travel

The concept of consumer surplus has increasingly been applied in many recent B/C analyses of transportation projects. Consumer surplus is an economic concept intended to enhance the analysis of travel time and costs. It is based on the principle of weighing the willingness of individuals to pay (in time and money) for a particular trip with the actual cost of the trip, and is capable of more accurately assessing the benefits of any induced travel resulting from the improvement (Allen et al., 2012).

Each user of the transportation facility is willing to pay a certain price (in terms of time, accident risk, vehicle operating costs, tolls, etc.) to travel on that facility. This amount will differ from user to user. However, every user typically incurs the same travel time costs. The difference between what a group of users is willing to pay in terms of travel costs (travel time, etc.) and what they actually pay is called consumer surplus.

In a benefit cost analysis, we are concerned with the change in consumer surplus attributable to a transportation improvement. Measurement of consumer surplus is most often used in the assessment of travel time savings in place of simple measures of the total change in facility travel time observed between the baseline and alternative scenarios.

#### *2.6.2.3. Difficult to Quantify MOEs*

Several additional MOEs for potential benefits of ITS strategies have been identified and studied. However, due to the lack of information on these MOEs and their linkage to the ITS strategies, the evaluation of change estimated of these MEOs within the confines of a B/C analysis framework has often proven difficult. These MOEs include:

- Customer Satisfaction
- Traveller Feelings of Safety and Security
- Community Liveability

Several ITS strategies such as ATIS emergency management have shown a lot of improvement in terms of travellers' satisfaction (PAIRC, 2011).

### 2.6.3. B/C Analysis for New Road Construction

This section will discuss B/C analysis for traditional transportation projects in general. The B/C analysis for ITS measures discussed in Section 2.6.4. indicate significant differences. Traditional MEOs used in B/C analyses include (US Federal Highway Administration, 1995):

- Travel Time (and the reliability of travel time)
- Crashes
- Fuel Use
- Non-fuel Vehicle Operating Costs
- Emissions/Air Quality
- Agency Efficiency

Steps in the typical B/C analysis process are organised as follows:

- Define the Base Case and the Alternative Project. Determine the useful life of the project: the number of years over which the benefits and costs of the project need to be evaluated;
- Determine the level of detail required and obtain performance data (for Project Alternative and Base Case) for explicitly modelled periods;
- Measure user costs (for Project Alternative and Base Case) for affected link(s) or corridor(s). Estimate in physical units all benefits and all costs of the project for each year of its useful life;
- Develop basic user cost factors (values of time, vehicle unit operating costs, accident rate and cost parameters, vehicle emission rate and cost parameters, etc.). Select economic factors (discount rate, analysis period, evaluation date, inflation rates, etc.);
- Calculate user benefits. Convert physical units of benefits and costs into monetary value, using appropriate prices and values. Once the monetary values of benefits

and costs are compiled for each year, calculate their present values, using an appropriate discount rate. Then, add up the present values of annual benefits to determine the total benefits (B) of the project. Similarly, add up the present values of annual costs to determine the total cost (C);

- Extrapolate/interpolate benefits to all project years (unless all time periods are explicitly modelled);
- Calculate the total net benefits, called the net present value (NPV), by subtracting the total cost from the total benefit,

$$NPV = B - C \tag{2}$$

- Calculate the benefit-cost ratio, dividing total benefit by total cost, B/C ratio = $\frac{B}{C}$;
- The decision rule is then: If NPV ≥ 0, implement the project. Else, do not implement it. Alternatively, if $\frac{B}{C} \geq 1$, implement the project. Else, do not implement it.

Transportation economic research has shown that most benefits of transportation improvements result from travel time and cost savings for road users. User benefits are: reductions in travel time (time savings), vehicle operating costs, accidents and improvements in the reliability of transportation systems or services.

Most of the other benefits from transportation investments are indirectly a product of these primary user benefits (Bester, 2013). Benefits can be classified as follow in Table 2-9.

**Table 2-8: Classification of User Benefits (Bester, 2013)**

| | | |
|---|---|---|
| **(1) Reducing Vehicle Running Costs**<br><br>When new facility does not induce a significant change in volume of the additional traffic, savings in running cost can be measured by calculating the difference between vehicle running cost with and without a new or improved facility.<br>Vehicle running cost consist of energy/fuel consumption, tyre wear, oil consumption, vehicle capital cost, vehicle maintenance cost | **Existing Traffic** | Improved current traffic (in base year). Existing road widened/improved operation. |
| | Normal Traffic Growth | Traffic growth that will have occurred in spite of the creation of new facility.<br>The growth can be attributed to the general growth of population, an increase in the per capita ownership of vehicles and an increase in average use per vehicles |
| | Diverted Traffic | Traffic of the same transport mode that is diverted from other facilities because of the opening of the new or improved facility |
| | Transferred Traffic | Traffic that is attracted from other modes to a new or improved facility |
| | Development Traffic | Traffic developed after implementation of a new facility because of any changing use of the land served by the facility |
| | Generated Traffic | Traffic that did not exist previously and has been generated solely through a reduction of disutility of travel, brought about by lower costs and higher service quality offered by the improvement or provision of the transport facility |
| | Additional Traffic | Zero on new facility. Existing traffic on existing road. Existing plus new road in network, traffic will redistribute. |
| | Future Traffic | Existing and additional traffic affected by “old” and “new” facility. Traffic is redistributed after opening of new facility. |
| **(2) Time Saving** | Individual | Time saving mean that trip times using a new or improved facility are shorter compared with trips using the existing facility between the same origins and destinations |
| | Vehicles | Travel time saving in relation with the vehicles can be measured from two angles: whether the same trip can be covered in less time or whether a long distance can be covered or more journeys can be made at the same time (useful for taxis). |
| **(3) Reducing Accidents Costs** | Fatalities and Injuries to People | When planning for new or improved facility, transportation planners have for main objectives to reduce the number and severity of accident |
| | Damage to Vehicles, Goods and other Properties | The cost of the anticipated benefits is deducted from the current cost of accidents. |

The cost for the transportations improvements are generally composed of capital cost (non-recurrent) and operations and maintenance costs (recurrent cost).the total cost of transportation infrastructure supply and usage comprise non-recurrent and recurrent costs. The three component of the total cost can be identified, namely infrastructure cost, user cost and external cost (Bester, 2013). Table 2-10 illustrates the classification of transport costs.

**Table 2-9: Classification of Transportation Costs (Bester, 2013)**

| | | |
|---|---|---|
| **Infrastructure Costs** | Capital or Investment Costs | Initial cost : preliminary investigation, planning design, land exploration, construction providing infrastructure by means of permanent facilities/structures<br>Reconstructions and structural changes to existing facilities |
| | Maintenance Costs | Routines maintenance and repair |
| | Administration Costs | Routine administration, management and monitoring |
| | Policing Costs | Law enforcement, guard and life-saving services |
| | Traffic Control Costs | Vehicle and load inspection and control of traffic-flow to enhance orderly facility usage |
| | Research Costs | Developing and improving methods of infrastructure supply |
| **External Costs** | Accident Costs | Resources wastage due to accidents that cannot be recovered from the perpetrators of accidents and are therefore borne by society: loss of output, the subsidized share of rescue services, hospitalization and medical services. Police investigation, free legal services and non-changeable cost |
| | Costs of Congestion | Wastage of time<br>Additional vehicle operating cost<br>Non-quantifiable disutility: frustration, stress |
| | Damage to the Environment | Pollution, noise, vibration, unsightliness and visual intrusion |
| **User Costs** | Vehicle Operation Costs | Running or movement cost of vehicles and standing charges (time-cost) of vehicles |
| | Overhead Costs | Fixed costs not directly related to vehicles |

### 2.6.4. B/C Analysis for ITS Strategies

In the absence of the sufficient funds for undertaking capital investment on road projects, the focus has shifted towards the improvement of the existing road network. This has led to an increase in the number of minor works and traffic operations projects competing for limited funds. Thus, it is often necessary to prioritize and rank widely varying project types. Fortunately, B/C analysis provides a framework that may be adapted to the challenges of this analysis need (Bester, 2013).

B/C analysis provides several capabilities that are key in supporting different planning needs throughout the operations planning process. B/C analysis is usually performed to determine if a project represents a sound investment and to compare alternative projects to identify the most efficient projects for prioritization purposes. This analysis can also provide benefits and costs information that can be used as justification for the financing of ITS projects. B/C analysis requirements need to be carefully considered in order to provide an accurate comparison and avoid introducing bias into the B/C analysis. By implementing these analyses, comparing different types of projects, more care and effort is required in the implementation of the analysis to:

- Identify the set of MOEs that could be affected by the range of different projects. Not all the various projects can impact on all the MOEs, but it is essential to identify the full range of services to provide a comprehensive analysis significantly;
- Identify sources of data needed to support the estimation of impacts on the identified MOEs. Analysts should strive to identify the data sources that are equally applicable to all types of projects;
- Identify analysis methods and modelling techniques that will be appropriate to assess the differential impacts on identified MOEs methods. Some methods of modelling may be appropriate for analysing certain types of projects, but not for others;
- Establish values (amounts in rand) that will be applied to the incremental change in MOEs in order to monetize the benefit.

The robustness of the analysis B/C can be adapted to fulfil the various needs in the planning process. Early detection and identification of ITS projects that meet the identified objectives can be performed using a simple sketch-planning-level B/C analysis.

This is to provide rough estimates of benefits and costs appropriate for the early detection of projects and a systematic process for examining the most promising projects to carry forward in the planning and analysis process (FHWA, 2012).

During B/C analysis of ITS projects the value of the Costs represents the life-cycle costs of implementing and operating the project. This is important for ITS projects since they typically incur a greater proportion of their costs in years after deployment to operate and maintain the system, and replace obsolete equipment, when compared to more traditional improvements that have high initial construction costs.

These life-cycle costs consists of initial capital cost (planning, implementation, construction and equipment's Costs), Operation and maintenance (O&M) costs, replacement costs and end of projects costs (Andersen, 2013).

### 2.6.5. B/C Analysis Methods

Various methods can be used for B/C analysis. These methods are used in the economic evaluation of projects. They provide fundamental information about relative magnitude of the benefits and cost that accrue over time to decision-makers. Refer to Appendix 1 for the methods used in B/C analysis of this research.

## 2.7. Economic Evaluation of ITS

### 2.7.1. International Studies

Information regarding the costs of ITS deployments is very limited. The ITS Handbook (PIARC, 1999) was the only international source offering benefit/cost relationships, found in past studies.

The ratio of certain ITS measures in various countries have been measured to be in the magnitude of two to eight, with the higher numbers associated with urban settings, as can be seen in Table 2-11.

The implementation of ITS measures, considered by PIARC, strived to attain safety, improved capacity, economic and environmental benefits. Furthermore, where possible, road user satisfaction was also included.

**Table 2-10: International Benefit/Costs Ratios for ITS measures (PIARC, 1999)**

| ITS Project | Benefit/Cost Ratio | Comment |
|---|---|---|
| Incident Detection | 3.8 | Repaying investment in a year |
| Intersectional Signal Control | 3.4 | Repaying investment in a few months |
| Area Traffic Control | 7.6 | Extending existing technology to adjacent towns |
| Parking Management | 1.7 | Even for stand-alone applications |
| Emergency Vehicle Priority | 0 | No cost saving but faster response time (golden hour) meant fewer people required major treatment |
| Weight in Motion | 1.8 | Time saving for heavy vehicles |

Thomas (2001) compared the upgrading of a three lane freeway to a four lane freeway with that of the implementation of a freeway management and found (based on USA averages) an expected 15% increase capacity is possible by investing R0.5million (approximately $55 500) per kilometre roadway in a freeway management system. This gain is possible when compared to an investment of R5million (approximately $555 000) per kilometre roadway for an extra lane to obtain an increase in capacity of 33%.

### 2.7.2. South African Studies

De Jongh-Schreuder and Venter (2005) reported a significantl benefit/cost ratio of a manual traffic control system against that of an automatic system (140.4 compared to 40.4). The explanation for this variance is the lower costs, which is mostly maintenance and user related costs. Within the manual implementation, the traffic volume and time travelled benefits are greater with an automated system implementation.

The University of Cape Town's Department of Civil Engineering performed an economic evaluation comparing the implementation of ITS measures against adding additional transport infrastructure in Cape Town. The costs of construction and maintenance related to the construction of an additional new lane and the introduction of ITS services were compared. The ITS measures were as follows (Carolus, 2002):

- Motorist Information and Warning Signs (VMS)
- Closed Circuit Television (CCTV) Surveillance Cameras
- Incident Detection Equipment
- SOS Emergency Equipment
- Central Control Room

Table 2-12 presents a summary of the costs and benefits, in monetary terms, considered over a period of 25 years. No safety changes were expected if an additional lane would be added. Furthermore, distinct insurance and running costs only ensue if an ITS service is introduced. An extra lane will result in a short term decrease in vehicles per lane and, consequently, a travel time gain. In the long term, this reduction will disappear due to expected higher traffic volumes.

**Table 2-11: Comparison of ITS measures with adding a lane in Cape Town (Carolus, 2002)**

| **Type of Cost** | **Adding a Lane Per km (R*1000)** | **ITS Per km (R*1000)** |
|---|---|---|
| Construction Costs | 29 540 | 30 000 |
| Maintenance Costs | 6 506 | 27 377 |
| Safety Costs (Accidents) | | 3 263 |
| Pollution Costs | 93 529 | |
| Travel Time | 176 221 | 154 559 |
| Running Costs | | 9 168 |
| Total (NPV) | 46 647 | 98 612 |
| **B/C** | **2.29** | **2.67** |

The Net Present Value (NPV) for the provision of an additional lane and for the introduction of an ITS system, were positive, at R46.6 million and R98.6 million respectively (1Euro=R8 in 2002). Therefore, it is evident that the largest benefit to the public is provided by the implementation of an ITS system. ITS system indicated a higher benefit/cost ratio of 2.67 to 2.29. ITS can therefore be regarded as a feasible prospect, since both the NPV and the benefit/cost ratio are higher (Carolus, 2002).

Carolus (2002) recommended that ITS be implemented to increase the capacity of the road, since it will assist to cope with the increase in traffic growth. In the South African landscape, an ITS system will be cost-efficient and potential benefits may be greater, since maintenance costs for the implementation of ITS services might be overestimated (Vanderschuren, 2006).

## 2.8. Concluding Remarks

Transportation is a driving force behind economic development worldwide. As living standards rise, there is a resultant swift growth of demand for transport capital, transport structures and vehicles. Sufficient capital is required to improve standards and living conditions and is one of the greatest challenges that developing countries, like South Africa faces.

Stellenbosch faces serious challenges due to congestion along its major arterial routes as well as in the town itself. Public transport and non-motorised transport is also neglected in the town.

ITS initiatives are considered as innovative alternative solutions. The objective of ITS is to improve road traffic conditions using modern technology, which is empowering to transportation management and operations who seek to ensure road safety and efficiency using existing road infrastructure. ITS have the potential to improve mobility and accessibility in Stellenbosch. Improved mobility and accessibility will create economic opportunities for the poor.

International and South African sources report a wide variety of ITS benefits. Internationally, increased safety benefits were reported, together with a reduction in traffic congestion, which resulted in travel time savings. In South Africa, a general reduction in travel time was noted. Vehicle throughput results were not uniform; interchange control, ramp metering indicated an increase in throughput and HOV lanes and toll roads indicated a reduction in throughput as a result of a decrease in the demand.

B/C ratios for ITS projects are generally reported as higher than those of traditional new road construction.

# 3. Research Methodology

## 3.1. Overview

The solution of transport problems, in particular, traffic congestion and road safety does not only lie in the construction of more road infrastructures. In response to this dilemma, several information and communication technologies known as Intelligent Transportation Systems (ITS) are being applied worldwide in order to provide innovative solutions.

The objective of ITS is to improve road traffic conditions using modern technology, which is empowering to transportation management and operations who seek to ensure road safety and efficiency using existing road infrastructure (PIARC, 2011).

This chapter presents and explains the methods used to gather and manipulate the information used in this thesis and the procedures used to conduct the economic evaluation for the different ITS deployments within the TOPS-BC software.

## 3.2. Selection of ITS Measures and Analysis Tool

### 3.2.1. ITS Measures

ITS measures and their applications are very broad, with each requiring their own environment and set of governance. For the Stellenbosch area, a number of ITS applications can be implemented and will be beneficial. The following is a summary of the ITS measures chosen for the analysis in this thesis.

- Advanced Traveller Information System (ATIS)

Advanced Traveller Information System (ATIS) provide information in real-time on route guidance, roadside weather conditions as well as parking information, all of which are applicable in Stellenbosch. An ATIS will be possible in Stellenbosch, since collection of data using technologies such as GPS installed in the vehicles is possible. Furthermore, provision of variable road message signs is possible for real-time communication of the expected traffic conditions (bottleneck, congestion, accidents and alternative route information during the road maintenance and closure). Lastly, provision of websites and smart phone applications to provide a colour-coded network map showing congestion levels and incidents on the highway will likewise be possible in Stellenbosch.

- Advanced Transportation Management System (ATMS)

The full range of the Advanced Transportation Management System (ATMS) services are applicable to Stellenbosch, with the exception of ramp metering since this application is only applicable in a freeway environment.

- ITS Enabled Transportation Pricing Scheme

The ITS Enabled Transportation Pricing Scheme has various applications that will be suitable for Stellenbosch, except the freeway electronic toll collection system since Stellenbosch is not in a freeway environment. The congestion-pricing scheme will likewise be suitable for Stellenbosch since it can assist in reducing congestion.

VKT usage fees is however not applicable for Stellenbosch context, since VKT tax has a greater advantage for vehicles travelling long distance and especially for the freight carriers. Implementing this system will be expensive for Stellenbosch and will not produce benefits. The freight vehicles passing through Stellenbosch composed only approximately 9% of the traffic volume (Sinclair et al., 2012).

Variable parking fees is another application of ATMS, which is a subset of ITS enabled pricing and its concept is still under experimentation in overseas countries. This strategy can be applied in Stellenbosch but the cost of implementation will be significantly high compared to the benefit, since Stellenbosch is not a metropolis that sustains heavy traffic during off-peak times.

- Advanced Public Transportation System (APTS)

The provision of real time information through automatic vehicle location is possible in Stellenbosch, by use of the TOM-TOM system which is already in use in Stellenbosch (Ter Huurne, 2016). Incorporating this application in the available public transport might be challenging as there will be system requirements which exceeds the scope of this thesis. Electronic fares payment (smart card) also forms part of APTS and is applicable in Stellenbosch, dependent on the provision of proper public transport facilities. Stellenbosch currently has no effective public transport.

- Vehicle-to-Infrastructure Integration (VII) and Vehicle-to-Vehicle (V2V) Integration

The whole range of the Vehicle-to-Infrastructure integration system may be applicable to Stellenbosch since it only requires the DSRC-enabled sensors or tags.

- Commercial Vehicles Operations (CVO)

The whole range of the commercial vehicles operations system may be applicable in Stellenbosch, since Stellenbosch has an operational traffic department, which can implement applications such as vehicle monitoring and safety management systems, freight management and monitoring of driver credentials.

### 3.2.2. Selection of Appropriate ITS Measures

A number of ITS measures may be applicable in Stellenbosch, but only two were chosen to form the basis of the research analysis. These two are Actuated Traffic Signal Coordination as part of Advanced Transportation Management System and Parking Information Systems as part of Advanced Traveller Information Systems.

These two strategies were chosen because it is anticipated that their benefits will have a significant effect on reducing congestion along the Stellenbosch arterial as well as in the town of Stellenbosch.

This thesis will use the TOPS-BC instrument for the B/C investigation of the two proposed ITS and one new road construction. TOPS-BC is a versatile assessment tool that easily conforms to new developing transport systems.

TOPS-BC furthermore makes use of the sketch planning technique, which is an evaluation technique that gives straightforward, speedy, and low-cost estimation of ITS strategy coats and benefits. For these reasons, the author prefers TOPS-BC. An overview of the different worksheets in TOPS-BC is presented in Appendix 2.

Table 3-1 provides a summary of the ITS measures, their corresponding components as well as their potential long term applicability within the Stellenbosch area.

## 3.3. Experimental Design

The following sections detail the research methodology that was followed during the analysis. As discussed in Section 3.2 this thesis will conduct a B/C analysis for two chosen ITS measures and one new road construction.

The two ITS measures to be deployed will be an actuated traffic signal coordination along the Stellenbosch Arterial and Bird Street and provision of parking information in Stellenbosch town.

The new road construction will use the Stellenbosch Scenic Western Bypass which has been proposed as an alternative to alleviate congestion in Stellenbosch.

Figure 3-1 depicts the research design for the ITS strategies.

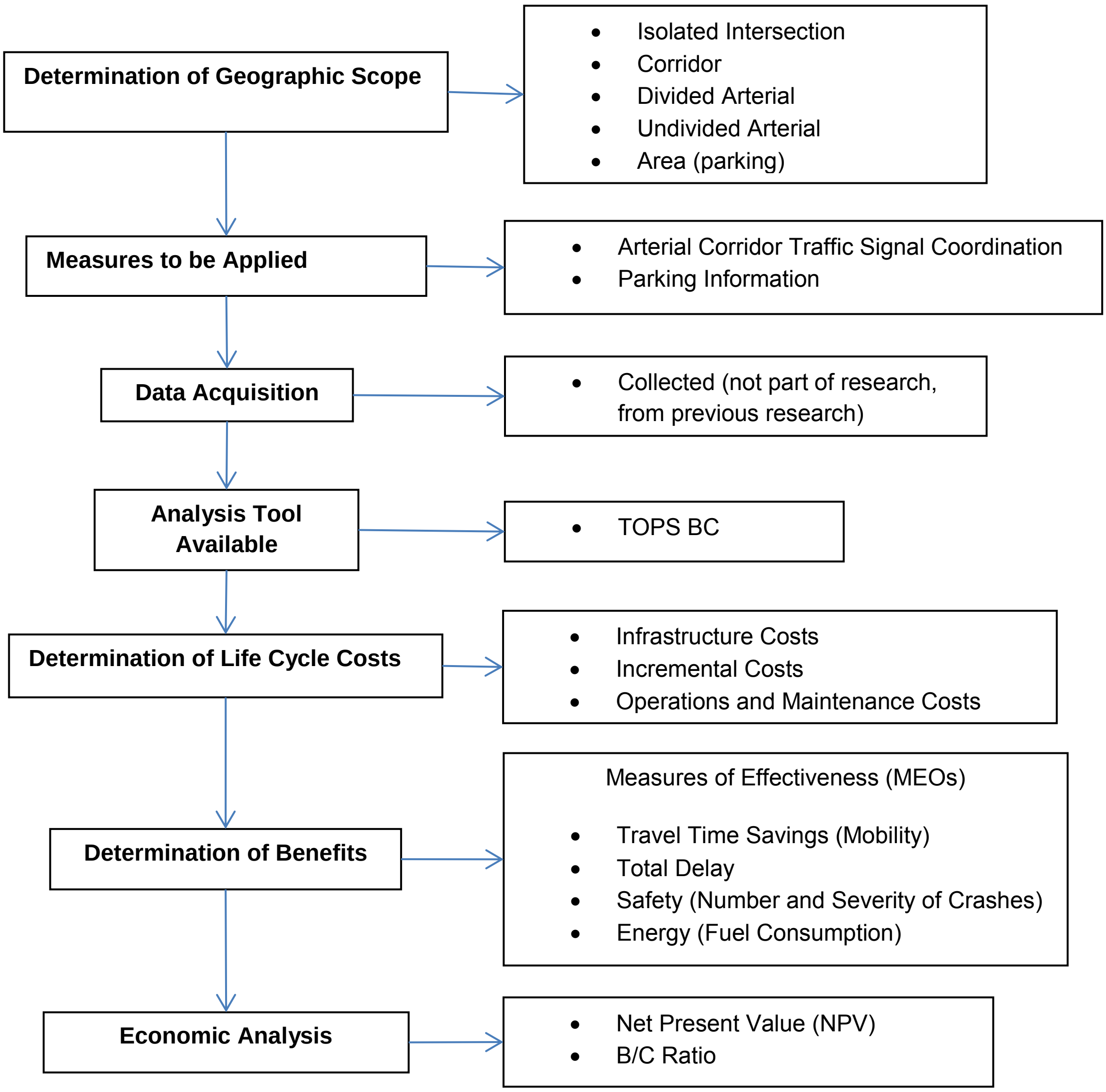



**Figure 3-1: Experimental Design of B/C Analysis for ITS Deployments in Stellenbosch**

Figure 3-2 depicts the research design for the new road construction.

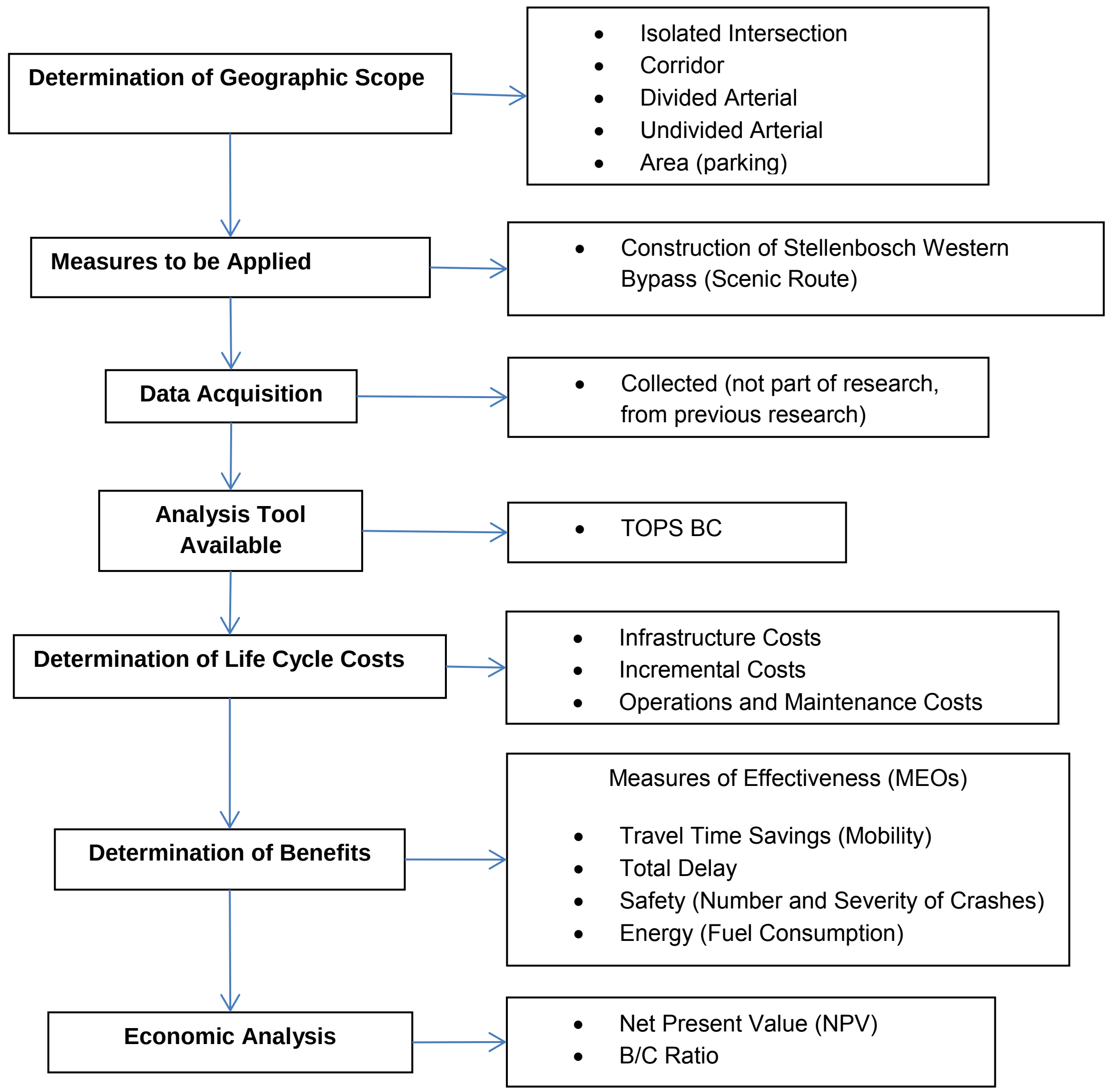


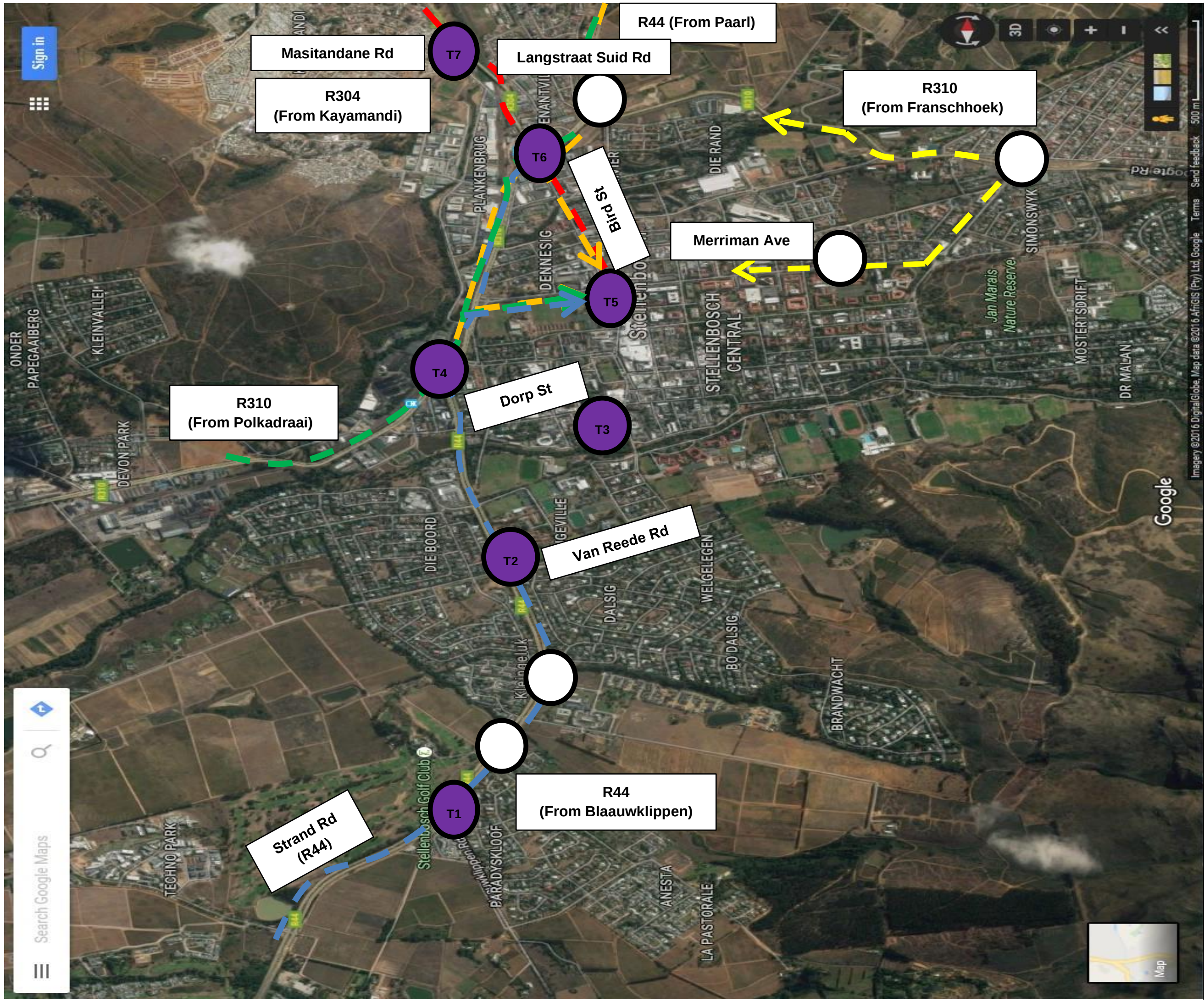

**Figure 3-2: Experimental Design of B/C Analysis for Traditional Transport Improvement in Stellenbosch**

## 3.4. Conceptual Design for Actuated Traffic Signal Coordination

This section presents the architecture of the actuated signal traffic coordination system for the arterial network of Stellenbosch. The system is based on the existing traffic signals deployed on the Stellenbosch arterial. The actuated traffic signal coordinated system provides an upgrade of the current traffic signal system of the Stellenbosch arterial and ensures the economic viability of the deployment.

### 3.4.1. Geographical Scope

The geographical location of the actuated traffic signal coordinated system is illustrated in Figure 3-3.




| Intersections in Research Analysis | |
|---|---|
| Blaauwklippen Rd X Strand Rd (R44) | |
| Paradyskloof Rd X Strand Rd (R44) | |
| Van Reede Rd X Strand Rd (R44) | |
| Dorp St X Strand Rd (R44) | |
| Adam Tas Rd (310) X Strand Road (R44) | |
| Dorp St X Adam Tas Rd (R310) | |
| Adam Tas Rd (R44) X Merriman Ave | |
| Adam Tas Rd (R44) X Bird St | |
| Merriman Ave X Bird St | |
| Adam Tas Rd (R44) X Langstraat Suid Rd | |
| Bird St (304) X Masitandane Rd | |
| **Legend** | |
| ○ (white circle) | Intersections in Open Network of Coordinated Traffic Signals |
| ● (purple circle) | Analysed Intersection in the Coordinated Network |
| SCALE 1:50 000 | |

**Figure 3-3: Locations of Actuated Traffic Signal Coordination in Stellenbosch (Google Earth)**

### 3.4.2. Components of Traffic Signal Coordination

Traffic signal controls are implemented for allocating opportunity to enter an intersection and reducing or eliminating delaying conflicts at intersections. Signals accomplish this by allocating green times to the various users at the intersections. Traffic signals may operate in a system of intersections. The application of timing plans depends on the road environment infrastructure available in the signal system. These components are described below. Figure 3-4 presents an overview of the system requirements of traffic signal coordination systems. The specifications of the devices are provided in this section.

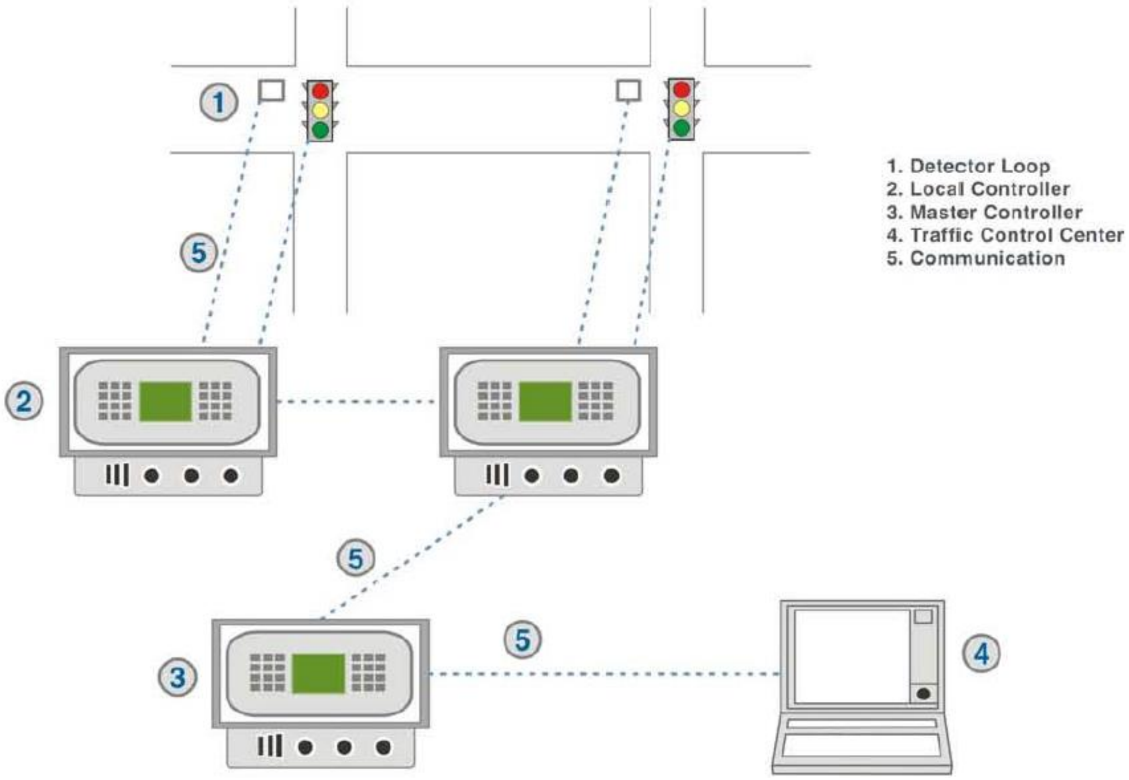



**Figure 3-4: System Requirements for Traffic Signal Coordination Systems**

- Loop Detectors

Detectors are used to identify the presence of a vehicle, so that the controller knows how to adjust the amount of green time provided. The purpose of a detector is to determine the presence of a vehicle, bicyclist or pedestrian, or the passage of a moving vehicle. This presence or passage detection is sent back to the controller, which adjusts the signal accordingly. Magnetic induction loops embedded in the road are mostly used in South Africa.

- Signal Controller

A traffic signal controller is an electronic mechanism mounted in a cabinet for controlling the sequence and phase duration of the traffic signal. Right-of-way is assigned by turning on or off the green indication. There are two basic types of traffic controllers, pre-timed and actuated. A pre-timed controller operates according to pre-determined schedules. An actuated controller operates with variable vehicular and pedestrian timing and phasing intervals, which are dependent upon traffic demands. If there is no demand for a phase, the actuated controller may omit that phase in the cycle (e.g., if there is not a demand for left turns, the left-turn phase will not be activated).

A fully actuated controller has detection devices on all approaches to the signalized intersection, whereas a semi-actuated signal only has detection on some of the approaches. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears or when the pre-set maximum green time has elapsed. Once the minor street demand has been satisfied, right-of-way is typically returned to the major street whether or not a major street detection has been registered.

- Traffic Control Centre

The traffic management will received the information about the traffic conditions and ensure coordination timing provides smooth traffic flow along the street such as that mobility is increased and fuel consumption is minimized.

- Communication Line

A fibre network allows the communication between the different components of the traffic actuated coordinate system. Communication facilitates coordination between controllers.

- Power Supply

The traffic lights for the actuated coordinated system will be connected to the municipality power supply for them to be continually powered.

- Data Collection

The vehicular data collected at the intersection approach by means of the detector loops are used for configuration of the traffic signal strategy during the peak and off-peak hours. The traffic signal strategies include pre-time, semi-actuated and fully actuated.

- Traffic Control Centre

The traffic operations controllers receive and process the data that are used for the traffic signal strategy at each intersection, taking into account the system as a whole. Instructions are thereafter given to the local controller to allocate green time to the different phases according to the traffic conditions and the hours of operation (peak or off-peak hours). The green phase is allocated to the different cycles and the adjacent intersections are included during the signal timing plan.

The traffic coordination system for Stellenbosch will consist of the local controller units associated with each intersection along the intersection on the major network's arterial. The signal coordination is achieved by operating these controller units in a way to provide a green indication at adjacent intersections in a green wave. A specific timing schedule is set for the controller units to allow the smooth flow of the traffic operation along the street at a planned speed.

In addition to managing the smooth progression of the traffic volume on the arterial, coordinated traffic signal system are also able to detect an incident. The coordinated system employs loop detector located at the upstream end of the road link to capture traffic profiles which are assumed to progress down the link with a dispersion model.

Delay and incidents are calculated from the predicted arrival profile and the current signal timing. The algorithm considers a smooth occupancy for adjacent pairs of sensors, one upstream and one downstream. An incident is detected if the upper bond of upstream occupancy is exceeded and incident will be expected downstream of the upstream detector. If the downstream occupancy lower bound is infringed at the same time, then an incident is confirmed. The upper and lower bounds are adaptive thresholds that vary with the prevailing traffic condition.

Stellenbosch does not have any ITS plan and only some intersections operate in isolation using pre-timed or semi-actuated signal control for the movement of traffic volume on the arterial system. For economic efficiency new deployment will be done for all intersections in the study area, together with the needed upgrade using the flow chart guideline in Figure 3-5. In this research only the O&M cost accounted for the life cycle cost and a discount rate of 10 % was applied during the calculation of the user costs.

### 3.4.3. System Architecture

Coordination is achieved by defining a common cycle length for all controller units and, at each intersection, specifying intervals within the cycle during which each phase may be served. Coordination requires the designation of one phase per ring as the coordinated phase, where all coordinated phases are part of the same concurrency group. Unlike the other phases, the coordinated phase is guaranteed to display the green indication for a designated portion on the cycle. Figure 3-5 depicts the requirements needed to upgrade the existing traffic signals to the actuated traffic signal coordination system.

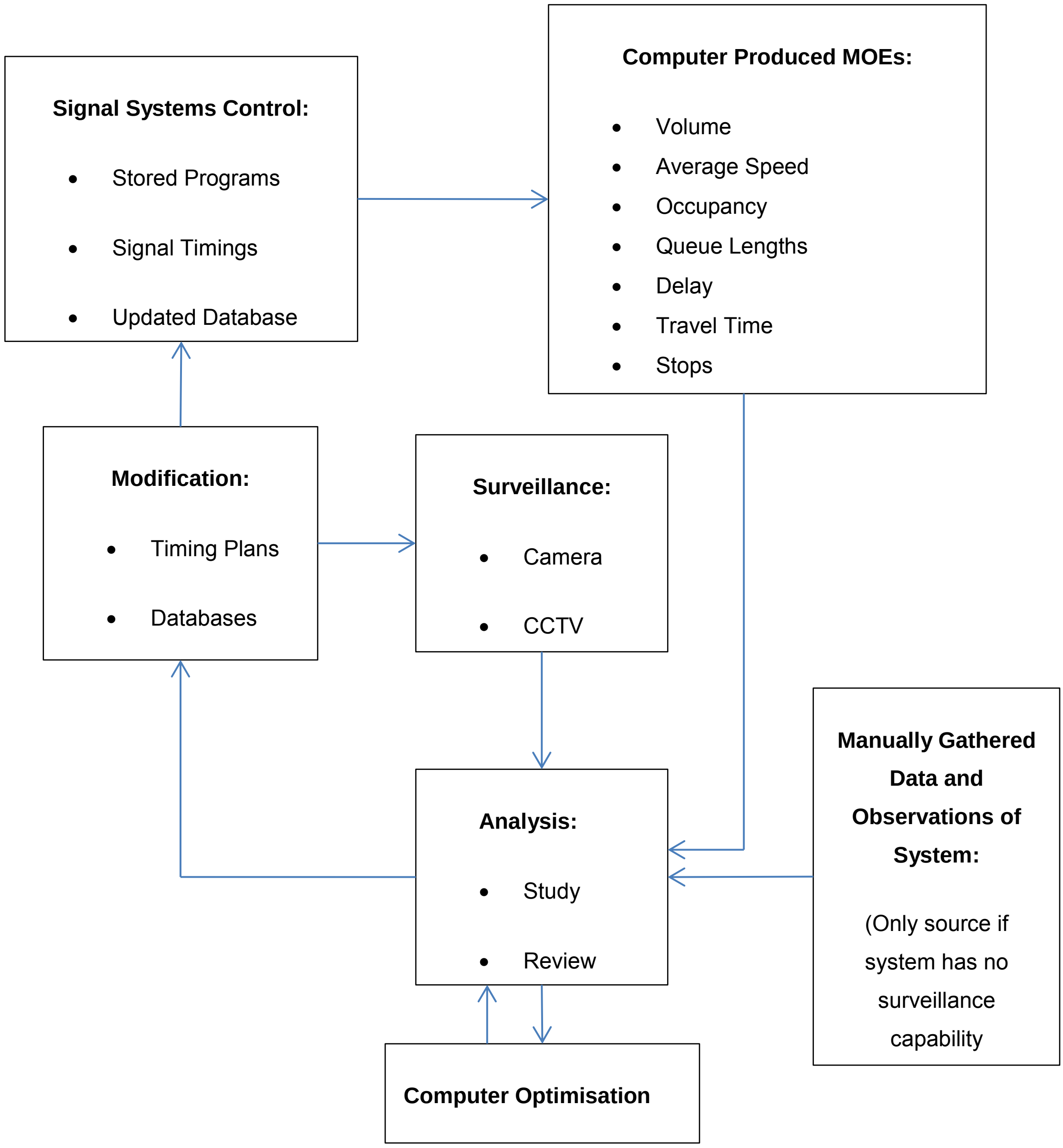



**Figure 3-5: Requirements to Upgrade Existing Traffic Signal (Traffic Signal Handbook, 2005)**

Figure 3-6 illustrates the system architecture for the actuated traffic signal coordination.

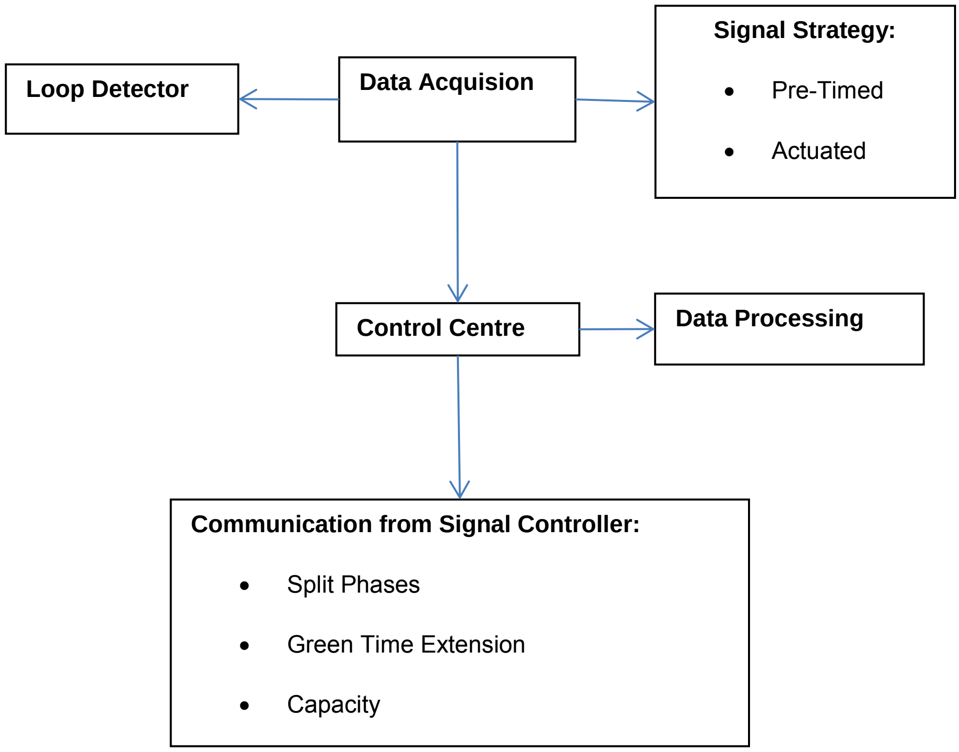



**Figure 3-6: System Architecture for Actuated Traffic Signal Coordination System**

### 3.4.4. Design Parameters

Actuated traffic signals are used at intersections to reduce the average delay of vehicles and to reduce the probability of crashes. Actuated traffic signals minimize the conflicts at the intersections by assigning the right of way to different traffic streams at different times. At complex intersections, the actuated traffic signal uses multi-phases (three or more) to achieve the goal of reducing delays and crashes.

When there is a fluctuation in traffic volumes, actuated traffic signals are capable of automatic adjustment. These traffic signals are able to detect arriving traffic at the intersection and transmit the information to the controller in order to adjust the phase's length and meet the needs of the prevailing conditions. Fully actuated traffic signals are recommended for intersections with a large variability in traffic volume.

To estimate the likely impacts resulting from the deployment for this research study, the analysis will be based on the following parameters:

- Variability of Travel Demand

Travel demand at arterials varies from day-to-day because of special events, weather conditions, changes in directionality, or other reasons. The effectiveness of a particular traffic management strategy must take into account the variability of travel demand. For example, under highly variable demand conditions in a corridor, actuated signal coordination is more effective than pre-set signal coordination.

- Overall Level of Congestion

Under high-volume/high-congestion traffic conditions, actuated corridor signal coordination would be less effective in a multi-regime gridlock control approach. In this case, central control signal coordination would work better than any corridor coordination scheme. In another example, systems with relatively low overall volume and highly variable demand directionality may get the largest benefit from isolated actuation.

- Time Interval between Signal Timing Plan Modifications

This parameter is as important in determining traffic signal benefits as the variability in travel demand or the level of traffic signal coordination technology.

- Density of Traffic Signals

For isolated traffic signal actuation, the density of traffic signals is an important parameter.

### 3.4.5. Scenarios Investigated

Segments of the R44, R310, R304, Merriman Avenue and Bird Street will be used to evaluate the impacts of the enhanced traffic capacity caused by the actuated traffic deployment and parking management system. Since Stellenbosch's arterial road system is composed of roads with divided and undivided lanes, the analysis will consider both types.

As it was not possible to analyse more than one corridor at once using TOPS-BC, different scenarios were considered and separate TOPS-BC spreadsheet were set up for each of them.

Table 3-5 presents the different intersections considered in the study area.

**Table 3-5: Different Intersections Considered in The Study Area**

| Intersections | Number of Lanes | Link Capacity (veh/hr/lane) | Free Flow Speed (km/hr) | Arterial Type |
|---|---|---|---|---|
| **Blaaukwlippen Rd X Strand Rd (R44)** | 4 | 1100 | 50 | Divided |
| **Paradyskloof Rd X Strand Rd (R44)** | 4 | 1100 | 50 | Divided |
| **Van Reede Rd X Strand Rd (R44)** | 4 | 1100 | 50 | Divided |
| **Dorp St X Strand Rd(R44)** | 4 | 1100 | 50 | Divided |
| **Adam Tas Rd (R310) X Strand Road (R44)** | 4 | 1100 | 50 | Divided |
| **Dorp St X Adam Tas Rd (R310)** | 4 | 1100 | 50 | Divided |
| **Adam Tas Rd (R44) X Merriman Ave** | 4 | 1100 | 50 | Divided |
| **Adam Tas Rd (R44) X Bird St** | 4 | 1100 | 50 | Divided |
| **Merriman Ave X Bird St** | 2 | 1200 | 45 | Undivided |
| **Adam Tas Rd (R44) X Langstraat Suid Rd** | 4 | 1100 | 50 | Divided |
| **Bird St (304) X Masitandane Rd** | 2 | 1200 | 45 | Undivided |
| **R304 X Makupula Rd (Kayamandi)** | 2 | 1200 | 45 | Undivided |

#### *3.4.5.1. Scenario 1: Segment of Strand Road (R44)*

The first scenario will deploy the actuated traffic signal coordination on the segment of the R44 between the intersection of Adam Tas Road and Strand Road (R44) and the intersection of Blaauwklippen and Strand Road (R44).

The segment length is 3.3 km and is composed of two lanes in each direction. Figure 3-7 illustrates the segment of Strand Road (R44) representing Scenario 1.

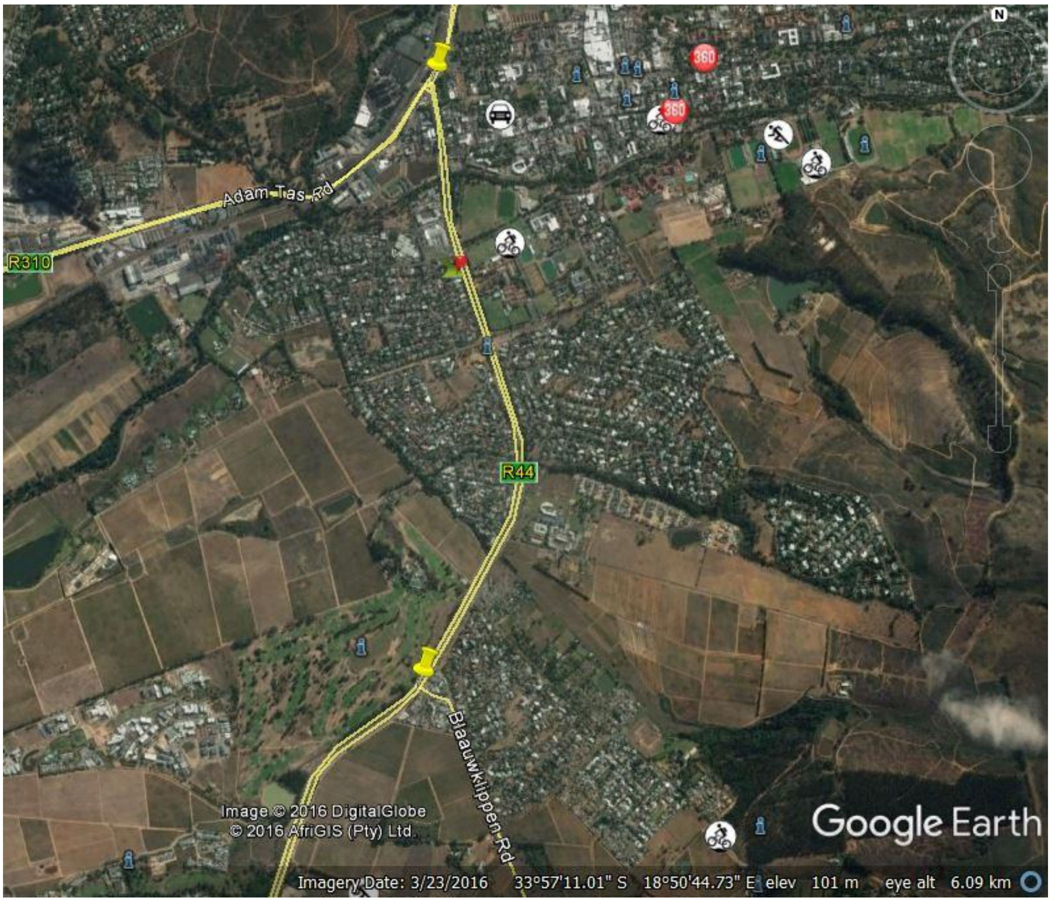



**Figure 3-7: Scenario 1 - Section of R44 Strand Rd (Google Earth)**

The actuated traffic signal coordination will be deployed on five intersections on the segment that make up the first corridor. These intersections are:

1. Adam Tas Road and Strand Road (R44)
2. Dorp Street and Strand Road (R44)
3. Van Reede Street and Strand Road (R44)
4. Paradyskloof Road and Strand Road (R44)
5. Blaauwklippen Road and Strand Road (R44)

The free flow speed on the segment is 50km/hr and the travel demand varies daily due to the road incidents. Traffic volumes fluctuate between 220 veh/hr and 2200 veh/hr, which imply that the V/C ranges between 0.1 to 1.0.

#### *3.4.5.2. Scenario 2: Segment of Bird Street (R304)*

The second scenario deployed the actuated traffic signal coordination on the segment of Bird Street (R304). The segment starts at the intersection of Bird Street (R304) and Masitandane Road and proceeds to the intersection of Bird Street (R304) and Merriman

Avenue. The segment length is 1.7 km and is composed of one lane in each direction (lane capacity is 1200 veh/hr/lane). The free flow speed recommend by the Stellenbosch' EMME/2 model is 45 km/hr. The travel demand of the segment varies daily between 120 veh/hr and 1200 veh/hr due to road incidents and traffic volumes. Figure 3-8 illustrates the segment representing Scenario 2.

The second scenario deployed the actuated traffic signal coordination on the segment of Bird Street (R304). The segment starts at the intersection of Bird Street (R304) and Masitandane Road and proceeds to the intersection of Bird Street (R304) and Merriman Avenue. The segment length is 1.7 km and is composed of one lane in each direction (lane capacity is 1200 veh/hr/lane). The free flow speed recommend by the Stellenbosch' EMME model is 45 km/hr. The travel demand of the segment varies daily between 120 veh/hr and 1200 veh/hr due to road incidents and traffic volumes. Figure 3-8 illustrates the segment representing Scenario 2.

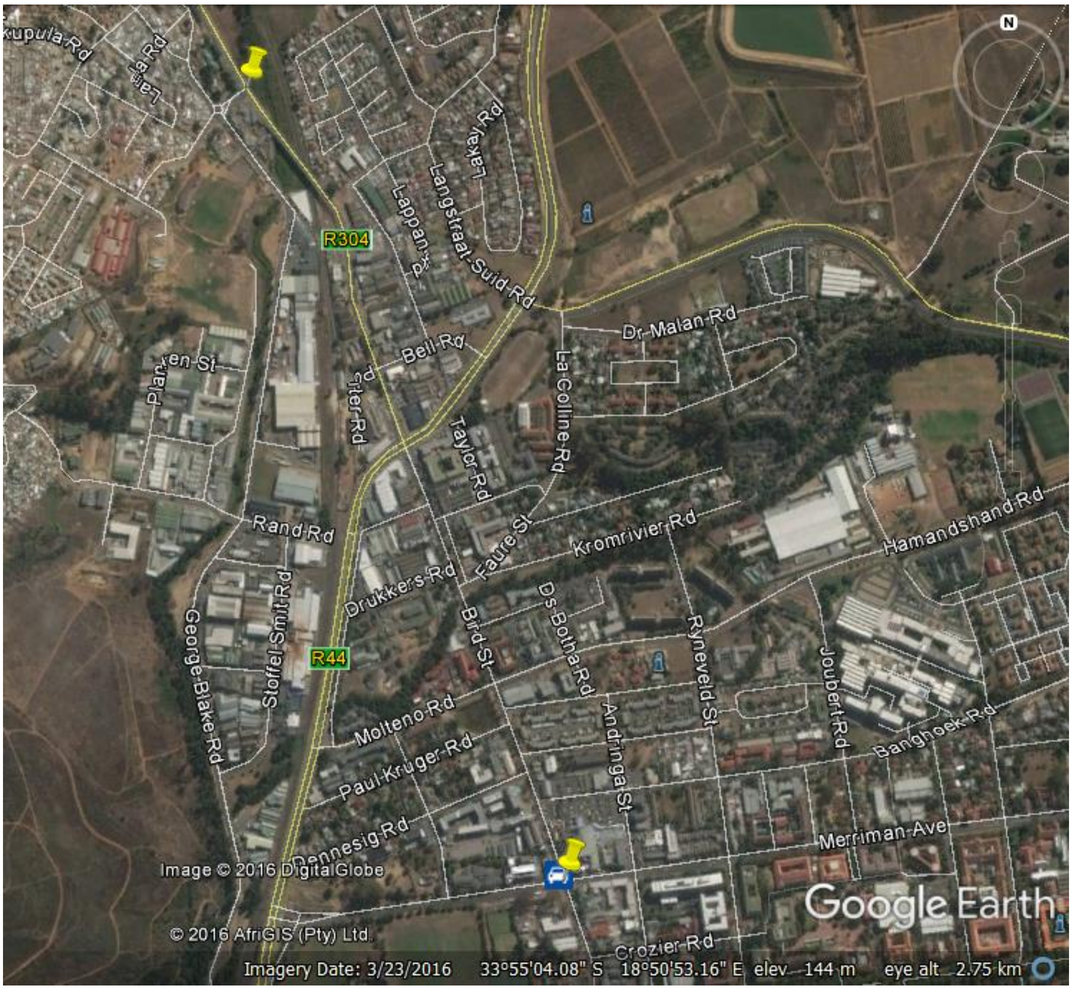



**Figure 3-8: Scenario 2 - Section of R304 Bird Street (Google Earth)**

The actuated traffic signal coordination will be deployed on three intersections on the segment that make up the second corridor. These intersections are:

1. Bird Street (R304) and Merriman Avenue
2. Bird Street (R304) and Adam Tas Road
3. Bird Street (R304) and Masitandane Road

## 3.5. Conceptual Design for Parking Management System

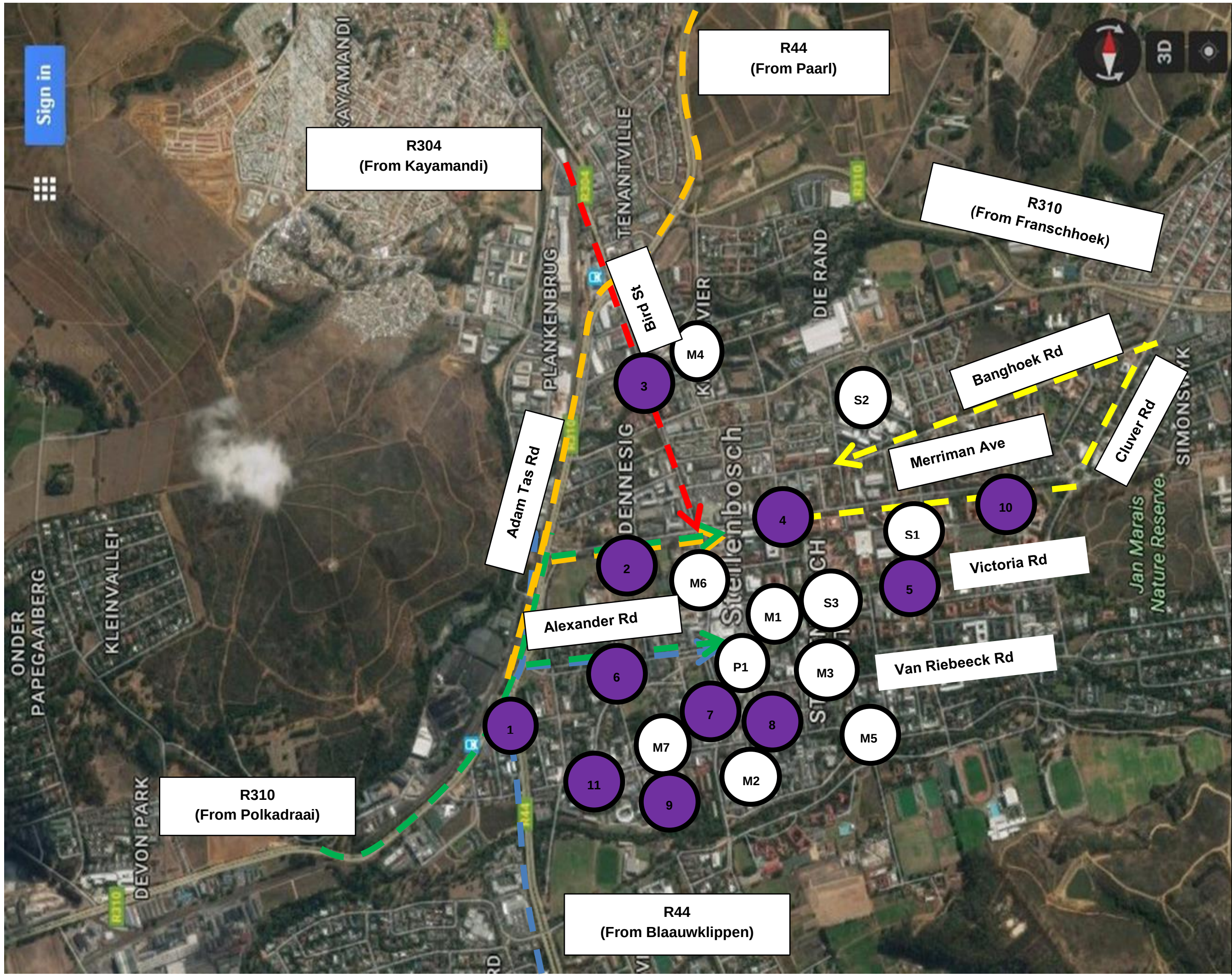
This section presents the architecture of the proposed parking information system for Stellenbosch. The developed system is to be integrated with the current parking management system provided by Stellenbosch Municipality.

Parking Management System is an application of the Advanced Traveller Information Systems (ATIS). Many European and Japanese cities have implemented smart parking management systems to use the parking capacity more efficiently. The systems typically provide real-time information to motorists by means of Variable Message Signs (VMSs) that post the number of available parking spaces in the parking lots, roadway traffic conditions, as well as guidance to open spaces in park-and-ride lots. Parking management system provides motorists availability of the parking lots and alternative roads to reach the parking facility in a geographic area cover by the system. Parking management system has support VMS technologies, which:

- Display parking availability information to motorists on an adjacent commuting corridor into downtown;
- Contain a centralized intelligent reservation system, which permit commuters to check parking availability and to reserve a space via telephone, mobile phone, Internet, or PDA;
- Comprise of a smart parking system that collects traffic count data from entrance and exit sensors at the entrance of the parking facilities. The system monitors parking lots with assistance of the intelligent reservation system to provide accurate, up-to-the-minute counts of parking availability.

### 3.5.1. Geographical Scope

The location of the VMS and parking bays that form part of the parking management system for Stellenbosch are illustrated in Figure 3-9.




| Parking Key | Parking Facility Names |
|---|---|
| M1 | Eikestad |
| M2 | Stelcor |
| M3 | Bloemhof |
| M4 | Stelmark |
| M5 | Noordwal |
| M6 | Aandklas |
| M7 | Checkers |
| S1 | Neelsie |
| S2 | Engineering |
| S3 | Sasol Art Museum |
| P1 | Eikestad Underground |
| **Legend** | |
| | Parking Facility |
| | Variable Message Signs (VMS) |
| S | Stellenbosch University Parking |
| M | Municipality Parking |
| P | Private |
| SCALE 1:50 000 | |

**Figure 3-9: Location of Parking Management System Devices (VMS) in Stellenbosch (Google Earth)**

### 3.5.2. Components

The component listed below represent the devices required for the parking management system. The specifications of the devices are provided in this section.

- Electronic Counter

An electronic switch installed on the current manual booms to monitor incoming and on-going traffic from the parking facility in order to estimate the availability of the parking.

- GSM Modem

The GPS modem is used to transfer the data received from the electronic counter via cellular network.

- Variable Message Signs (VMS)

Once the information from the controller is received and processed, the VMS displays the information regarding the availability of parking

- Mobile Application

A mobile application supports the parking management system. Information on availability of parking is provided through the mobile application and allows the pre-trip and en-route motorists to reserve a parking via the application.

- Website

The parking management system is also support by a website that similarly displays information on the availability of parking, a map of the different locations of parking and the different tariffs. The website also allows users to download the mobile application for parking management.

- Power Supply

The majority of the times the parking management component are linked to the municipality power supply. Generators are however provided to cover the system in case of power failure.

- Data Collection

The collection of parking data is obtained by means of the electronics switch installed at the booms at the entrance of the parking lots. An algorithm estimates the number of parking lost available using the information provided by the electronic switch.

- Traffic Management Centre

The traffic management centre plays the role of the control centre of the parking management system. The data received from the detector at the entrance and the parking request from the users is processed and transmitted via the traffic management centre to the rest of the system.

### 3.5.3. System Architecture

The Parking Management System consists of a series of consecutive transmission processes. The received and processed parking data sets are exchanged between the different system components (entities) and communicated to the user of the system. The parking management architecture is illustrated in the Figure 3-10.

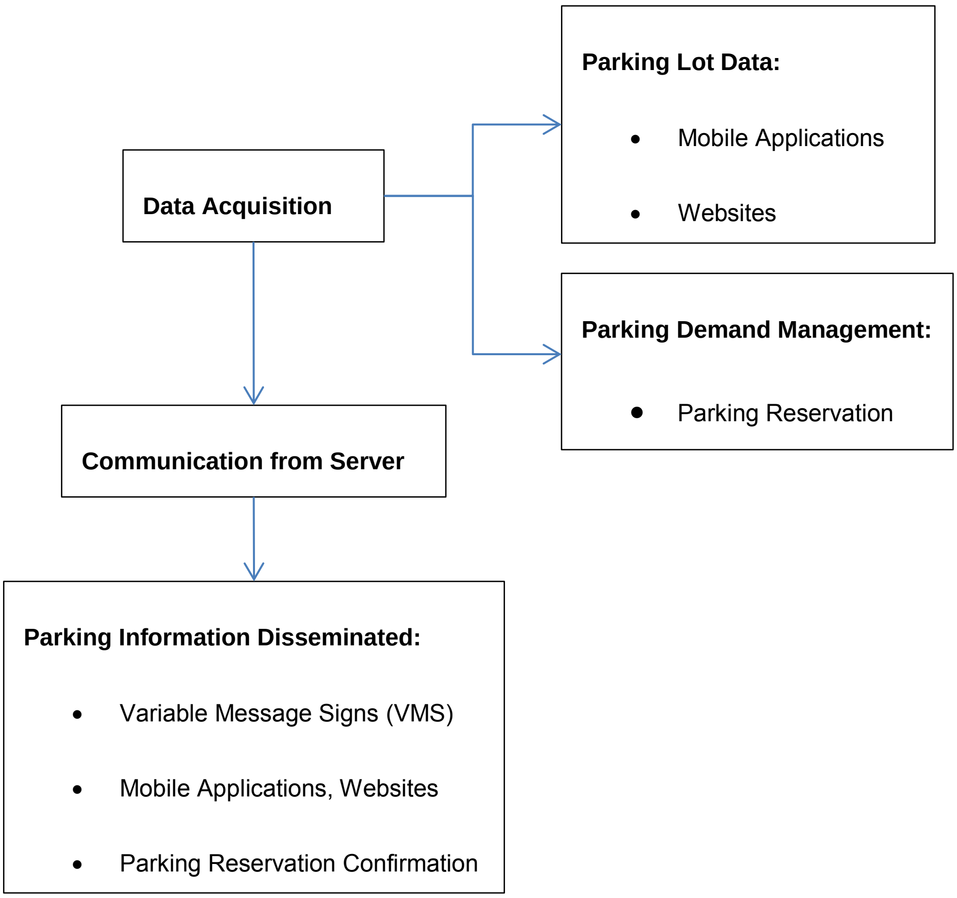



**Figure 3-10: System Architecture of Parking Management System**

### 3.5.4. Design Parameters

To estimate the likely impacts resulting from the deployment the methodology was based on the following parameters:

- Travel Time and Throughput

For each VMS-equipped link, multiply [traffic volume] times [percent time sign is turned on] times [percent vehicles passing sign that save time] times [average amount of time savings in hours]. Sum over all VMS-equipped links. This is the overall estimate of person-hours saved as a result of VMS deployment.

- Travel Time Reliability

Travel time reliability impacts are taken into account in the travel time and throughput calculation.

During the analysis to capture the traffic volume provided a good indication to quantify the benefits proved from de parking management system. VMSs benefits resulted from the percent of the time the VMSs was switched on and provide useful information for the drivers. The IDAS methodology based on historical trends for parking management system found that the time when the VMS is turned on and information is disseminated varies between 10% and 20%, percentage of vehicles passing the sign and saving time is approximately 28% and approximately 11 minutes saved in travel time (IDAS User's Manual, 2008).

The fastest the VMSs provided the information on available parking and allowed the drivers to save time the more benefits are obtained from the strategy. The strategy was mostly deployed during peak hours, morning (7h30 to 8h30) and during lunchtime (12h30-13h30). The afternoon peak hours was not included during the analysis. The trips patterns did not show a great parking demand since the majority of the traffic volume was leaving Stellenbosch.

The traffic count system located at the entrance of the parking facilities allowed to collect data from entrance and exit sensors. The data collected allows the system to know the amount of available parking and displays the information on the VMSs. Table 3-2 shows the different location of the VMSs in Stellenbosch.

**Table 3-1: Different VMS Locations in the Stellenbosch Area**

| VMS Name | Street Name | Location GPS Coordinate | Parking Key |
|---|---|---|---|
| **VMS1** | Adam Tas Road | 33°56’12.7”S 18°51’05.1”E | M1, M4, M2 |
| **VMS2** | Merriman Street | 33°55’57.0”S 18°51’24.2”E | M4, M2, S1, M4 |
| **VMS3** | Bird Street | 33°55’53.5”S 18°51’30.4”E | M6, P1, M4 |
| **VMS4** | Merriman Street | 33°55’56.0”S 18°51’33.2”E | P1, M1 |
| **VMS5** | Victoria Street | 33°56’09.7”S 18°51’42.5”E | M2, M7, P1 |
| **VMS6** | Alexander Road | 33°56’09.7”S 18°51’30.0”E | M7, M2, P1 |
| **VMS7** | Bird Street | 33°56’11.6”S 18°51’33.8”E | M7, M1, M3, M2 |
| **VMS8** | Plein Street | 33°56’16.1”S 18°51’34.9”E | M2, M7, P1 |
| **VMS9** | Mill Street | 33°56’16.1”S 18°51’34.7”E | M7, M3, P1, M1 |
| **VMS10** | Merriman Avenue | 33°55’52.0”S 18°52’06.4”E | S1, P1, M4 |
| **VMS11** | Dorp Street | 33°56’20.9”S 18°51’29.2”E | M2, P1, M6, M7 |

#### 3.5.5. Scenarios Investigated

##### *3.5.5.1. Scenario 1: Divided Arterial Lanes – Adam Tas Street*

The first scenario will deploy the parking management system on Adam Tas Street.

##### *3.5.5.2. Scenario 2: Undivided Arterial Lanes – Bird Street*

The second scenario will deploy the parking management system on Bird Street.

### 3.6. Traffic Forecasting for Analysis of ITS Strategies

The data used for the intersection approach in the analysis were collected in 2009 for the research on Sustainable Stellenbosch (Sinclair et al., 2012). The traffic volume data of the am peak hours of the EMME model dated from 2009 to 2012 received from the traffic authorities of the Stellenbosch Municipality were used to calibrate the data from Table 2-2. The ITS strategies analysed in the TOPS-BC tool in this research were deployed using 2016 as its baseline.

Due to the lack of 2016 historical data, the AADT from 2009 of the different intersection approaches were projected in time to estimate the traffic volume of the baseline year 2016. TOPS-BC's recommendation of 20 years lifetime for the different ITS strategies deployed for Stellenbosch was used as assumption during the traffic forecast. The second assumption used for the traffic forecast was the traffic volume growth factor. Bester (1989) reported that the Western Cape Province's traffic volume was 3.1%. In recent years, Sinclair et al (2012) reported that the traffic volume growth factor for the area is 3.7 %.

Taking into account the trend of historical data from the previous research, this research assumes that the traffic growth factor for the analysis is 3.7% per annum. This growth factor will be used for the calculation of the different AADT in 2016. A further assumption in this research is that the vehicle distribution is composed of Heavy Vehicles and Passenger Vehicles, with Commercial Vehicles making up 20% of Passenger Vehicles and Private Vehicles making up 80% of Passenger Vehicles.

A Design Hourly Volume (DHV) and Directional Design Hour Volume (DDHV) will be used since it was reported that the level of congestion for the inbound traffic during the morning peak hours was greater than the outbound traffic. (Ter Huurne, 2016) reported that the inbound morning traffic from Paarl and Somerset West had increased by 60% on both approaches of the R44.

The analysis was conducted during the peak hours and it was assumed that during peak times two thirds of the traffic flow will be travelling in one direction. The DHV derived from the forecasted AADT using a $K_{30}$ factor was obtained from the following formula (Project Traffic Forecasting Handbook, 2014)

$$DVH = AADT * K_{30}/100 \tag{3}$$

The K factors represent the typical condition found around the world for free-flow conditions and are representative of the typical traffic demand. The magnitude of the K factor is directly related to the variability of the traffic demand over time. Table 3-3 presents the recommended $K_{30}$ factors for different road types.

**Table 3-2: Recommended K-factor ($K_{30}$) for Traffic Forecasting (Project Traffic Forecasting Handbook, 2014)**

| Road Type | $K_{30}$ (%) | | | |
|---|---|---|---|---|
| | Low | Average | High | Standard Deviation |
| Rural Freeway | 9.60 | 11.8 | 14.6 | 1.43 |
| Rural Arterial | 9.40 | 11.0 | 15.6 | 1.42 |
| Urban Freeway | 9.40 | 9.7 | 10.0 | 0.28 |
| Urban Arterial | 9.20 | 10.2 | 11.5 | 0.92 |

Rural and recreational roads exhibit the highest K factors, while urban roads and highways, with their repeated home-to-work trips exhibit low K factors. The trend of historical data recommended using a K factor of 11 for the urban roads. Due to the high rate of recreational trips performed by tourist in the Stellenbosch Winelands, the value of 11.45% for the K factor was used to calculate the DHV.

The directional distribution of the traffic volume impacts the DHV and the LOS. The urban roads have two-thirds of their traffic in one direction during the peak hours. The peak occurs in one direction during morning and evening time, thus both directions of the facility must be adequate for the peak directional flow. The directional distribution is an essential parameter use to determine DDHV for the design year and geometric road design. The DDHV was obtained by multiplying the DHV by the directional factor $D_{30}$ (Project Traffic Forecasting Handbook, 2014).

$$DDHV = DHV * D_{30}/100 \quad (4)$$

Table 3-4 presents the different recommended $D_{30}$ factors for urban and rural roads.

**Table 3-3: Recommended Directional D-factor ($D_{30}$) for Traffic Forecasting (Project Traffic Forecasting Handbook, 2014)**

| Road Type | $D_{30}$ (%) | | | |
|---|---|---|---|---|
| | Low | Average | High | Standard Deviation |
| Rural Freeway | 52.3 | 54.8 | 57.3 | 1.73 |
| Rural Arterial | 51.1 | 58.1 | 79.6 | 6.29 |
| Urban Freeway | 50.4 | 55.8 | 61.2 | 4.11 |
| Urban Arterial | 50.8 | 57.9 | 67.1 | 4.60 |

The AADT provided in Table 2-2, together with 3.7% traffic growth factor for Stellenbosch, was used to estimate the traffic volume for the baseline year (2016) of deployment. The $K_{30}$ value used during the analysis to determine the hourly volume was 11.45, since Stellenbosch experiences a great variability in traffic demand due to the repeated trips home-to-work and recreational trips from the tourists.

The $D_{30}$ value was used to estimate the directional traffic volume during the peak hours. It was noted that the directional distribution impacts both level of service and the capacity differently on multilane (Adam Tas Road) and single lane (Bird Street). Two-thirds of the traffic travel during the peak hours mostly in one direction, accounting for the morning and afternoon peak. Table 3-5 and Table 3-6 illustrate the different design hour volume and directional design volumes for Stellenbosch.

**Table 3-4: Design Hour Volume for Various Counting Stations in Stellenbosch**

| Counting Station | Design Hour Volume (DHV), $K_{30}$ = 11.45 | | | | |
|---|---|---|---|---|---|
| | Total Private Vehicles | Total Private Vehicles | Total Heavy Vehicles | Total Private Vehicles | Total Heavy Vehicles |
| | 2000 | 2009 | 2009 | Projected 2016 | Projected 2016 |
| R44 Blaauwklippen | 2348 | 4054 | 145 | 6177 | 221 |
| R44 Cloetesville | 1480 | 2214 | 127 | 3374 | 193 |
| R304 Kayamandi | 1620 | 2089 | 99 | 3183 | 151 |
| Polkadraai | 1562 | 2199 | 139 | 3351 | 212 |
| Helshoogte | 613 | 789 | 43 | 1202 | 65 |

**Table 3-5: Directional Design Hour Volume (Inbound) for Various Counting Stations in Stellenbosch**

| Counting Station | Directional Design Hour Volume (DDHV), $D_{30}$ = 67.10 | | | | |
|---|---|---|---|---|---|
| | Total Private Vehicles | Total Private Vehicles | Total Heavy Vehicles | Total Private Vehicles | Total Heavy Vehicles |
| | 2000 | 2009 | 2009 | Projected 2016 | Projected 2016 |
| R44 Blaauwklippen | 1576 | 2720 | 97 | 4145 | 148 |
| R44 Cloetesville | 993 | 1486 | 85 | 2264 | 129 |
| R304 Kayamandi | 1087 | 1402 | 67 | 2136 | 101 |
| Polkadraai | 1048 | 1476 | 93 | 2245 | 142 |
| Helshoogte | 412 | 530 | 29 | 807 | 44 |

## 3.7. Analysis Procedure for Actuated Traffic Signal Coordination

### 3.7.1. Life Cycle Cost Analysis

The Actuated Traffic Signal Coordination system that proposed for Stellenbosch will be a new system, since the existing traffic signals operate on pre-timed or semi-actuated. For the life cycle costs, the analysis will exclude infrastructure costs (poles and signal heads), since the system will use existing infrastructure.

For the system, a new link signal LAN will be needed to increase the capacity of communication between the control room and the component of the system. The signal controller will need to be upgraded to provide the required advanced signal control. The traffic lights to display the phases (green, yellow, red) will remain if they contain all the aspects. Once they reach the end of their useful life, the remaining will be upgraded and replaced. The loop detector for data collection will remain except for when they reach the end of their useful life and will need to be replaced. It is important to note that costs for redoing loops might be necessary, since these loops are very fragile.

Normally infrastructure costs, incremental costs, and operation and maintenance costs make up the life cycle costs for new projects. For each intersection where the strategy was deployed, 20 years lifetime was estimated and 2016 was assumed as the first year of the strategy deployment.

The monetary values were obtained from the ITS database at www.itscosts.its.dot.gov and calculated in TOPS-BC in United States dollars (year 2015) and afterwards converted in South African Rand with an exchange rate of 1 USD = ZAR 14.6.

The discount rates are the most used for B/C analysis and are based on interest rates with the inflation component not taken into account. This rate is usually calculated by subtracting the rate of inflation (consumer price index) from the interest rate of an investment. These real rates are to be used in B/C analysis for discounting real (constant Rand) flows. Many current B/C analysis tools use average annual benefits and costs in their analyses, including the IDAS and the TOPS-BC tool. A value of 10% was used for the discount rate in the research as recommended for economical evaluation of South African transportation projects (Bester 2013), although previously a real discount rate of 15% was reported for South Africa (Banister & Berechman, 2000).

The life cycle costs are obtained from different South African and some overseas suppliers. The costs from overseas include the freight cost. The infrastructure cost contains the cost of the design, implementation, hardware and software to operate traffic signal coordination as a network of intersections. The operational costs are the costs to maintain the system working and providing the services targeted. The operational cost for the infrastructure costs vary from 5% to 10% of the capital cost, in practice they are a percentage of the wages of the operators.

The maintenance cost derived from a schedule of maintenance planned for the equipment, infrastructure equipment as well as incremental equipment. Except routine maintenance every two weeks, a complete check for the maintenance of the equipment is scheduled for every 3 months.

Average annual costs are estimated based on the capital cost of a piece of equipment divided by the anticipated useful life of the equipment. To this capital cost, an estimate of annual O&M cost is added to estimate the total average annual costs.

### 3.7.2. Benefits Analysis

#### *3.7.2.1. Travel Time Benefits*

For the travel time calculation, TOPS-BC considers speed as the most important factor affecting the benefits of an ITS strategy. A difference in “before” and “after” speed is the primary way to account for congestion and delay and improvement benefits in TOPS-BC. The speed differential between before and after deployment provided the data to calculate the vehicle hours of travel and delay in the corridor.

In this research, the before and after speed was the only way to account for the operations of the traffic signal case study along the corridor of the R44 and R304. The overall travel time was converted into speed and similarly accounted for the stop delay in the corridor. TOPS-BC does not consider the number of traffic signals in the calculation.

TOPS-BC incorporates various literature on the benefits resulting from different ITS deployments around the world. These benefits form the cores of the assumption during the analysis performed in TOPS-BC. TOPS-BC assumption states that traffic signal coordination system increases the speed on the corridor. When well deployed, the speed increases by 20% and the travel time improvement varies between 8% and 20%. The default values for improvement in the TOPS-BC are all calibrated at 10% of capacity improvement and volume/capacity ratio varies in the range of 0.1 to 1.

To best indicate the improvement of the segment capacity that result from the traffic signal coordination deployment, TOPS-BC uses an adjustment factor called the link capacity multiplication factor. The values of the link capacity multiplication factors are derived from various literature and databases that are incorporated in the TOPS-BC tool. The link capacity multiplication factor allows the estimation of the increase of the capacity of the segment under analysis. Under the same traffic demand conditions, enlarged link capacity will decrease the v/c ratio and increase the average traffic flow speed.

The link capacity multiplication factor used in this thesis is 20%, with the volume/capacity ratio varying between 0.1 and 1. For example, if a single road lane capacity is 1500 veh/hr/lane TOPS-BC will express the different typical levels of congestion expected to occur in the range of traffic volume, varying 150 veh/hr to 1500 vehicle/hr which corresponds to the range of V/C of 0.1 to 1. V/C = 150veh/1500veh =0.1

The coordinated traffic signal intents to provide smooth flow of traffic along roads in order to reduce travel times, stops and delay (National Traffic Signal Report Card, National Transportation Operations Coalition, 2005). Well-timed, coordinated system permits continuous movement along an arterial where the throughput movement receives preference along the major street of the arterial network with minimum stops and delays, which, reduces fuel consumption and improves air quality (Fundamentals of Traffic Engineering 15th ed., UCB-ITS-CN-01-1, January 2001).

Thus, this research also focuses on the travel throughput movement in order to exhibit the impact of the coordinated traffic signal on the Stellenbosch arterial system. Coordinated traffic signals in an area with 20% daily demand variability will increase the facility capacity between 6.5-25% for light congestion, 5.5-19% for moderate and heavy congestion. In an area with predictable demand but variable peak direction, an increase in capacity between

5.5-19% for light and moderate congestion and 4-13% for heavy congestion will be possible (IDAS Appendix B, 2008).

During TOPS-BC analysis, the 10% default capacity improvement is represented by the change the capacity which is value of 1500veh/h/lane to 1550 veh/hr/lane. Thus, 1550 is deriving from (1500 + (1500*0.1) = 1650). Therefore, for the speed “before” and “after” the improvement will result from the change in capacity and the speed factor for the 85th percentile as recommended (Bester, 2012) for planning projects. The speed before improvement when capacity is 1500veh/hr/lane and speed after improvement when capacity is 1650veh/hr will be compared.

Another important factor during travel time calculation is the free flow speed. The free flow speed is defined as the posted speed limit plus 8 km/hr (TRB, 2000) and will depend on where in the range of speeds the segment is, as it will vary accordingly. The historical data for the posted speed and free flow speed can be obtained from the local traffic division authorities. The method for determining the free flow speed is to average off-peak corridor travel times over time. Data for this thesis was obtained from the Stellenbosch EMME/3 model, but in cases where historical data are available for arterial analysis, the stop time at traffic signals must be taken into account.

Furthermore, volume and the volume/capacity ratio are important factors in the TOPS-BC calculations. The current volume is the only volume input, however, when improvement at intersection are needed, the capacity can be overridden for both the baseline and the improvement scenarios. Volume and Volume/Capacity (V/C) are used to calculate the vehicle kilometres travelled and the crash rates and are therefore crucial for the benefits calculation.

The period of analysis must likewise be correct in order to obtain accurate results. The number of hours of the analysis must match the length of the period of the volume data, that is, if the volumes are for a peak one hour, the period of analysis must be one.

A difference in “before” and “after” speed is the primary way to account for congestion and delay and improvement benefits in TOPS-BC. TOPS-BC incorporate also the IDAS table of incident related delays. During the analysis TOPS-BC calculates the V/C before and after the capacity improving resulting from the deployment and uses a function of Lookup to express the value of incident related delays which later converted to hours in order to be evaluated and exhibit the monetized value of non-recurring travel time savings.

***Recurring Travel Time***

Recurring Travel time is a performance measure used to quantify the extent of a road improvement. The recurring travel time derives from the speed calculated from Equation 14 the change in vehicles miles travel (VMT) and vehicle hours travel (VHT). For the analysis, a static Average Person Hours of Travel (PHT) was used to estimate the net travel time gained from the improvement. The travel times obtained from the calculation are from peak hour and direction of the highest volume.

The Recurring Travel Time is derived from the estimated link speeds in the corridor. The Speeds were estimated using the speed-flow relationship from the Highway Capacity Manual (TRB, 2000), where a speed factor for varying degrees of congestion (as measured by volume/capacity ratio) can be found.

$$S = FFS + [1 - e^{\ln\left(FFS + \frac{1 - C*CAF}{45}\right)\frac{vp}{C*CAF}}] \tag{5}$$

Where:

$S$ = Segment Speed (km/hr)

$FFS$ = Segment Free-Flow Speed (km/hr)

$C$ = Original Segment Capacity (veh/hr/lane)

$CAF$ = Capacity Adjustment Factor, CAF = 1.0, 0.95, 0.90, 0.85 (for speed estimation)

$vp$ = Segment Flow Rate (veh/hr/lane)

When $vp$ approaches zero in Equation 14, S approaches the free-flow speed. Similarly, when $vp = C * CAF$, S approaches the speed at capacity.

The traffic data from the Stellenbosch EMME/2 model for the segment of Strand Road (R44) on the zonal model is classified as a divided arterial downtown class 3. This segment is assigned a legal speed limit of 45 km/hr and a link capacity per lane of 1100veh/hr.

For this reason, this thesis assumes a free flow speed of 50 km/h since it was reported in the Highway Capacity Manual (TRB, 2000) that free flow speed is the legal speed limit plus an additional 8km (5 miles).

The capacity adjustment factor for arterial road provided in the TOPS-BC literature was used. Since the roadway was composed of two lanes of 1100 veh/hr each (= 2200vh/ for the two lanes) the excepted traffic volume that will travel the roadway capacity were stratified between 110veh/h to 2200 veh/hr to reflect the range of V/C between 0.1 and 1.

Figure 3-11 shows the relationship between the speed factor and the traffic demand under different levels of congestion, using Equation 9.

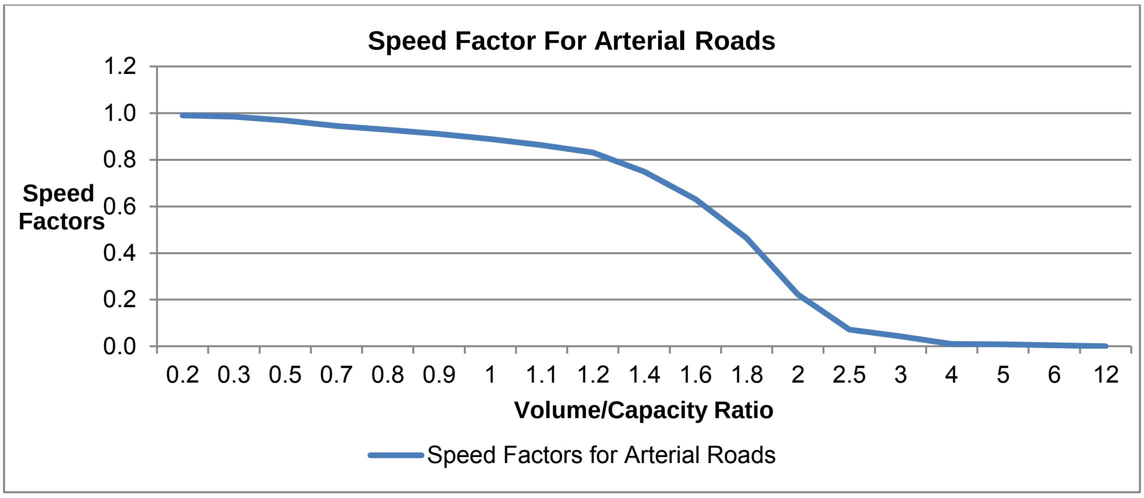



**Figure 3-11: Speed Factors for Arterial Roads (TOPS-BC Methodology Database, 2015)**

The Vehicle Kilometres Travelled (VKT) is directly linked to the length and volume of the segment.

Thus,

$$VKT = Segment\ Length * Volume \tag{6}$$

The Vehicle Hours Travelled (VHT) are obtained from the following equation:

$$VHT = \frac{VKT}{Speed} \tag{7}$$

Finally, the Average Person Hours of Travel (PHT) to be monetised are obtained from the equation:

$$PHT = VHT * Average\ Auto\ Occupancy \tag{8}$$

***Non-Recurring Travel Time***

TOPS-BC incorporates a range of incident related delays based on the US arterial system, which generate the delay situation. TOPS-BC provides an option to reduce the overall delay. The program then maximises the throughput movement based on the reduced delay, using the link capacity. These delays result from the side street movement, closing of a lane, etc. Although this thesis uses the US incident delay rates, it is assumed applicable since it covers a wide range of possible delays that is also found in SA, particularly in Stellenbosch. Using this approach can also be more conservative, since the US has far higher traffic volumes and delays on their arterial systems. In this thesis, the capacity improvement is therefore not from a pure freeway analysis, since it accounts for a wide range of delays, including intersection activity (delays).

The calculation of the non-recurring travel time saving is based on the rate in the IDAS Travel Time Reliability Lookup Tables, that was found in the IDAS User's Manual that are used in conjunction with the Strategic Highway Research Project for deriving non-recurring travel time.

It is stated that incident-related non-recurring traffic delay accounts for approximately 25 percent of all congestion delays and the most substantial proportion of non-recurring delay sources in most urban areas. The travel time reliability calculation are based on the analysis period (peak hour, peak period, off peak or daily), number of lanes and volume-to-capacity ratio. Travel time reliability that varies daily and incident delays are the first factors that affect the travel time. The relation for travel time reliability is derived from the level of service (LOS) E capacities.

- Incident Related Delay

The most prevalent example of these methods is the analysis originally developed and implemented as part of the analysis capabilities of the FHWA's IDAS sketch-planning tool (www.idas.camsys.com). TOPS-BC methodology refers to IDAS Traffic Reliability Look-up table to calculate the incident related delay. The incident related delays occurring on the roadway segment are estimated using the following steps:

- Step1: Determine the number of lanes, duration of the analysis and the v/c ratio of the segment under analysis.
- Step 2: Use interpolation to find the traffic incident related delay per vehicle per km from the table.
- Step 3: Determine the improved V/C ratio using the link capacity multiplication factor and repeat the Step 1 and 2 to find the improved traffic incident delay.
- Step 4: Calculate the difference in traffic incident related delays before and after the ITS deployment
- Step 5: Calculate the total nonrecurring travel time savings for all vehicles on the segment during analysed period.

The IDAS incident delay analysis involves the use of look-up rate tables containing estimates of the amount of incident-related delay likely to be experienced for a facility on a per VMT basis. These rates were predicted based upon long-term monitoring and analysis of annual incident delay experience on a number of national freeway corridors. These rates are sensitive to several key input factors, including the following:

- The Number of Facility Lanes:

The incident-related delay rate for freeways with a greater number of lanes is less than for facilities with fewer lanes, assuming other factors are also equal. This is due to the more substantial blockage of capacity caused by similar incidents on roadways with fewer lanes. For example, identical incidents blocking a single lane would reduce capacity by one-half of the available lanes on a two-lane facility, but only reduce capacity by one-quarter of the available lanes on a four-lane facility.

- The Facility Volume-to-Capacity (V/C) Ratio

The level of base congestion (prior to the occurrence of the incident) is represented by the V/C ratio. Facilities with a higher V/C ratio will have higher incident-related rates associated with them, as it would be expected that incidents on these more congested facilities would cause a quicker breakdown in conditions and a longer time required to allow the incident-related queue to dissipate once the incident was cleared.

Different rates are also estimated based on the length of the analysis period (one-hour, two-hour, three-hour, four-hour, or daily). The v/c ratios are then interpolated using Figure 3-12 derived of the IDAS look-up to determine the related incident traffic delay taking into account that our V/C ratio varies from 0.1 to 1. An adjustment factor of 1.16 was use to reflect the LOS E where the values different of level LOS E.

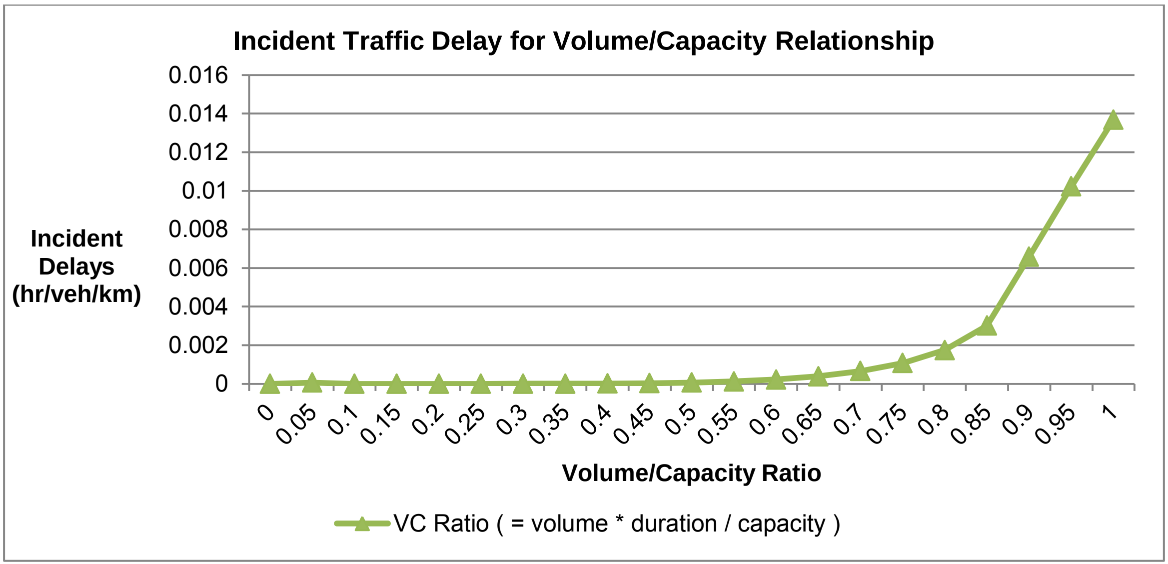



**Figure 3-12: Incident Traffic Delay for V/C Ratios**

TOPS-BC does not include the intersection split volumes (right turn or left turn) into the B/C analysis for the traffic signal coordination system. TOPS-BC solely maximizes the throughput movement on the major arterial and furthermore only uses the average peak link volume of each approach (inbound and outbound) to conduct the B/C analysis. Speed is the most important factor affecting the benefits of an operations strategy.

A difference in "before" and "after" speed is the primary way to account for congestion and delay and improvement benefits in TOPS-BC. The speed differential between "before" and "after" deployment is used to calculate the vehicle hours of travel and delay in the corridor. It is the overall travel time (converted to speed) that accounts for the stop delay in a corridor. The number of traffic signals therefore does not form part of the calculation.

From the improved capacity, a difference can be calculated between incident delay "before" and "after", which is expressed as the saving in Incident Delay. Non-recurring travel time can then be expressed as follows:

$$PHT\ for\ Incident\ Delay = Saving\ in\ Incident\ Delay * AutoOccupancy \quad (9)$$

***Travel Time Valuation***

The recurring travel time and non-recurring travel time will be joined together in order to illustrate the total savings in travel time generated by the ITS strategy deployment. To monetize travel time a discount rate of 10% for a 20 years' lifetime horizon project will be used.

From the 250 working days the 13 South African public holidays were subtracted, therefore 237 days will be used for the travel annual benefits. The monetised value for both recurring and non-recurring travel time will be calculated as follows:

$$Monetized\,Travel\,Time = PHT * \{(\%\,Truck * TruckVaueofTime) + (1 - \%CommercialAuto * ValueofTimeCommercialAuto) + (1 - \%Truck - CommercialAuto) * AutoValueofTime\} \quad (10)$$

### *3.7.2.2. Energy Benefits*

The estimation of vehicle operating costs is based on simple evaluations applied directly to vehicle miles of travel (VMT). For analysis, a static rate of average fuel use (litre per VMT) is applied to any change in VMT to estimate the net change in fuel use.

The following steps were used for the estimation of the fuel consumption benefits with TOPS-BC:

- Step 1: determine length, traffic volume of the segment under analysis.
- Step 2: Estimate vehicles miles travel (VHT) for the traffic volume.
- Step 3: Estimate vehicle type distribution, (%passenger vehicles, %trucks).
- Step 4: Estimate the total fuel consumption using the TOPS-BC method for the segment under analysis.
- Step 5: Estimate the total fuel reduction using the TOPS-BC reduction factor for traffic signal coordination system.
- Step 6: Estimate the total fuel saving from the traffic signal coordination system deployment.
- Step 7: Monetise the fuel savings.

TOPS-BC estimates that the traffic signal coordination reduces the fuel consumption by 13%. A study on 73 signal systems across 43 cities in Texas showed a savings of 13.5% of fuel per intersection, while in Los Angeles a 13% decrease in fuel consumption was reported. In Burlington, Canada traffic signal retiming at 62 intersections resulted in reducing fuel consumption by 6% (ITS Benefits Database, n.d.).

The rates of fuel consumption the TOPS-BC for automobiles and trucks were calibrated to reflect the South African context. After calculating the VMT and the fuel consumption, the number of fuel used is expressed as follows:

$$Number\ of\ Litres = \frac{VKT * \frac{\%Truck}{FuelEconomyTruck+(1-\%Trucks)}}{FuelEconomyAuto} \quad (11)$$

Where,

Fuel Economy of Auto (Passenger Vehicles) is 21.6 and Trucks (Heavy Vehicles) is 18.5. The monetary value of the energy benefits can be expressed as follows:

$$Monetised\ Energy\ Benefit = Number\ of\ Litres * Cost\ of\ Litres \quad (12)$$

#### *3.7.2.3. Safety Benefits*

The benefit valuations applied to a reduction in the number of crashes are often substantial particularly in the case of fatality and injury crashes. Actual cost method captures the actual accountable costs of crash (e.g. cost of medical treatment of the victims, the loss of the victim's wage for the family and any property damage). Crash severities used to estimate the safety benefit are fatality crashes, injury crashes and property damage crashes.

To estimate the change in crashes attributable to the TSM&O during the B/C analysis, crash rates (crash occurrence per million VKT) are applied to the change in VKT in the transportation network. The safety benefits are estimated from the set of accident rates. The rates built-in of TOPS-BC are recalibrated to reflect the local Stellenbosch conditions. The rates are stratified into fatal accidents, injury accidents and damage to property.

TOB-BC calculates the accidents (safety benefits) based on the travel times, V/C ratios, and VKT (speed, vehicles types and facility type). The crash rates before and after the deployments were estimated separately. A rand value was assigned to the reduced amount of accidents. Expected crash reduction rates between 2% and 7% were used in the analysis.

The exact relation between speed and crashes depends on many factors. However, in a general sense the relation is very clear: if on a road the driven speeds become higher, the crash rate will also increase. The crash rate is also higher for an individual vehicle that drives at higher speed than the other traffic on that road. As speeds get higher, crashes also result in more serious injury, for the driver who caused the crash as well as for the crash opponent

Speed is one of the basic risk factors in traffic (Wegman & Aarts, 2006). Higher driving speeds lead to higher collision speeds and thus to more severe injury. Higher driving speeds also provide less time to process information and to act on it, and the braking distance is longer. Therefore, the possibility of avoiding a collision is smaller. In short: high driving speeds lead to a higher crash rate, also with a greater likelihood of a severer outcome (Aarts, 2004; Aarts & Van Schagen, 2006).

Rósen et al., (2011) found that at a collision speed of 20 km/h nearly all pedestrians survive a crash with a passenger vehicles, about 90% survive at a collision speed of 40 km/h. At a collision speed of 80 km/h the number of survivors is less than 50%, and at a collision speed of 100 km/h only 10% of the pedestrians survive as can be seen in Figure 3-13.

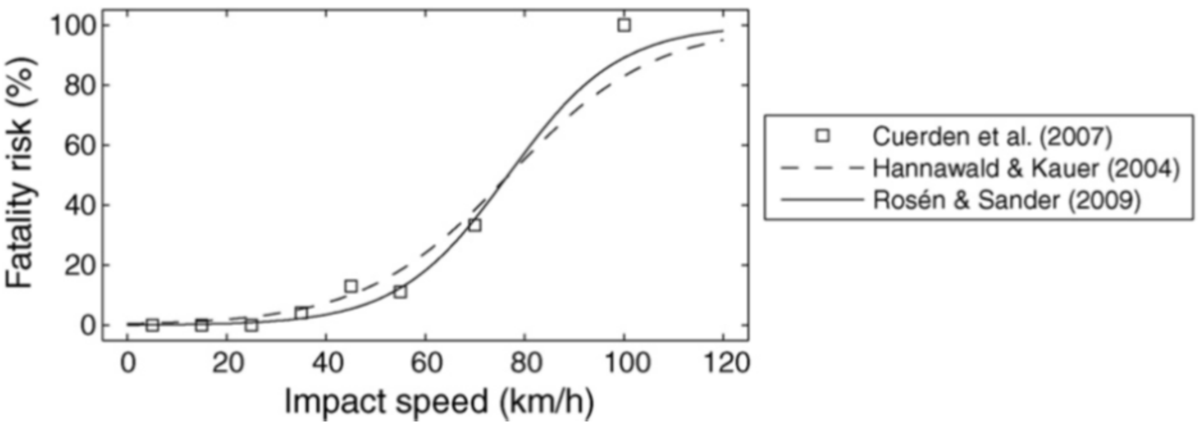



**Figure 3-13: The Fatality Rate of Pedestrians in Crashes with Passenger Cars as a Function of the Collision Speed (Rosén et al., 2011)**

TOPS-BC furthermore assumes that traffic signal coordination reduces the crashes by 7% to 13%. This thesis will conduct a sensitivity analysis to assess the effect of the varying crash reduction rates.

### 3.7.3. Value of Time (VOT)

As reported in 2007 by the South African Statistics Agency the value of the per capita income of South African citizens is approximately R 3,038.00. The average costs per hour of the working population was R3.43. Since the cost of a working hour can be determined by using the percentage of people employed and the number of working hours per year taking into account that South Africa has 237 working days (minus weekends and public holidays).

The growth in income is 7.93%, while the real growth in income is only 3.7%. These are used in the calculation of the Value of Time (VOT). The VOT in South African is therefore R3.84 and R46.52 for hours and working hours respectively. Using the average occupancy and the split of work/no work an average VOT of R42/hr is assumed for this research. The Stellenbosch population is however likely to have a higher VOT.

### 3.7.4. Vehicle Occupancy

The travel time in the economic evaluation of transportation travel time savings are evaluated per road user. An average auto occupancy rate is required for the travel time savings evaluation.

The observation of the road user pattern during the morning peak has shown that few passenger vehicles travel with passengers, generally the commuters travel alone. When there are passengers, normally these are students attending classes at the University of Stellenbosch or other educational institutions in the surrounding area of Stellenbosch.

The average auto occupancy of 1.5 is assumed for this research, since the trend of previous and average vehicle occupancy rate of 1.46 as reported by Ter Huurne (2016). Researchers classified the average auto occupancy in the area in a range between 1.3 and 3 (Sinclair et al, 2012).

### 3.7.5. Accident Costs

The accident costs as illustrated in Table 3-6 were used for the safety benefit calculations. The values originated from the National Institute of Transport and Road Research (1999) and was projected to 2016 values.

**Table 3-6: South African Accident Costs (Bester, 2013)**

| Accident type | Cost (Rand)<br>Rounded values |
|---|---|
| **Fatal injuries** | 1,200,000.00 |
| **Seriously injured** | 275,000.00 |
| **Slightly injured** | 72,000.00 |
| **Damage only** | 47,200.00 |

## 3.8. Analysis Procedure for Parking Management System

### 3.8.1. Life Cycle Cost Analysis

The lifecycle of the parking management system includes infrastructure costs, incremental costs, and O&M costs. The infrastructure costs include the costs of designing, implementing, installing the TMC hardware and Software for information dissemination and the cost of TMC system integration. The incremental cost include the cost to install or upgrade the communication line, the Variable Message Sign and Variable Message Sign Tower. The O&M Costs are the costs of maintaining the system operational during its life cycle. For each VMSs that was deployed for the parking management strategy, a 20 years life time was estimated and 2016 was assumed as baseline year of the deployment.

For the life cycle cost analysis of the Parking Management System the following cost consideration were included:

- Variable Message Sign (VMS) - Low capital cost is for smaller VMS installed along arterial. High capital cost is for full matrix, LED, three-line, walk-in VMS installed on roadway. Cost does not include installation;
- Variable Message Sign Tower - Low capital cost is for a small structure for arterials. High capital cost is for a larger structure spanning three to four lanes. VMS tower structure requires minimal maintenance;
- Portable Variable Message Sign – Trailer mounted full matrix VMS (three-line, 8-inch character display); includes trailer, solar or diesel powered, and equipped with

cellular modem for remote communication and control. Operating costs are for labor and replacement parts;

- Entrance/Exit Ramp Meters - Ramp meters are used to detect and count vehicles entering/existing the parking facility. O&M based on annual service contract;
- Tag Readers - Readers support electronic payment scheme. O&M costs based on annual service contract;
- Database and Software for Billing & Pricing - Database system contains parking pricing structure and availability. O&M costs based on annual service contract;
- Parking Monitoring System - Includes installation, detectors, and controllers;
- Hardware for Traffic Information Dissemination - Includes one workstation. O&M estimated at 5% of capital cost;
- Software for Traffic Information Dissemination - Software is Commercial off-the-shelf (COTS);
- Integration for Traffic Information Dissemination - Integration with other systems.

### 3.8.2. Benefits Analysis

#### *3.8.2.1. Travel Time Benefits*

Parking Management is an application of Multimodal traveller information. Traveller information intended to reach the recipients while they are traveling. The information may be provided through several different channels, including telephone, in-vehicle system, roadside Variable Message Signs (VMS). The VMS is used for the analysis of the Parking management systems in this research.

The Travel Time Benefit for the Parking Management System can be expressed as follows:

$$\begin{aligned} Travel\ Time &= (\%ActiveDMS * \%ActiveDrivers * Minutes\ Saved) \\ &\quad + (1 - \%ActiveDrivers) * (\%Non - ActiveDrivers) * \frac{Volume}{60}) \end{aligned} \tag{13}$$

Based on the assumption that only 10% to 20% of the disseminated information is important to the drivers and that 28% of drivers will see the information and use it to access the parking.

It is also assumed that when the drivers use the disseminated information a time saving of 11 minutes will be gained. Volume of vehicles will therefore be expressed as the volume of vehicles that pass the information sign (IDAS User's Manual Edition 2008, Appendix B).

### 3.9. Traditional Transportation (Stellenbosch Western Scenic By-Pass)

The Western Scenic Tourism Route (Western Bypass) was proposed in the Stellenbosch CITP as one of the solutions to alleviate the congestion in Stellenbosch.

#### 3.9.1. Proposed Alignment

The Western Bypass will be approximately a 11.8 km surfaced road. The first segment of the road will start from the R44 at Blaauwklippen between Paradyskloof and Jamestown and proceed to the R310. From the R310 the road will bypass Devon Valley and Kayamandi and will cross the R304, to end at the R44 north of the Cloetesville area. Figure 3-15 presents the proposed alignment of the Western Bypass.

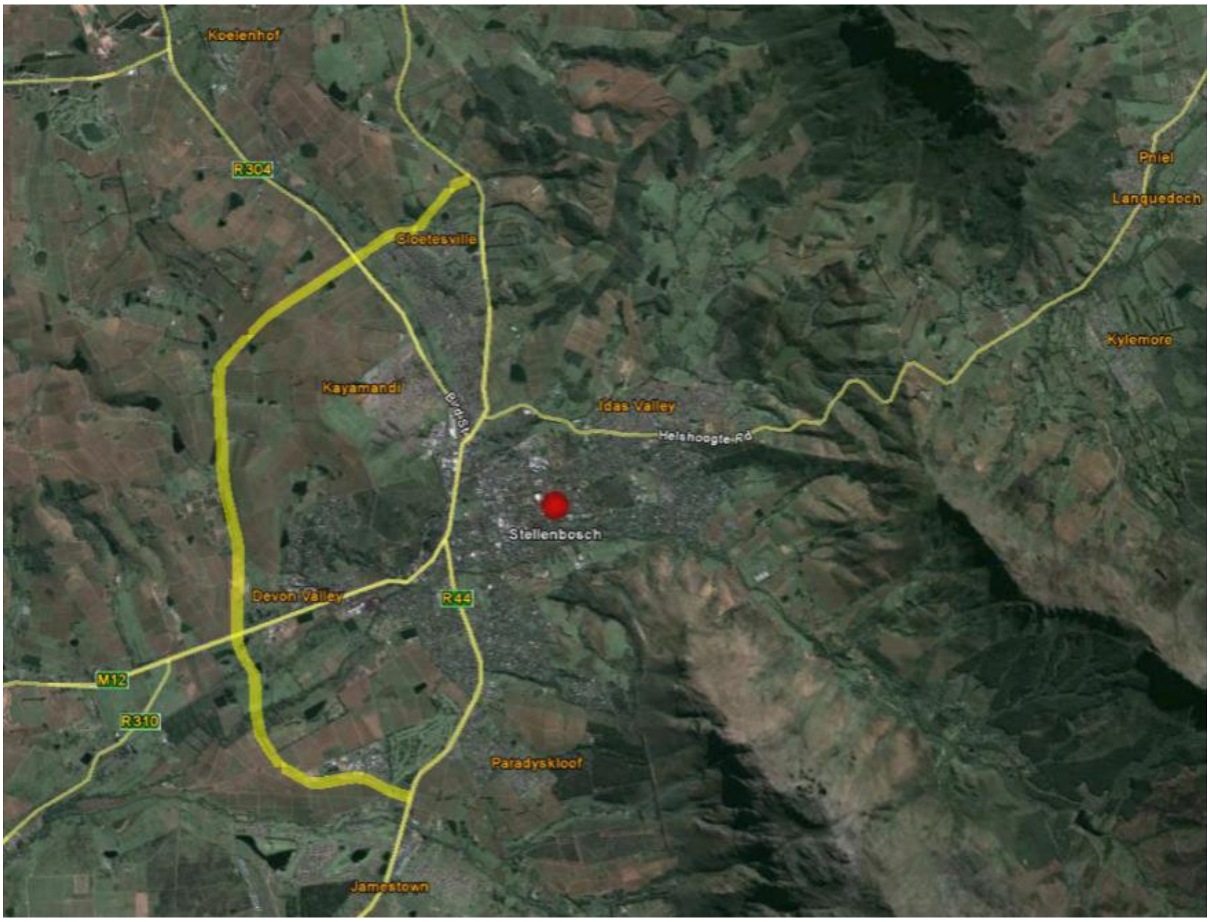



**Figure 3-14: Proposed Alignment of Stellenbosch Western Scenic Bypass (Google Earth)**

Table 3-10 provides a description of the different segments that will make up the proposed Western Bypass.

**Table 3-7: Description of Segments of Western Bypass**

| Length of Segment (km) | Start of Segment | End of Segment |
|---|---|---|
| 3.5 | R44 (Blaauwklippen Rd) | R310 (Polkadraai Rd ) |
| 6.3 | R310 (Polkadraai Rd) | R304 (Bottelary Rd) |
| 2 | R304 (Bottelary Rd) | R44 (North of Cloetesville) |

The Western Bypass was proposed as a solution to alleviate the recurring congestion on the R44 through the town of Stellenbosch. The bypass will carry the through traffic volume from Paarl and Somerset West and reduce the level of congestion within the town of Stellenbosch. However, the proposed bypass alignment is passing through several commercial farms and private properties that will need to be displaced (destroyed) at very expensive land expropriation cost.

This study intended to perform a preliminary economic evaluation of the bypass construction to determine sustainability of the project since the bypass was proposed as alternative solution to the congestion that suffers the town of Stellenbosch. The need for sustainable solutions that address the needs for social and economic growth of both small and large urban areas exists.

The study will estimate the life cycle costs of the proposed bypass over a 20 years life time horizon and quantify the operational benefits that resulting from the bypass construction assuming that a great amount of traffic volume will be deviated from the R44 and carried on the bypass. A preliminary construction cost estimate will be carried out. The costs estimate for this thesis included only the costs of construction of the pavement layers. The costs of surveying, designing and construction supervision are not taken into account for the life cycle cost. The operational benefits are stratified into travel time benefits, energy benefits and safety benefits.

Figure 3-16 shows the extent of the project and changes in traffic volumes. The red lines indicate an increase in traffic and the green a reduction in traffic. The number adjacent to the lines indicates the predicted increase/decrease in the number of vehicles for that section of road. As can be seen, the number of vehicles using the new road increases to 868 vehicles. The reductions of vehicles on the existing streets are most evident on the R44 and the R310.

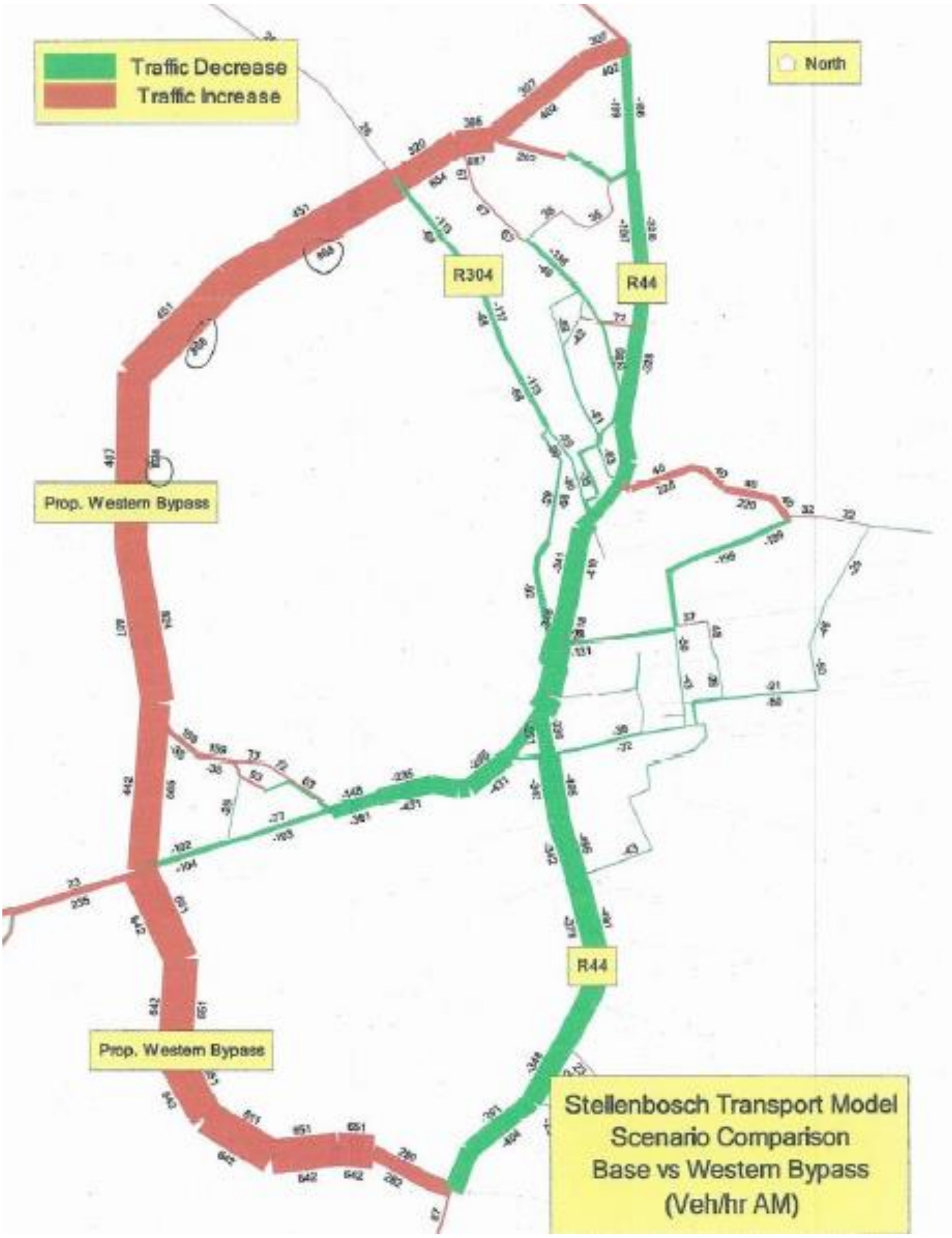



**Figure 3-15: Anticipated Traffic Volumes with Construction of Proposed Western Bypass (Vela VKE, 2011) EMME/2 Model**

The Arterial Management System of Stellenbosch will be considered as the "do nothing" alternative before the improvement. The western Bypass is considered as the improvement in the system, thus reduction of congestion of Stellenbosch Arterial System will be considered as the improvement resulting from the bypass construction. The benefits estimated during the analysis will be travel time benefits, energy benefits and safety benefits.

The TOP-BC tools will be used to estimate and valuate the benefits on the Arterial System. The Net Present Value will then be used to rank the project or compare the bypass alternative to the Actuated Traffic Signal Coordination System and the Parking Management System.

### 3.9.2. Design Traffic

From the CITP produced in 2011 it was established that the peak hour volume on the Western Bypass will be 868, also known as the directional hourly volume. From Equation 3, the Annual Average Daily E80 (AADE), can be calculated as follows:

$$AADE = \frac{DHV}{K_{30}(\%)} = \frac{868}{\frac{11.45}{100}} = 7581$$

This anticipated traffic is however outdated and required an adjustment to the design year (base year), 2016. Following the guidelines in TRH4 (1996), for projection to the initial base year, the following traffic growth factor was obtained:

$$gx = (1 + 0.01 * i)^x = (1 + 0.01 * 3.7)^5 = 1.1992 \qquad (14)$$

Where,

$gx$ = Traffic Growth Factor

$i$ = Annual Growth Rate Percentage of E80s

$x$ = Time in Years between Determination of Axle Load Data and Start of Design Period

The growth factor percentage of 3.7% obtained for Stellenbosch was used to evaluate the influence of the traffic growth rate for the area. Traffic passing on the bypass is expected to increase significantly over the structural design period. A design period of 20 years was assumed to be realistic for the pavement structure.

From above calculated growth factor, the following initial Annual Average Daily E80 ($AADE_{initial}$) was obtained:

$$AADE_{initial} = AADE * gx = 7581 * 1.1992 = 9091 \quad (15)$$

Where:

$AADE_{initial}$ = Annual Average Daily E80 during Design Year

$AADE$ = Annual Average Daily E80 Obtained from Previous Data

$gx$ = Traffic Growth Factor

From above, the cumulative E80s was calculated (See Equation 18 below). This is essentially the duration of the pavement structure, as it relates the cumulative damage of heavy vehicles over the assumed structural design period.

$$E80_{total} = AADE_{initial} * fy \quad (16)$$

But first, the calculation of the cumulative growth factor, $f_y$ was required.

$$fy = 365 * (1 + 0.01 * i) * \frac{(1 + 0.01 * i)^y - 1}{0.01 * i} = 10\,926.69 \quad (17)$$

Where:

$fy$ = Cumulative Growth Factor over the Structural Design Period

$i$ = Annual Growth Rate Percentage of E80s

y = Predicted Structural Design Period

As a result,

$$E80_{total} = AADE_{initial} * fy = 9091 * 10\,926.69 = 99.3 * 10^6$$

This corresponds with a ES100 pavement structure, with between 30 and 100 Million Equivalent Standard Axles (MESA), classified as a Type A Pavement Structure.

### 3.9.3. Proposed Pavement Structure

The initial approach for the pavement design was carried out by using the catalogue design approach that is detailed in TRH 4. The initial pavement design of the Western Bypass considered a number of variations due to various influences, particularly that of the subgrade conditions and availability of quality granular materials. This was an essential consideration since the structural capacity of the pavement is a function of the combined long term load spreading of all pavement layers, with specific focus on the subgrade quality and the type and quality of the base material.

The catalogue designs from TRH4 were taken as departure point and benchmark. The catalogue pavement structure from TRH4 is as shown in Figure 3-16.

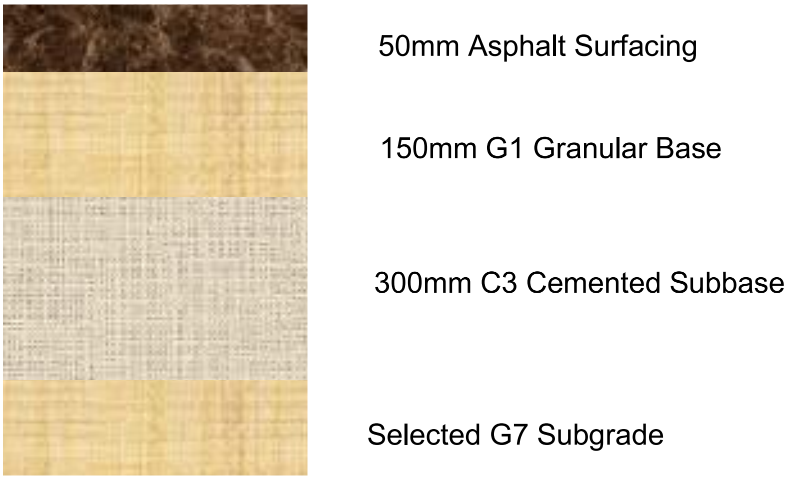



**Figure 3-16: Proposed Pavement Structure for Class ES100 from Catalogue Design – TRH 4**

# 4. Results and Synthesis

## 4.1. Overview

The following section presents the results obtained from the economic evaluation of the proposed ITS strategies for Stellenbosch that was performed with the assistance of the TOPS-BC Tool. Various methods can be used for B/C analysis and assist decision makers with fundamental information relative to the magnitude of benefits and costs of proposed projects. The benefits and costs analysis for the two ITS strategies proposed for Stellenbosch will be presented against that of the proposed traditional improvement.

## 4.2. Actuated Traffic Signal Coordination System

### 4.2.1. Scenario 1: Segment of Strand Road (R44)

#### *4.2.1.1. Life Cycle Cost Analysis*

The following breakdown of the life cycle costs for the actuated traffic signal coordination for Scenario 1 can be seen in Table 4-1.

**Table 4-1: Breakdown of Life Cycle Costs Analysis for Scenario 1- Per intersection - Segment of Strand Road (R44)**

| **Estimated Life Cycle Costs of Actuated Traffic Signal Coordination Systems** | | | | |
|---|---|---|---|---|
| **Equipment** | **Useful Life (Yrs)** | **Total Capital / Replacement Costs ( R )** | **Annual O&M Costs ( R )** | **Total Annual Costs ( R )** |
| | 20 | 252,000.00 | 2,800.00 | 15,400.00 |
| **TOTAL Infrastructure Cost** | | 252,000.00 | 2,800.00 | 15,400.00 |
| **Incremental Deployment Equipment (per Intersection)** | | | | |
| Signal Controller | 15 | 25,200.00 | 2,800.00 | 4,480.00 |
| Communication Line | 20 | 7,000.00 | 8,400.00 | 8,750.00 |
| Loop Detectors (2) | 5 | 84,000.00 | 8,400.00 | 25,200.00 |
| **TOTAL Incremental Cost** | | 116,200.00 | 19,600.00 | 38,430.00 |
| Number of Infrastructure Deployments | 1 | | | **15,400.00** |
| Number of Incremental Deployments (per intersection) | 1 | | | **38,430.00** |
| Year of Deployment | 2016 | | | |
| **Average Annual Cost ( R )** | | | | **53,830.00** |

Figure 4-1 displays the lifecycle costs framework of an actuated traffic signal for 20 years life time horizon for B/C analysis.

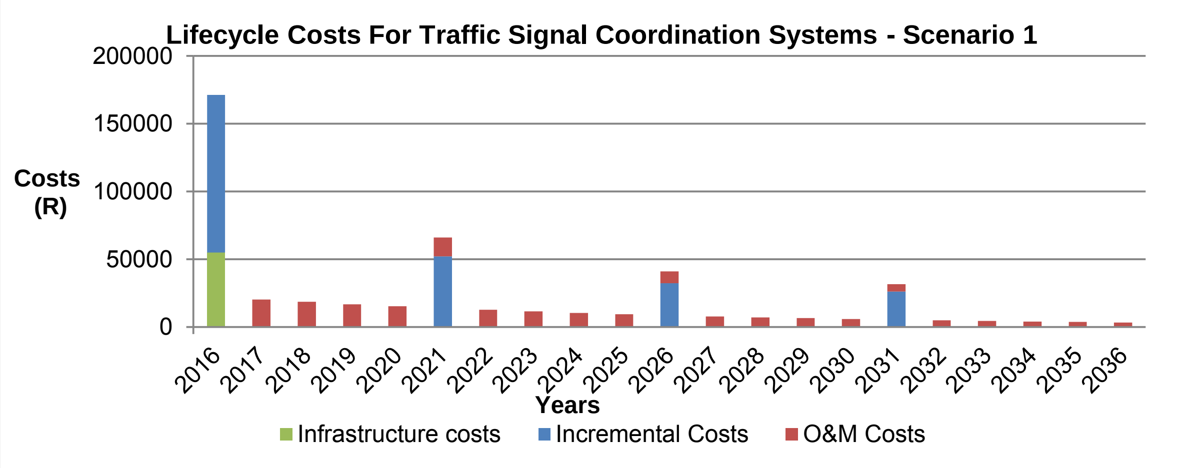



**Figure 4-1: Life Cycle Cost of the Traffic Actuated Signal Coordination System for Scenario 1 – Segment of Strand Road (R44)**

Table 4-2 present the various life cycle costs and the resultant Present Worth Cost (PWC) for Scenario 1 – Segment of Strand Road (R44).The PWC over the 20 years life time horizon is calculated using a 10% discount rate.

**Table 4-2: Breakdown of Life Cycle Costs of for One Installation of Scenario 1 – Segment of Strand Road (R44)**

| Years | Infrastructure Costs (R) | Incremental Costs (R) | Operation & Maintenance Costs (R) | Total Costs (R ) |
|---|---|---|---|---|
| **2016** | 252000.00 | 116 200.00 | | 368 200.00 |
| **2017** | | | 20 364.00 | 20 364.00 |
| **2018** | | | 18 512.00 | 18 512.00 |
| **2019** | | | 16 829.00 | 16 829.00 |
| **2020** | | | 15 300.00 | 15 300.00 |
| **2021** | | 52 157.00 | 13 909.00 | 66 066.00 |
| **2022** | | | 12 644.00 | 12 644.00 |
| **2023** | | | 11 495.00 | 11 495.00 |
| **2024** | | | 10 450.00 | 10 450.00 |
| **2025** | | | 9 500.00 | 9 500.00 |
| **2026** | | 32 386.00 | 8 636.00 | 41 022.00 |
| **2027** | | | 7 851.00 | 7 851.00 |
| **2028** | | | 7 137.00 | 7 137.00 |
| **2029** | | | 6 488.00 | 6 488.00 |
| **2030** | | | 5 899.00 | 5 899.00 |
| **2031** | | 26 142.00 | 5 362.00 | 31 504.00 |
| **2032** | | | 4 875.00 | 4 875.00 |
| **2033** | | | 4 432.00 | 4 432.00 |
| **2034** | | | 4 029.00 | 4 029.00 |
| **2035** | | | 3 663.00 | 3 663.00 |
| **2036** | | | 3 330.00 | 3 330.00 |
| **Present Worth Cost ( R )** | | | | **669 590.00** |

The total monetised value of the life cycle cost analysis considers the number of equipment needed for each intersections to upgrade the current system to fully actuated coordinated system along the corridor in Segment 1. The infrastructure cost and incremental costs the of base year 2016 is excluded from the analysis, due to existing infrastructure being used.

#### *4.2.1.2. Travel Time Benefits*

**Recurring Travel Time Benefit**

The recurring travel-time savings benefits of the traffic actuated varies widely according to the location of deployment, as well as the sophistication of the algorithm used. TOPS-BC creates a scenario where empirical data representing conditions without the strategy (before deployment) are compared to data representing conditions with the strategy (after deployment), in order to assess the incremental change.

The segment of Strand Road (R44) experiences a great variability of traffic demand due to the combination of the daily home-to-work trips and the recreational trips performed by the great amount of tourist visiting the Winelands District. Figure 4-2 shows the relationship between the speed and the traffic demand under different levels of congestion before the deployment of the actuated traffic signal coordination (from not congested to extremely congested), with the Capacity Adjustment Factor (CAF) of 85%, to express the 85 percentile speed, for Strand Road (R44).

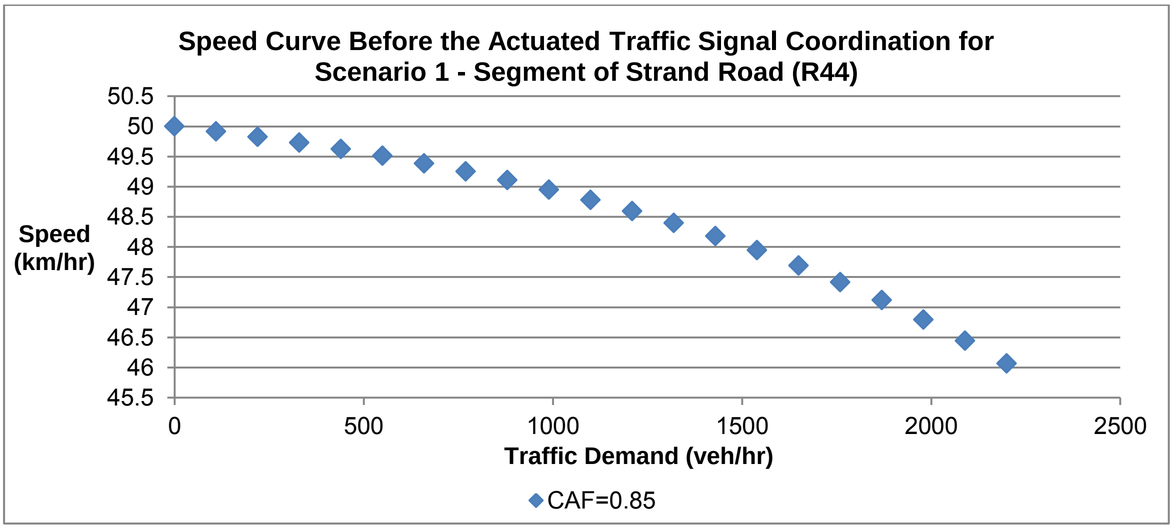



**Figure 4-2: Relationship between Speed and Traffic Demand under Different Levels of Congestion for Scenario 1 – Segment of Strand Road (R44)**

Figure 4-3 represents Scenario 1 with improvement of the capacity after the deployment of the ITS strategy and shows the change of average speed under varying traffic demand.

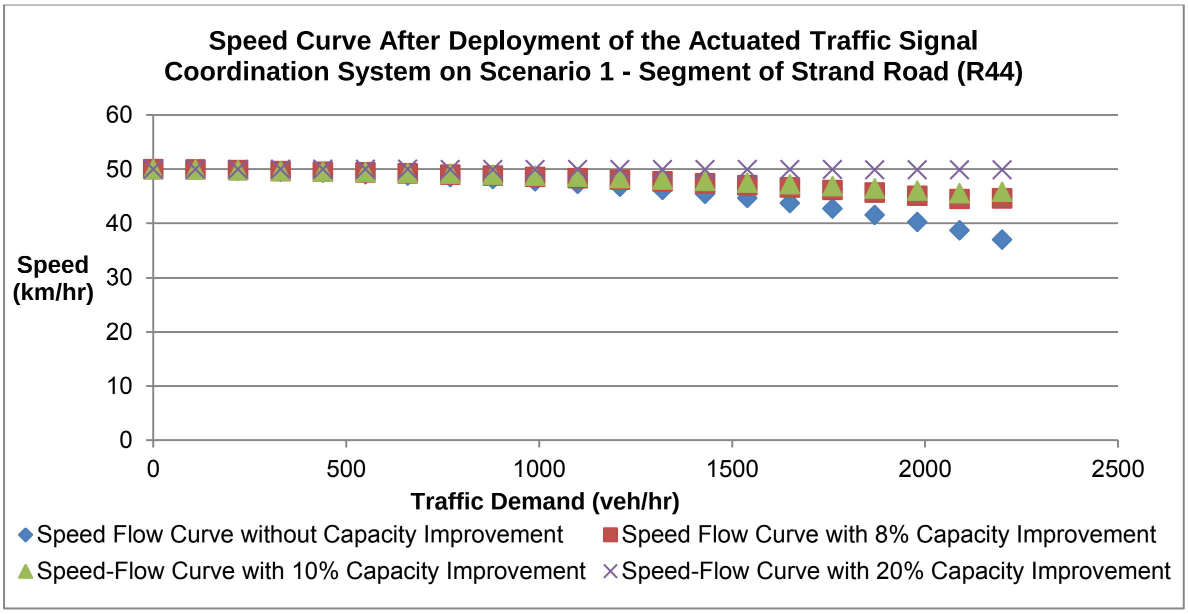



**Figure 4-3: Speed-Flow Curve After Deployment on Scenario 1 - Segment of Strand Road (R44)**

It is evident from Figure 4-3 that the capacity performances of the R44 segment will improve after the actuated traffic signal coordination strategy is deployed.

The two lane (in one direction) segment with a 50 km/h free flow speed (FFS) can have an expected capacity of 2*1100 = 2200 veh/hr, however the flow is not uniformly distributed in the two lanes. Thus, one lane could have stable flows in excess of 2200 veh/hr/lane.

The actual traffic volumes were used for the “before” case, when the DDVH on the 3.3km long segment.is 2561 veh/hr and the estimated free flow speed is 55km/hr. Although it can be observed that there is a lack of improvement for the under-saturated conditions, there is an increase in speed for the queue when the capacity reached the 8% improvement.

Table 4-3 illustrates the relationship between the average speed flow and capacity improvement due to the deployed ITS strategy for Scenario 1. It can be observed that the V/C ratio of the segment without the deployment reaches 0.3 while the V/C ratio of the segment with deployment reached only 0.25.

**Table 4-3: Capacity Improvement for Scenario 1 – Segment of Strand Road (R44)**

| Traffic Volume (veh/hr) | 220 | 440 | 660 | 880 | 1100 | 1320 | 1540 | 1760 | 1980 | 2200 |
|---|---|---|---|---|---|---|---|---|---|---|
| Segment Capacity (veh/hr/lane) | 2200 | | | | | | | | | |
| Improved Capacity 8% (veh/hr/lane) | 2376 | | | | | | | | | |
| Improved Capacity 10% (veh/hr/lane) | 2420 | | | | | | | | | |
| Improved Capacity 20 % (veh/hr/lane) | 2640 | | | | | | | | | |
| Segment V/C | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
| Improved V/C 8% | 0.093 | 0.185 | 0.27 | 0.37 | 0.46 | 0.55 | 0.65 | 0.74 | 0.833 | 0.93 |
| Improved V/C 10% | 0.09 | 0.18 | 0.272 | 0.363 | 0.45 | 0.54 | 0.63 | 0.72 | 0.81 | 0.91 |
| Improved V/C 20% | 0.083 | 0.16 | 0.25 | 0.33 | 0.416 | 0.5 | 0.583 | 0.66 | 0.75 | 0.83 |
| Segment Speed (km/hr) | 49.69 | 49.3 | 48.79 | 48.12 | 47.25 | 46.12 | 44.64 | 42.72 | 40.22 | 36.96 |
| Improved Speed 8% (km/hr) | 49.78 | 49.51 | 49.19 | 48.79 | 48.32 | 47.73 | 47.01 | 46.15 | 45.093 | 44.61 |
| Improved Speed 10% (km/hr) | 49.78 | 49.51 | 49.19 | 48.79 | 48.31 | 47.73 | 47.019 | 46.15 | 45.09 | 44.61 |
| Improved Speed 20% (km/hr) | 49.98 | 49.96 | 49.95 | 49.94 | 49.93 | 49.91 | 49.91 | 49.89 | 49.88 | 49.86 |

Travel times obtained from the calculations are for peak hour and direction of the highest volume. Therefore, calculating the recurring travel time implies the need for the vehicle type distribution for the analysis and the value of the average auto occupancy from the Travel Demand Model of Stellenbosch.

From the traffic count in Table 2-2 the vehicle type distribution was estimated where the traffic volume includes 10% of heavy vehicles and 90% of passenger vehicles and the average auto occupancy used for the analysis is 1.5.

Figure 4-4 represents the relationship between the average travel time and the traffic demand before the deployment of the ITS strategy.

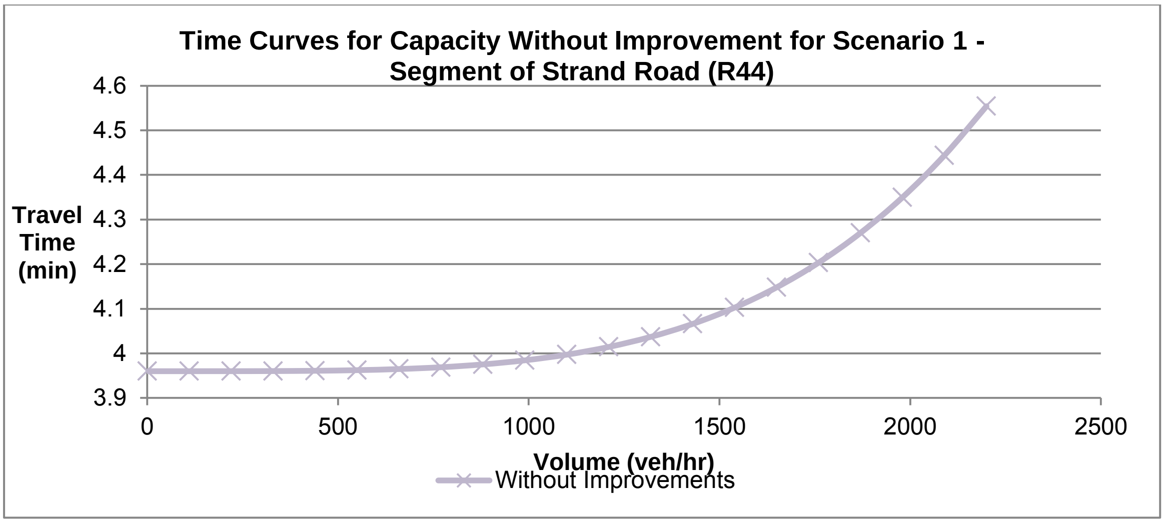



**Figure 4-4: Time Curves for Capacity without Improvement for Scenario 1 – Segment of Strand Road (R44)**

The travel time is relatively stable on the segment until the traffic volume reached 1100 veh/hr (V/C Ratio equal to 0.5) after that point the travel time increased as a result of the queue up on the segment until the traffic volume reached 2200 veh/hr (V/C Ratio equal to 1).

Once deployed the ITS strategy reduces the travel time for the vehicles under saturated condition and the speed increased for the vehicles when capacity improved. The travel time start decreasing when the capacity improved by 8% and the V/C Ratio is equal to 0.4 (880 veh/hr).

Figure 4-5 represents the travel time enhancement on the road segment resulting from the capacity improvement.

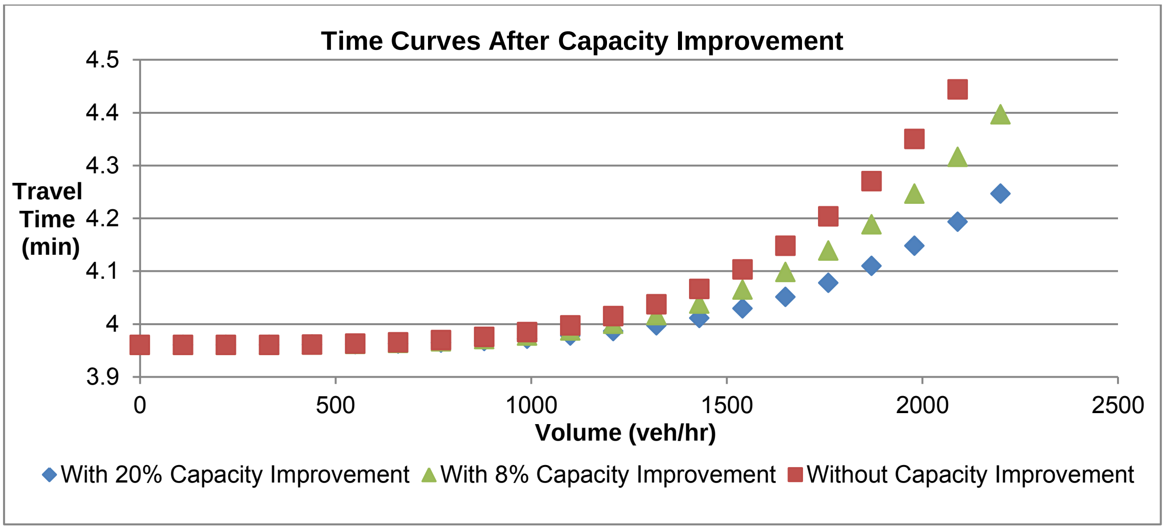



**Figure 4-5: Time Curves for Capacity with Improvement**

### Non-Recurring Travel Time Benefit

For the segment of Strand Road (R44), traffic volumes were obtain from a 1-hour traffic count and the rate of incident delays were calculated with the curve in Figure 3-6 where the V/C ratio were interpolated to find the incident related delay. Table 4-4 represent the expected incident related delays on the segment of road.

The incident delays encountered on the segment are very small values since the multilane facility segment suffers only of one-quarter reduced capacity. A higher V/C ratio will yield a lower incidents related delay. The incident related delays at 1100 veh/hr is smaller than the incident related delays at 2200 veh/hr.

**Table 4-4: Non-Recurring Travel Time Savings Estimate Using 20% Link Capacity Improvement – Scenario 1**

| Segment Length (km) | Volume (veh/hr) | Capacity (veh/hr/ln) | V/C | Improved V/C at 20% | Base Incident Delay (hr/veh/km) | Incident Delay 20% (hr/veh/km) | Save in Incident Delay (hr/veh/km) |
|---|---|---|---|---|---|---|---|
| 3.3 | 0 | 2200 | 0 | 0 | 0 | 0 | 0 |
| 3.3 | 110 | 2200 | 0.05 | 0.04 | -1.76E-03 | -1.70E-03 | -6.99E-05 |
| 3.3 | 220 | 2200 | 0.1 | 0.08 | 5.65E-08 | 5.42E-08 | 2.24E-09 |
| 3.3 | 330 | 2200 | 0.15 | 0.12 | 4.14E-06 | 3.97E-06 | 1.63E-07 |
| 3.3 | 440 | 2200 | 0.2 | 0.16 | 1.28E-05 | 1.23E-05 | 5.06E-07 |
| 3.3 | 550 | 2200 | 0.25 | 0.2 | 3.07E-05 | 2.94E-05 | 1.22E-06 |
| 3.3 | 660 | 2200 | 0.3 | 0.24 | 6.29E-05 | 6.03E-05 | 2.50E-06 |
| 3.3 | 770 | 2200 | 0.35 | 0.28 | 1.15E-04 | 1.11E-04 | 4.56E-06 |
| 3.3 | 880 | 2200 | 0.4 | 0.32 | 1.95E-04 | 1.87E-04 | 7.71E-06 |
| 3.3 | 990 | 2200 | 0.45 | 0.36 | 3.09E-04 | 2.98E-04 | 1.23E-05 |
| 3.3 | 1100 | 2200 | 0.5 | 0.4 | 4.69E-04 | 4.50E-04 | 1.86E-05 |
| 3.3 | 1210 | 2200 | 0.55 | 0.44 | 6.82E-04 | 6.54E-04 | 2.70E-05 |
| 3.3 | 1320 | 2200 | 0.6 | 0.48 | 9.60E-04 | 9.22E-04 | 3.81E-05 |
| 3.3 | 1430 | 2200 | 0.65 | 0.52 | 1.32E-03 | 1.27E-03 | 5.23E-05 |
| 3.3 | 1540 | 2200 | 0.7 | 0.56 | 1.79E-03 | 1.71E-03 | 7.09E-05 |
| 3.3 | 1650 | 2200 | 0.75 | 0.6 | 2.42E-03 | 2.32E-03 | 9.57E-05 |
| 3.3 | 1760 | 2200 | 0.8 | 0.64 | 3.34E-03 | 3.22E-03 | 1.33E-04 |
| 3.3 | 1870 | 2200 | 0.85 | 0.68 | 4.94E-03 | 4.75E-03 | 1.95E-04 |
| 3.3 | 1980 | 2200 | 0.9 | 0.72 | 8.14E-03 | 7.82E-03 | 3.23E-04 |
| 3.3 | 2090 | 2200 | 0.95 | 0.76 | 1.53E-02 | 1.47E-02 | 6.05E-04 |
| 3.3 | 2200 | 2200 | 1 | 0.8 | 3.18E-02 | 3.06E-02 | 2.45E-07 |

**Travel Time Saving Valuation**

The recurring travel time and non-recurring travel time were aggregated in order to illustrate the total savings in travel time generated by the ITS strategy deployment. Figure 4-6 presents the aggregated travel times under a capacity improvement of 20% and shows the efficiency of the deployment when the traffic demand increases.

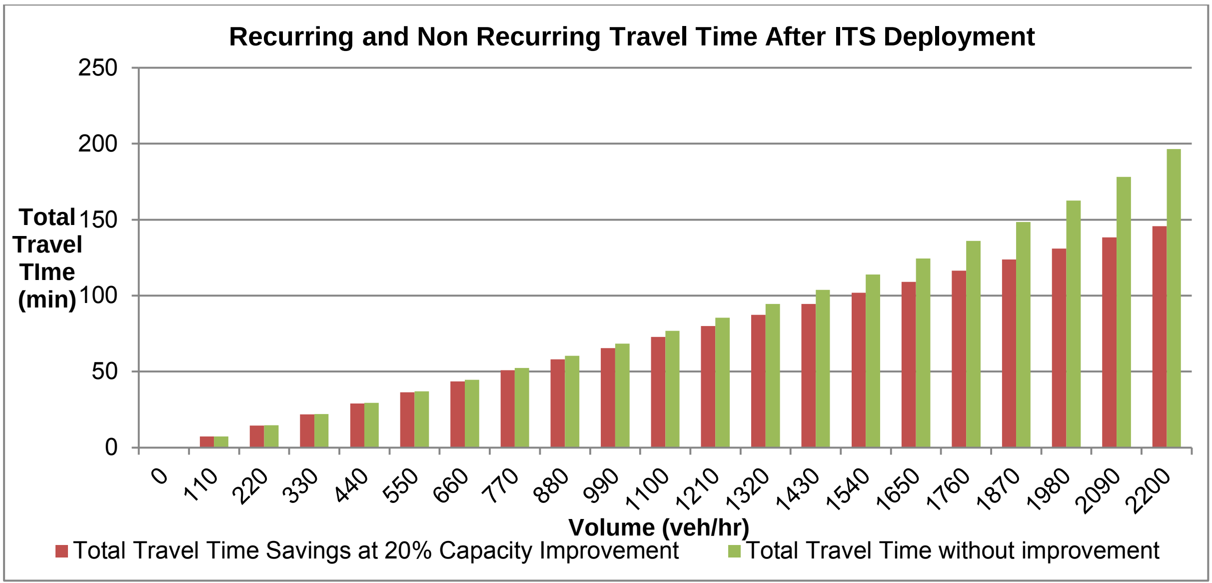



**Figure 4-6: Recurring and Non-Recurring Travel Time After ITS Deployment**

Passenger vehicles account for 90% of the traffic and heavy vehicles represent 10% of the traffic on the Strand Road (R44). Twenty percent of the passenger vehicles cars are bakkies used for private trips between Stellenbosch, Somerset and Strand.

The annual benefits estimation represent the travel times during the peak hours (morning and afternoon) and only for workings days excluding the weekends and public holidays. One-third of vehicle trips occur during the morning and afternoon peak hours and the majority of the passengers are commuters.

From the 250 working days per year the 13 public holidays were deducted, therefore 237 days were used for the annual monetised benefit. Using a discount rate of 10%, the annual monetised travel time savings benefits resulting from the actuated traffic signal deployment can be expressed as follow in Figure 4-7.

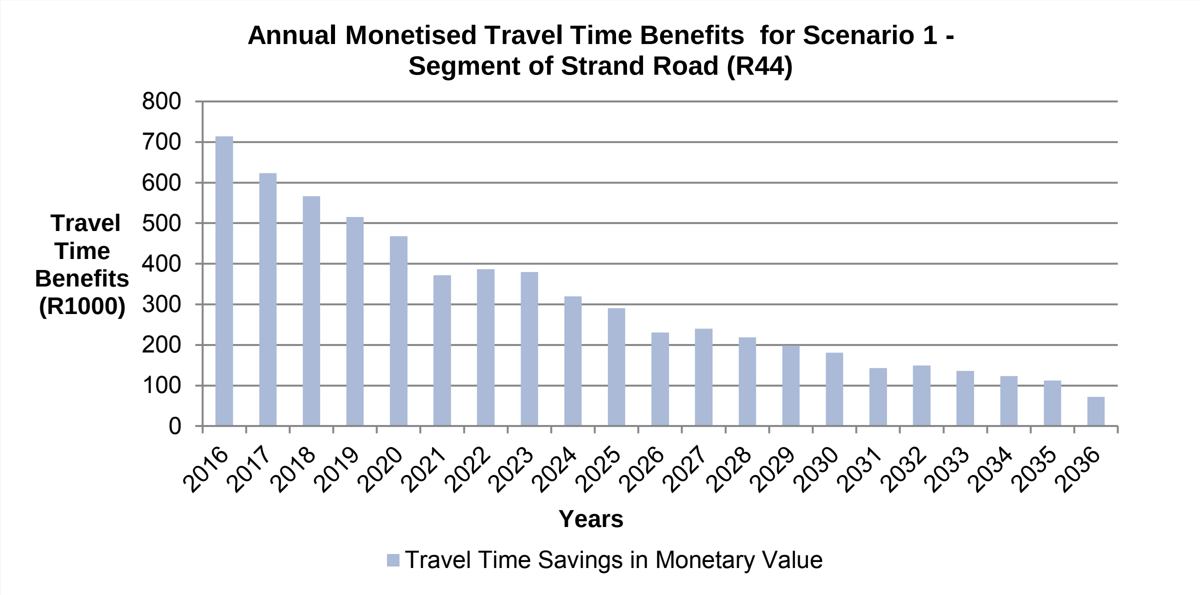



**Figure 4-7: Annual Monetised Travel Time Benefit for Scenario 1 - Segment of Strand Road (R44)**

The Benefits for the Travel Time for Scenario 1, the Strand Road (R44) segment, is calculated as R 623,266.00 in 2017 and a total or R 5,725,888.00 after the 20 years.

#### *4.2.1.3. Energy Benefits*

To access the energy benefits and show the efficacy of the actuated traffic signal over the lifetime of the deployment the vehicles type distribution was estimated for the 20 years' time as shown in Figure 4-8.

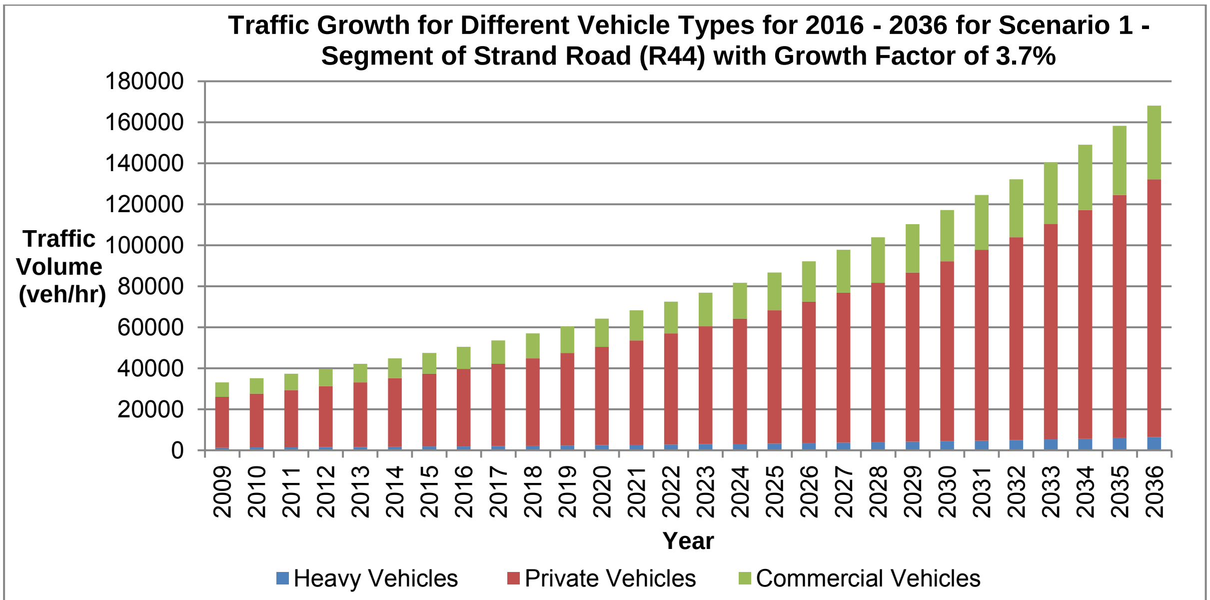



**Figure 4-8: Traffic Growth for Different Vehicle Types 2016 to 2036 for Scenario 1 – Segment of Strand Road (R44)**

**Vehicle Fuel Consumption Distribution**

The fuel consumption is a direct application of the VKT on the net fuel use. The VMT is derived from the volume and the length of segment that were analysed. The fuel consumption of the heavy vehicles, commercial vehicles and private vehicle were calculated using the vehicles type distribution as shown in Figure 4-9.

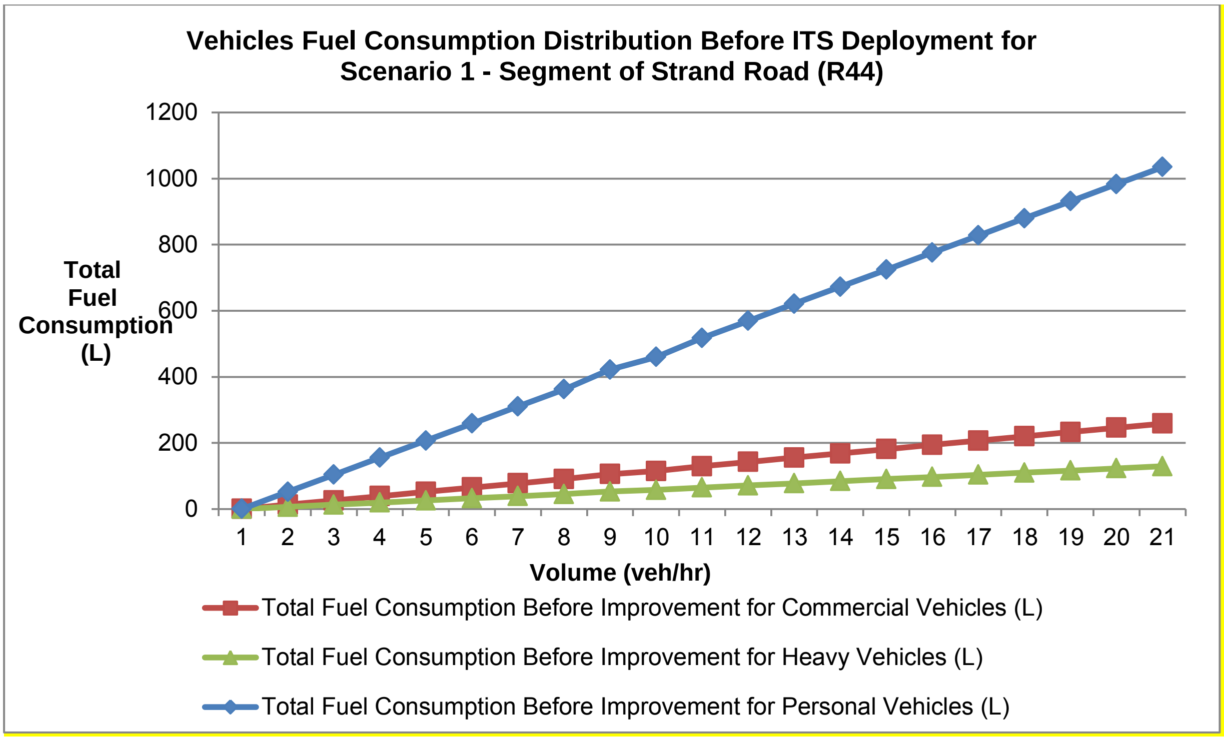



**Figure 4-9: Vehicles Consumption Distributions Before ITS Deployment for Scenario 1 – Segment of Strand Road (R44)**

The V/C ratio directly influenced the fuel consumption on the segment of the road. A higher traffic volume will have a greater impact on the fuel consumption. On the congested segment, the fuel consumption is stable until the V/C reached 0.3 (660 veh/hr), after that the fuel consumption doubled under the influence of the queue.

When perfectly deployed along the corridor, the most significant fuel consumption is observed from the vehicles travelling the segment when the volume on the segment reached 440 veh/hr. Figure 4-10 shows the fuel consumption for the various traffic demands after the ITS deployment.

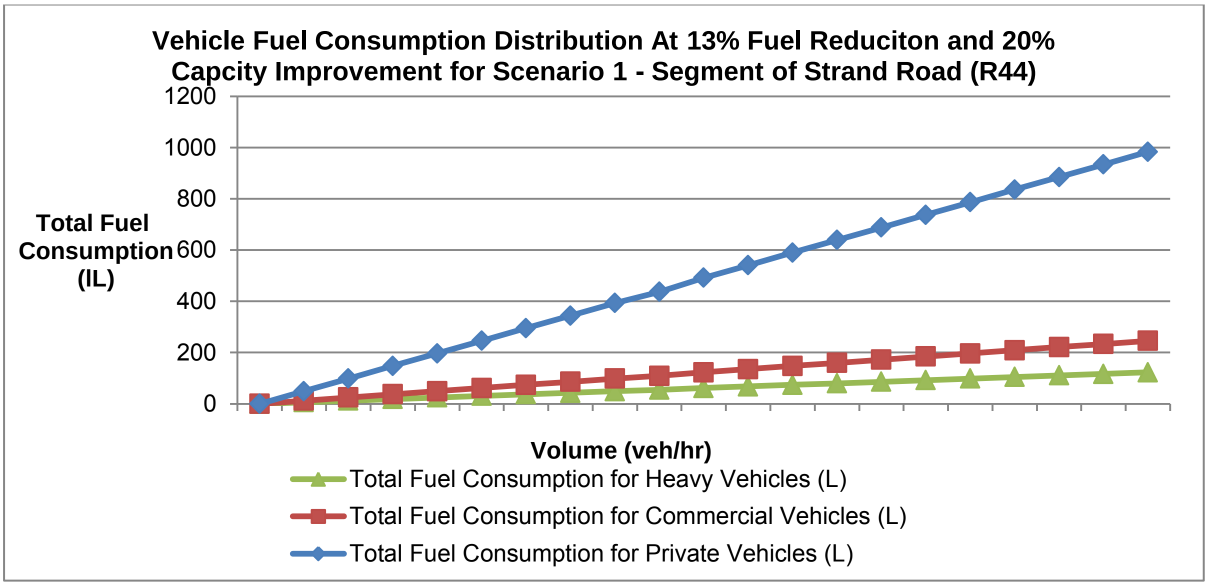



**Figure 4-10: Vehicles Consumption Distributions After ITS Deployment for Scenario 1 – Segment of Strand Road (R44)**

### Vehicle Fuel Saving

To show the efficiency of the ITS deployment on the segment, the fuel consumption before and after the deployment were compared. The difference was express in a quantified unit in order to monetise and represent the benefits in fuel saved. Figure 4-11 and Figure 4-12 represent the typical fuel consumption saving in litres for the segment under varying traffic demand.

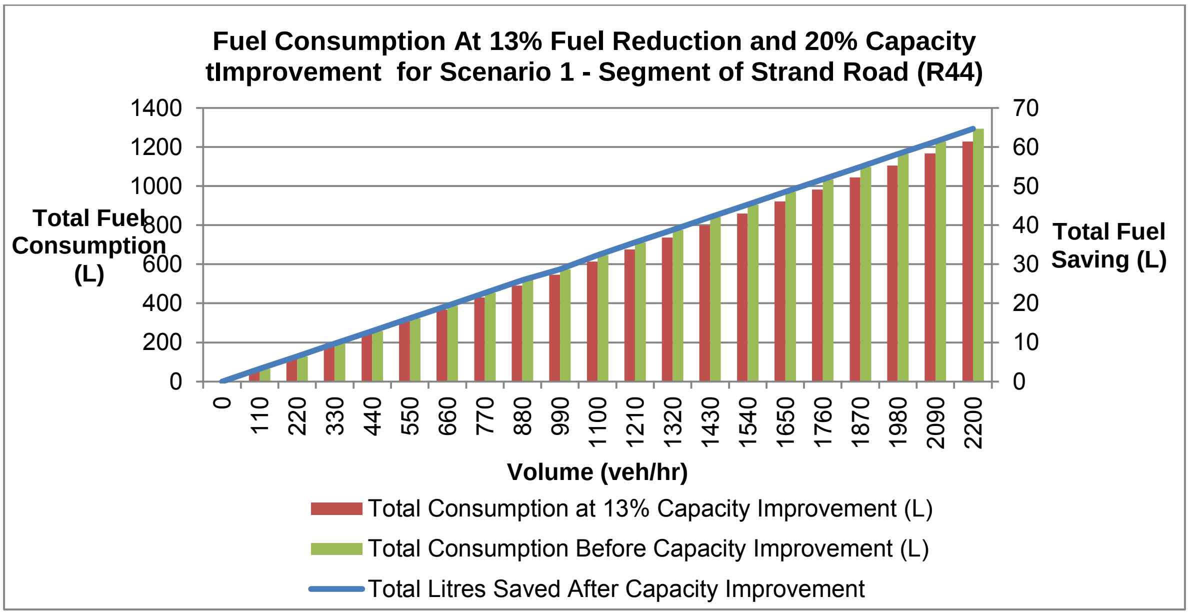



**Figure 4-11: Vehicle Fuel Consumption Saving After ITS Deployment for Scenario 1 – segment of Strand Road (R44)**

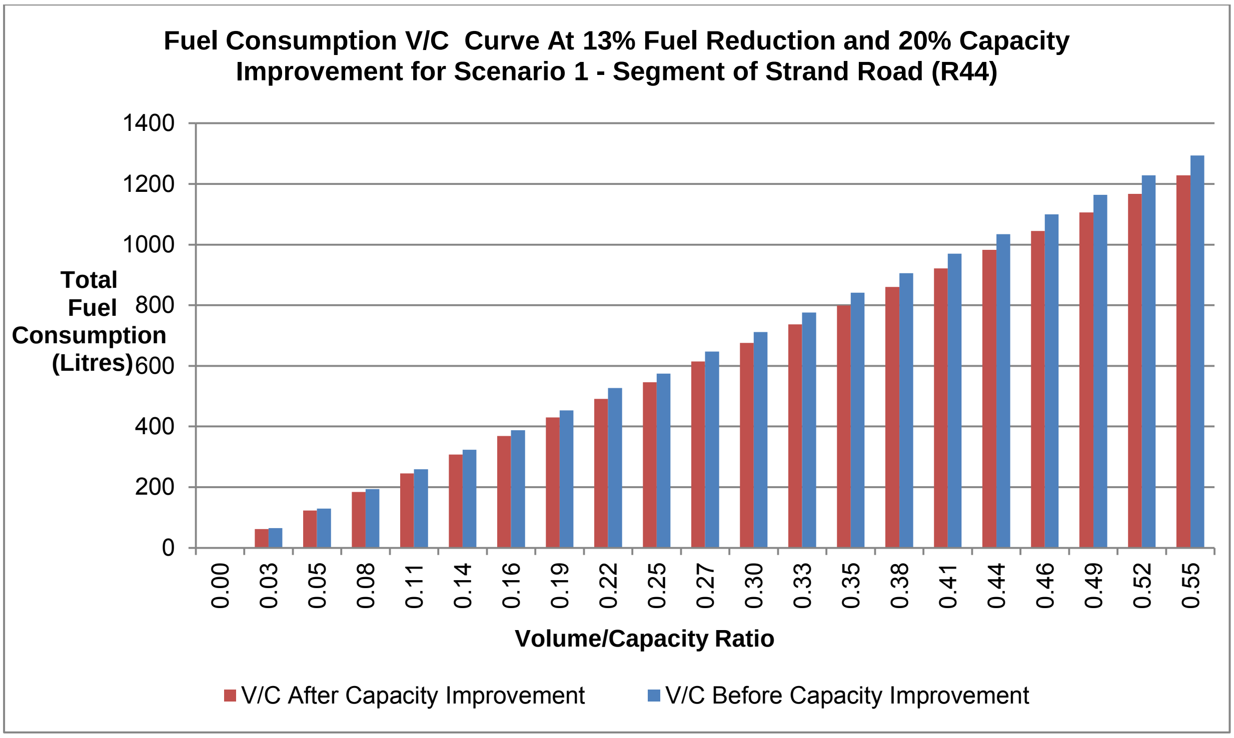



**Figure 4-12: Fuel Consumption V/C Curve After ITS Deployment for Scenario 1 – Segment of Strand Road (R44)**

The annual monetised fuel saving benefits resulting from the actuated traffic signal deployment can be expressed as follow in Figure 4-13.

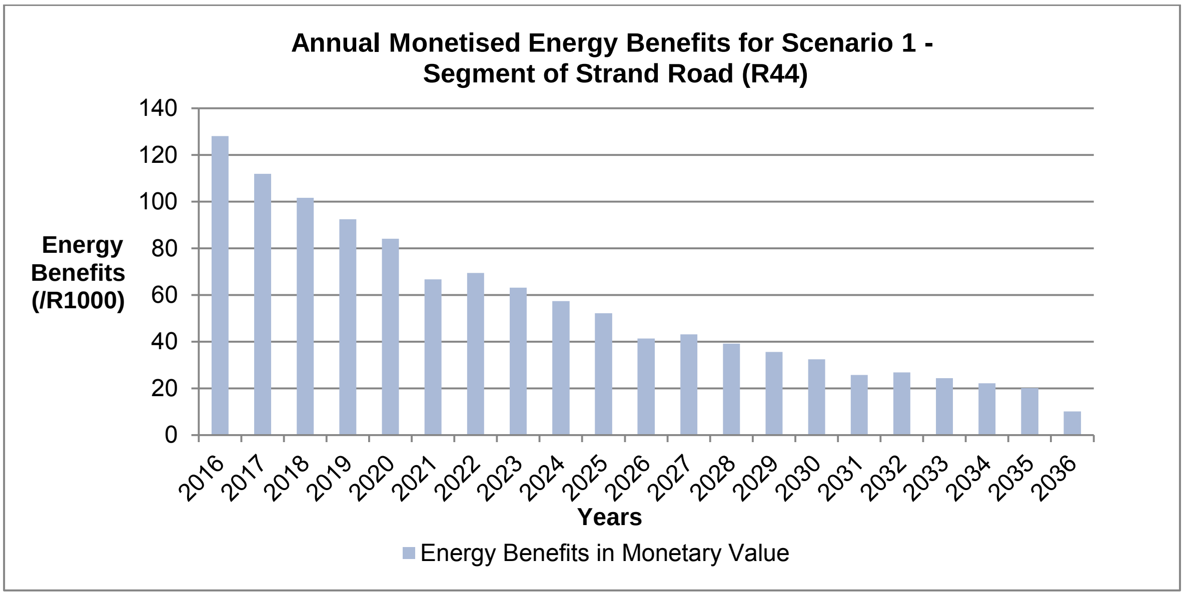



**Figure 4-13: Annual Monetised Energy Benefits for Scenario 1 - Segment of Strand Road (R44)**

The Energy Benefits for Scenario 1, which is the segment of Strand Road (R44) is calculated as R 111,874.00 in 2017 and a total of R 1,019,914.00 after the 20 years.

#### *4.2.1.4. Safety Benefits*

The crash rates after the deployments were based on an assumed percentage reduction. A Rand value was assigned to the reduced amount of accidents. Figure 4-14 show the crash distribution before the ITS deployment.

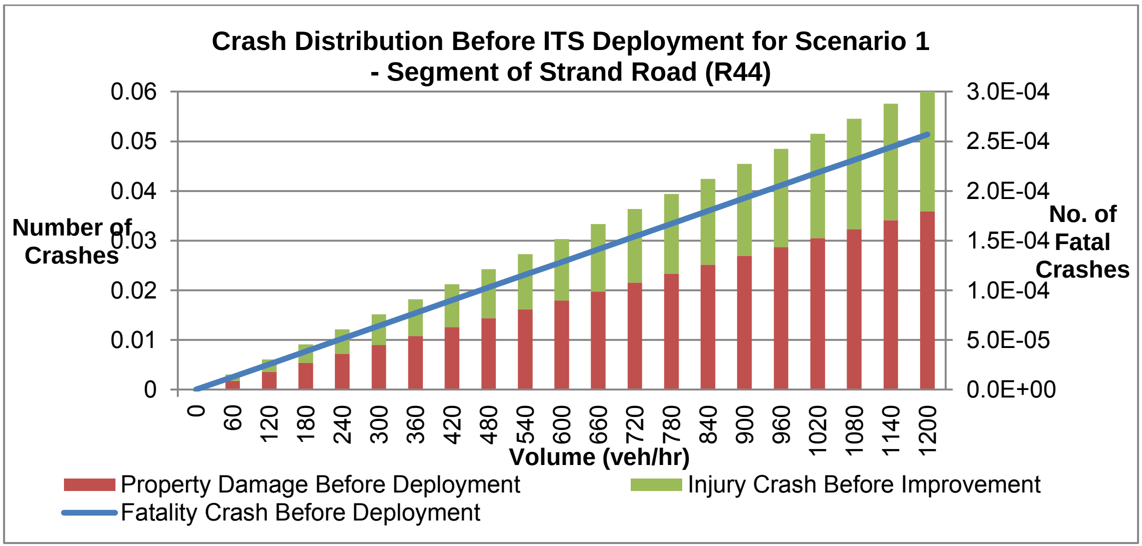



**Figure 4-14: Crash Distribution Before ITS Deployment for Scenario 1 – Segment of Strand Road (R44)**

The following sensitivity analysis was condicted for crash reduction rates between 7% and 13%. Figure 4-15 presents the influence of the crash reduction rates on the Fatality Crashes.

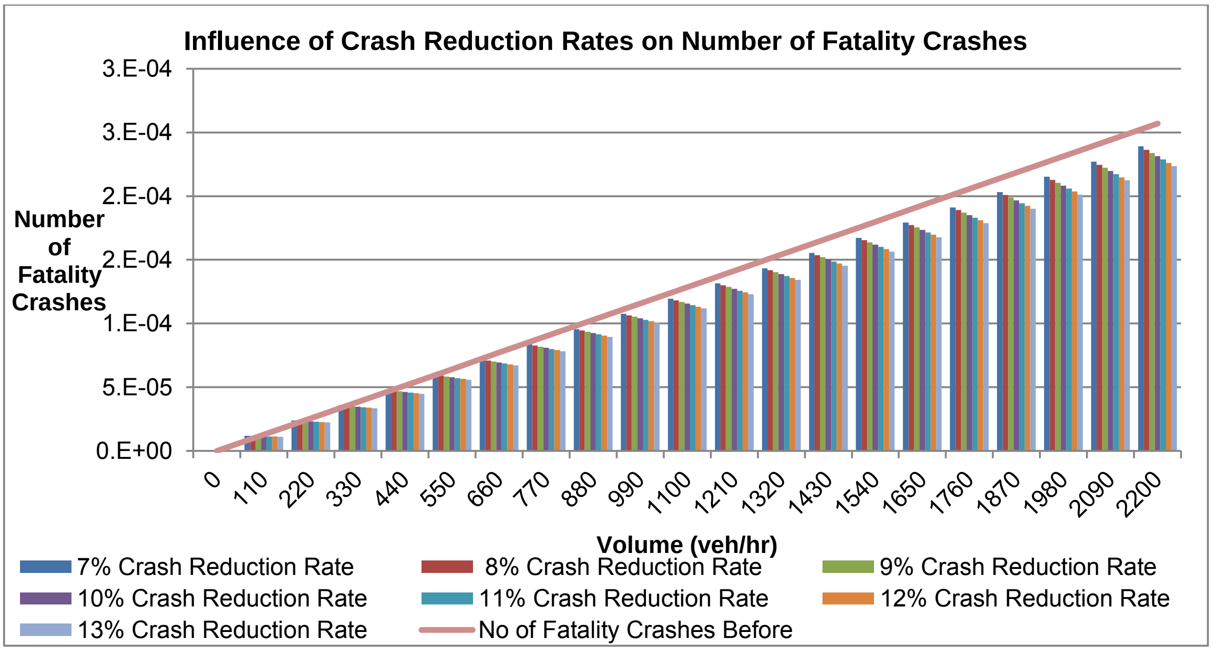



**Figure 4-15: Influence of Crash Reduction Rate on Fatality Crashes**

Figure 4-16 presents the influence of the crash reduction rates on the Injury Crashes.

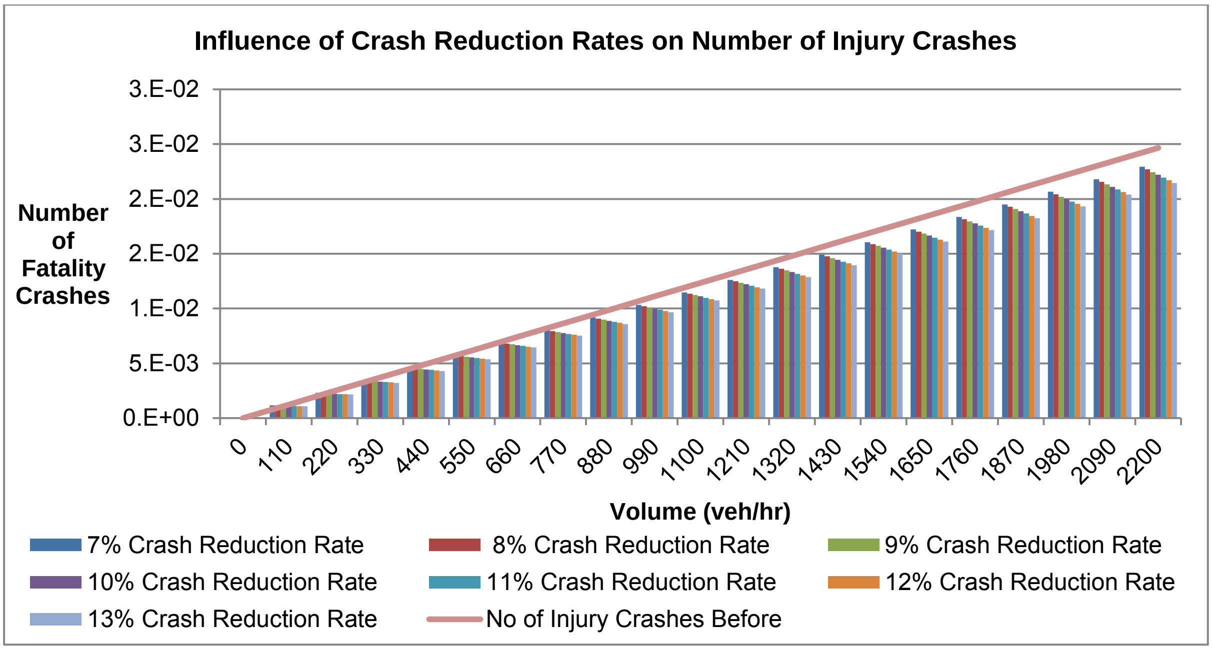



**Figure 4-16: Influence of Crash Reduction Rate on Injury Crashes**

Figure 4-17 presents the influence of the crash reduction rates on the Property Damage Only Crashes.

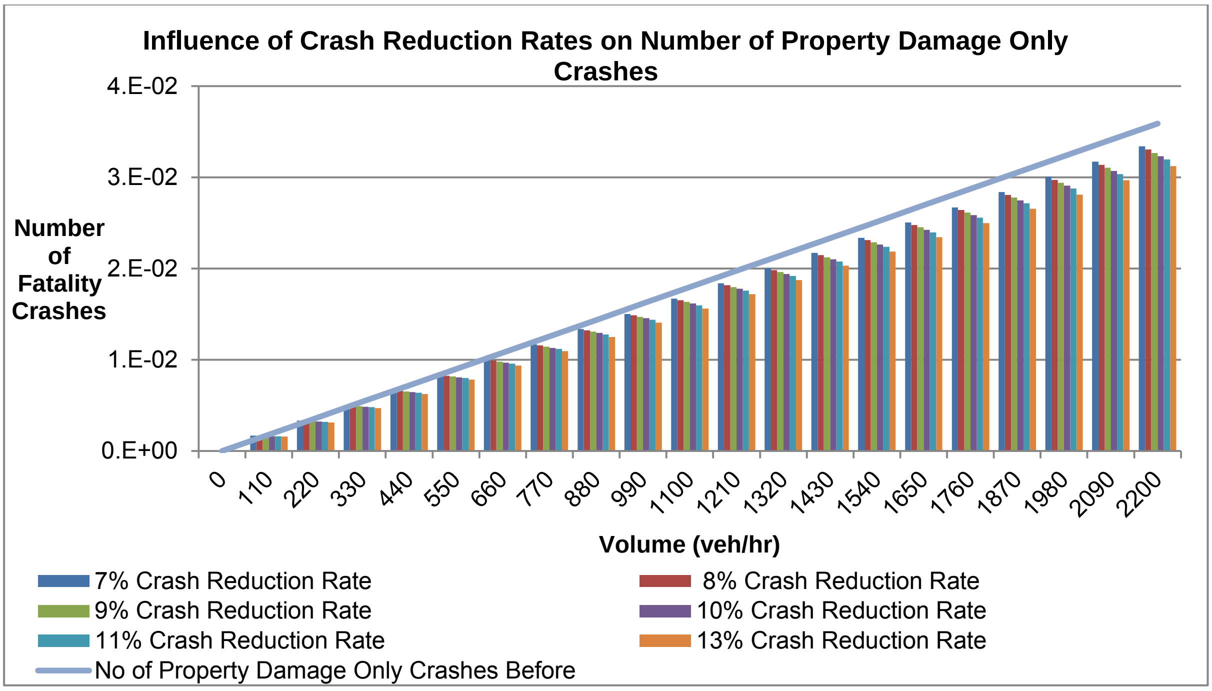



**Figure 4-17: Influence of Crash Reduction Rate on Property Damage Only Crashes**

This thesis will use 7% as the crash reduction rate, for illustration.

The weaving movement under saturated flow conditions increceases the possibilty of crash since the drivers need an appropriate gap to manoeuvre. Figure 4-18 and Figure 4-19 represent the typical trend of crash improvement at differents level of congestion.

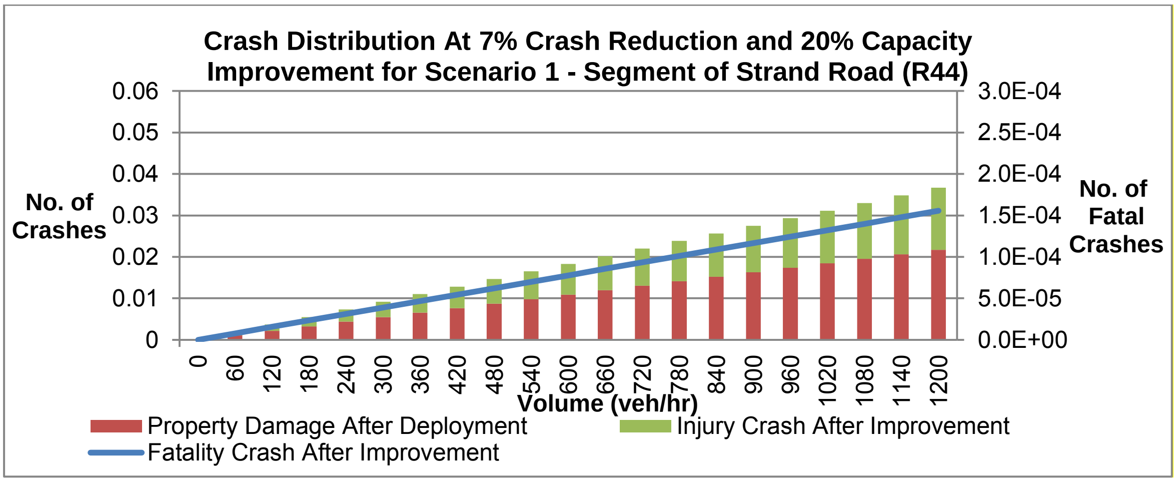



**Figure 4-18: Crash Distribution After ITS Deployment for Scenario 1 – Segment of Strand Road (R44)**

The actuated traffic signal deployment improved the mobility of the segment of road. As the speed in the platoon increased the risk of collision reduced, allowing drivers a longer time interval to manoeuvre and avoid collision. However, severity of crashes is higher with higher speeds, as well as on the multilane segment.

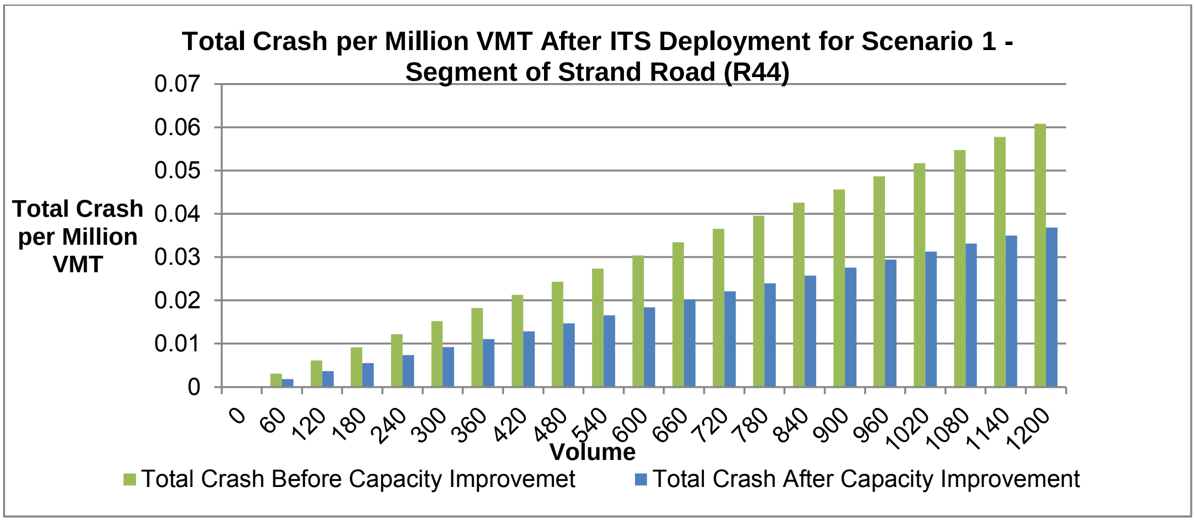



**Figure 4-19: Total Crashes Per Million VMT After ITS Deployment for Scenario – Segment of Strand Road (R44)**

The annual monetised safety benefit using a discount rate of 10% resulting from the actuated traffic signal deployment can be expressed as follows in Figure 4-20.

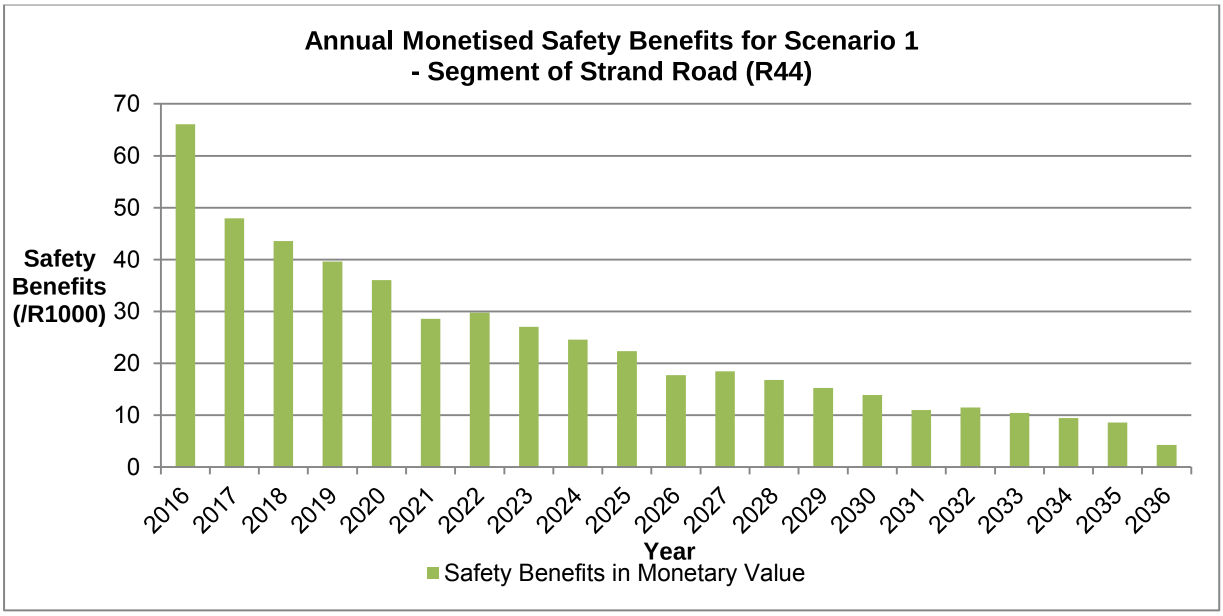



**Figure 4-20: Annual Monetised Safety Benefits for Scenario 1 - Segment of Strand Road (R44)**

The Safety Benefits for Scenario 1, which is the segment of Strand Road (R44) is calculated as R 47,950.00 in 2017 and a total of R 437,080.00 after the 20 years.

#### *4.2.1.5. B/C Ratio*

The B/C ratio for Scenario 1 of Actuated Traffic Signal Coordination is approximately 23.8.

### 4.2.2. Scenario 2: Segment of Bird Street (R304)

#### *4.2.2.1. Life Cycle Costs Analysis*

The following breakdown of the life cycle costs for the actuated traffic signal coordination for Scenario 2 can be seen in Table 4-5.

**Table 4-5: Breakdown of Life Cycle Costs Analysis for Scenario 2 per intersection - Segment of Bird Street (R304)**

| **Estimated Life Cycle Costs of Actuated Traffic Signal Coordination Systems** | | | | |
|---|---|---|---|---|
| **Equipment** | **Useful Life (Yrs)** | **Total Capital / Replacement Costs ( R )** | **Annual O&M Costs ( R )** | **Total Annual Costs ( R )** |
| | 20 | 252,000.00 | 2,800.00 | 15,400.00 |
| **TOTAL Infrastructure Cost** | | 252,000.00 | 2,800.00 | 15,400.00 |
| **Incremental Deployment Equipment (per Intersection)** | | | | |
| Signal Controller | 15 | 25,200.00 | 2,800.00 | 4,480.00 |
| Communication Line | 20 | 7,000.00 | 8,400.00 | 8,750.00 |
| Loop Detectors (2) | 5 | 28,000.00 | 4,200.00 | 9,800.00 |
| **TOTAL Incremental Cost** | | 60,200.00 | 15,400.00 | 23,030.00 |
| Number of Infrastructure Deployments | 1 | | | **15,400.00** |
| Number of Incremental Deployments (Per intersection) | 1 | | | **23,030.00** |
| Year of Deployment | 2016 | | | |
| **Average Annual Cost ( R )** | | | | **38,430.00** |

Figure 4-21 displays the lifecycle costs framework of an actuated traffic signal for 20 years life time horizon for B/C analysis.

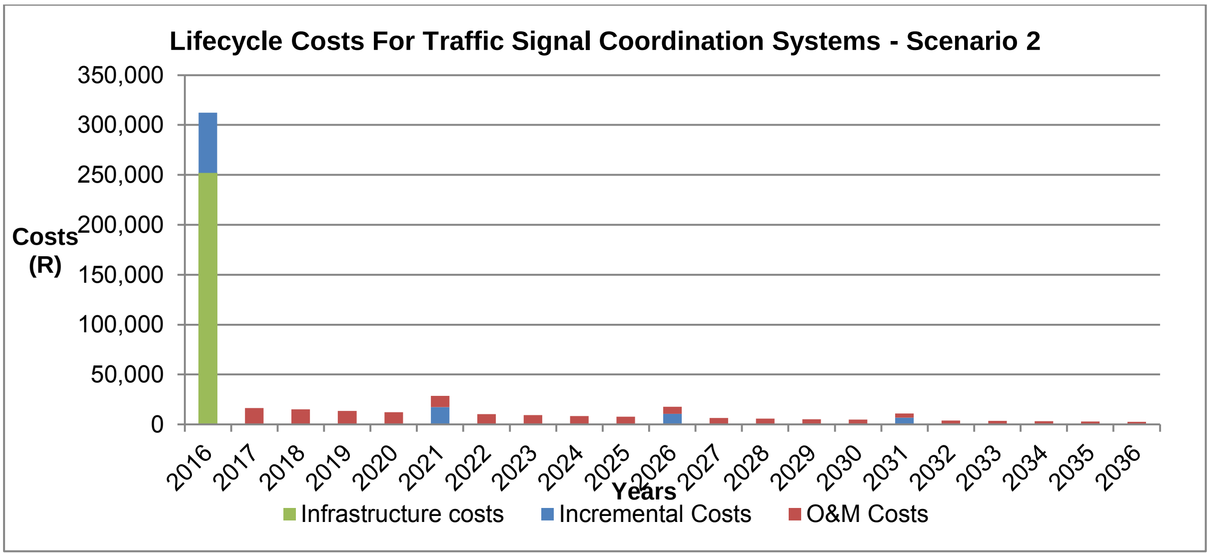



**Figure 4-21: Life Cycle Cost of the Traffic Actuated Signal Coordination System for Scenario 2 – Segment of Bird Street (R304)**

Table 4-6 presents the various life cycle costs and the resultant Present Worth Cost for Scenario 2. The PWC over the 20 year life time horizon is calculated using a 10% discount rate.

**Table 4-6: Breakdown of Life Cycle Costs of Scenario 2 per intersection– Segment of Bird Street (R304)**

| Years | Infrastructure Costs (R) | Incremental Costs (R) | Operation & Maintenance Costs (R) | Total Costs (R ) |
|---|---|---|---|---|
| **2016** | 25 2000.00 | 312 200.00 | 312 200.00 | 312 200.00 |
| **2017** | | 16 548.00 | 16 548.00 | 16 548.00 |
| **2018** | | 15 036.00 | 15 036.00 | 15 036.00 |
| **2019** | | 13 678.00 | 13 678.00 | 13 678.00 |
| **2020** | | 12 432.00 | 12 432.00 | 12 432.00 |
| **2021** | | 28 686.00 | 28 686.00 | 28 686.00 |
| **2022** | | 10 276.00 | 10 276.00 | 10 276.00 |
| **2023** | | 9 338.00 | 9 338.00 | 9 338.00 |
| **2024** | | 8 484.00 | 8 484.00 | 8 484.00 |
| **2025** | | 7 714.00 | 7 714.00 | 7 714.00 |
| **2026** | | 17 808.00 | 17 808.00 | 17 808.00 |
| **2027** | | 6 384.00 | 6 384.00 | 6 384.00 |
| **2028** | | 5 796.00 | 5 796.00 | 5 796.00 |
| **2029** | | 5 278.00 | 5 278.00 | 5 278.00 |
| **2030** | | 4 788.00 | 4 788.00 | 4 788.00 |
| **2031** | | 11 060.00 | 11 060.00 | 11 060.00 |
| **2032** | | 3 962.00 | 3 962.00 | 3 962.00 |
| **2033** | | 3 598.00 | 3 598.00 | 3 598.00 |
| **2034** | | 3 276.00 | 3 276.00 | 3 276.00 |
| **2035** | | 2 982.00 | 2 982.00 | 2 982.00 |
| **2036** | | 2 702.00 | 2 702.00 | 2 702.00 |
| **Present Worth Cost ( R )** | | | | **502 026.00** |

The total monetised value of the life cycle cost analysis considers the number of equipment needed to upgrade the current system. For each of the three intersections part of the analysis along the corridor, The PWC cost is R 502,026.00 as indicated in the Table 4-1. Since it is not a new system the infrastructure costs and Incremental costs of base year 2016 is excluded from the analysis.

#### *4.2.2.2. Travel Time Benefits*

Recurring travel-time

As stated in Section 4.2.1.2. the recurring travel time savings benefits of traffic actuated varies widely according to the location of deployment. In Scenario 2, the ITS strategy is deployed on an undivided arterial covering the segment of the road between the intersection of Bird Street (304) and Masitandane Road to the intersection between Bird Street (R304) and Merriman Avenue. Figure 4-22 shows the speed 85th speed percentile for varying degrees of congestion along the corridor.

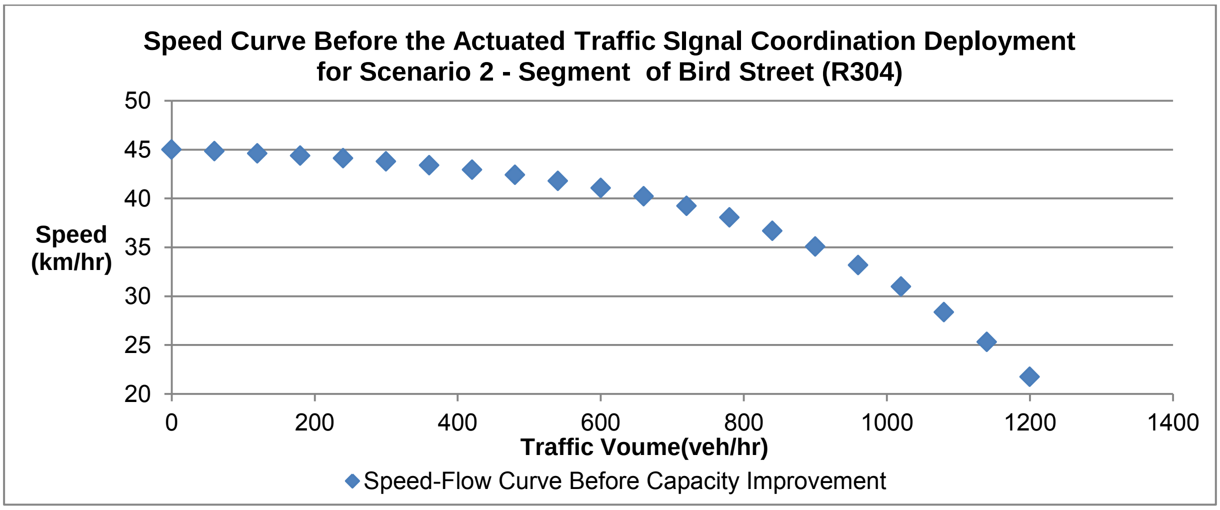



**Figure 4-22: Relationship between Speed and Traffic Demand under Different Levels of Congestion for Scenario 2 – Segment of Bird Street (R304)**

Figure 4-23 presents Scenario 2 with improvement of the capacity after the deployment of the ITS strategy and shows the change of average flow speed under influence of the same traffic demand. Compared to the multilane segment on the divided arterial, the speed on the undivided arterial is relatively constant on the road segment until the V/C ratio reaches 0.5.

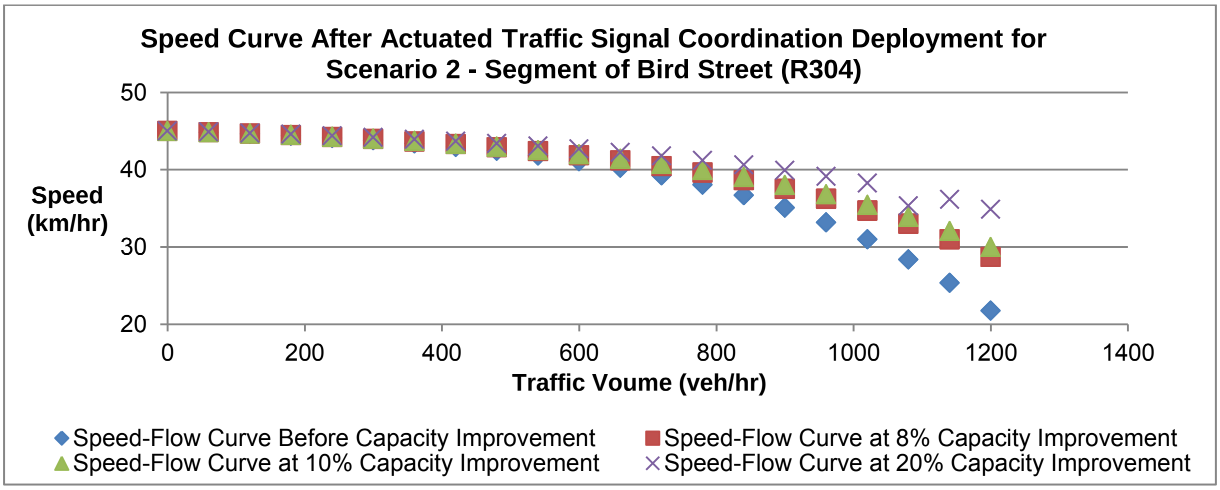



**Figure 4-23: Relationship between Speed and Traffic Demand under Different Levels of Congestion after ITS Deployment for Scenario 2 – Segment of Bird Street (R304)**

With the ITS deployment, the speed increases in the queue when the capacity reached the 8% of capacity improvement. It can be seen that the ITS strategy has a greater benefit on the multilane arterial since increased speed is noticed when the V/C ratio reached 0.3. The weaving movement and the use of the multilane segment capacity influence the speed variability. The directional volume was mostly concentrated on one lane. The speed improvement on the segment is derived from the capacity and the different level of congestion. When the volume is low there is little interaction between the vehicles and where drivers are free to drive at free flow conditions, which is the speed limit. The maximum speed is obtained when flow approaches zero. As traffic volume increases on the segment, the capacity utilisation increases while speed decreases on the segment. As volume constantly increase, likewise the speed constantly decreased on the segment. Table 4-7 illustrates the typical trend of speed improvement resulting from the ITS deployment on the arterial road segment on Bird Street (R304) between the intersection of Bird Street (304) and Masitandane Road to the intersection between Merriman Avenue and Bird Street (R304).

**Table 4-7: Speed Flow - Capacity Improvement for Scenario 2 – Bird Street (R304)**

| Traffic Volume (veh/hr) | 120 | 240 | 360 | 480 | 600 | 720 | 840 | 960 | 1080 | 1200 |
|---|---|---|---|---|---|---|---|---|---|---|
| Segment Capacity (veh/hr/lane) | 1200 | | | | | | | | | |
| Improved Capacity 8% (veh/hr/lane) | 1296 | | | | | | | | | |
| Improved Capacity 10% (veh/hr/lane) | 1320 | | | | | | | | | |
| Improved Capacity 20 % (veh/hr/lane) | 1440 | | | | | | | | | |
| Segment V/C | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
| Improved V/C 8% | 0.09 | 0.19 | 0.28 | 0.37 | 0.46 | 0.56 | 0.65 | 0.74 | 0.83 | 0.93 |
| Improved V/C 10% | 0.09 | 0.18 | 0.27 | 0.36 | 0.45 | 0.55 | 0.64 | 0.73 | 0.82 | 0.91 |
| Improved V/C 20% | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 | 0.83 |
| Segment Speed (km/hr) | 44.62 | 44.11 | 43.40 | 42.42 | 41.08 | 39.23 | 36.69 | 33.19 | 28.38 | 21.76 |
| Improved Speed 8% (km/hr) | 44.67 | 44.23 | 43.65 | 42.87 | 41.84 | 40.47 | 38.64 | 36.21 | 32.99 | 28.69 |
| Improved Speed 10% (km/hr) | 44.68 | 44.26 | 43.70 | 42.97 | 42.00 | 40.72 | 39.03 | 36.81 | 33.87 | 29.99 |
| Improved Speed 20% (km/hr) | 44.73 | 44.38 | 43.94 | 43.38 | 42.66 | 41.75 | 40.60 | 39.12 | 35.31 | 34.87 |

As in Scenario 1, the travel times derived from the speed was calculated during the peak hours and the improved travel times are obtained after the ITS strategy deployed. As traffic volume varies on the segment travel time and speed varies as well. Under uncongested conditions (lower volume), the vehicles have free movement and are able to travel along the road segment at free flow speed within a short period of time.

When volume increases (congested conditions), the speed reduces due to the increase of vehicles in the platoon travelling along the road segment, thus the travel time increase. Figure 4-24 represents the typical relationship between the travel time and the traffic volume.

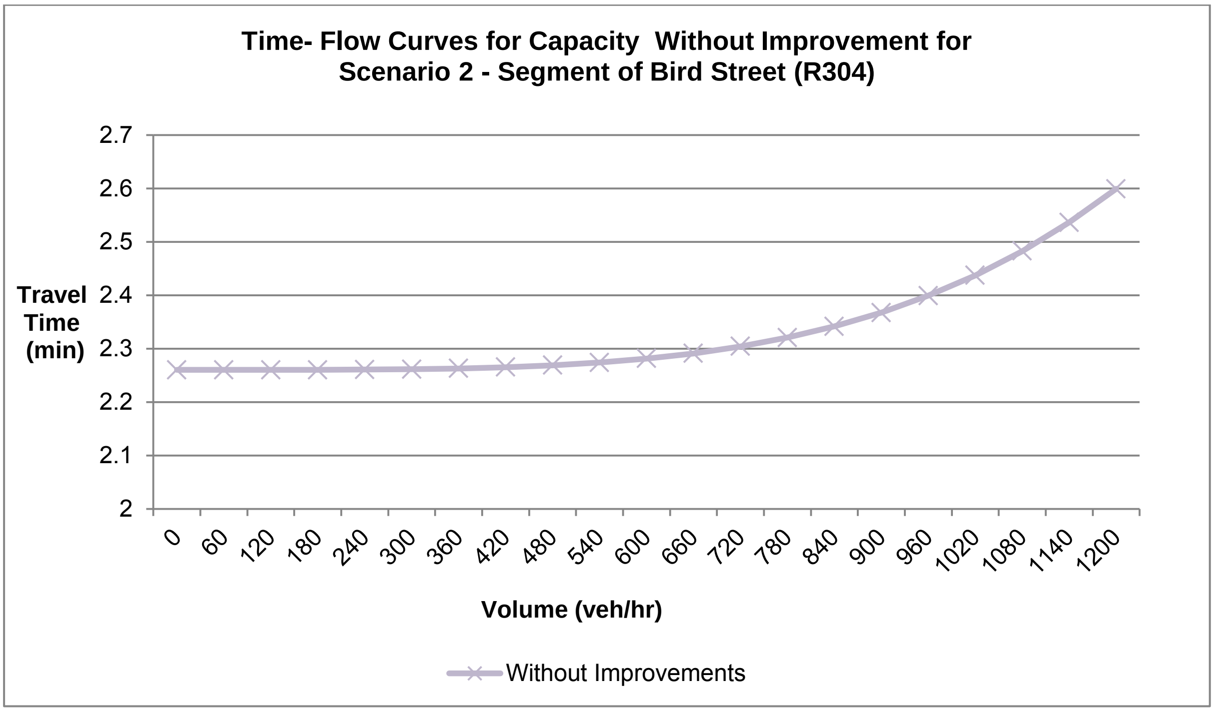



**Figure 4-24: Time-Flow Curves For Capacity without Improvement for Scenario 2 – Segment on Bird Street (R304)**

Fully actuated signal coordination is used to improve the traffic flow for intersections with a large fluctuation of traffic volume as in the case of Stellenbosch. The actuated traffic signal improved the utilisation of the lane capacity on the segment of road and allowed an increase of speed in the platoon. Figure 4-25 represents the reduction in travel time occurred on the segment of road at different level of congestion.

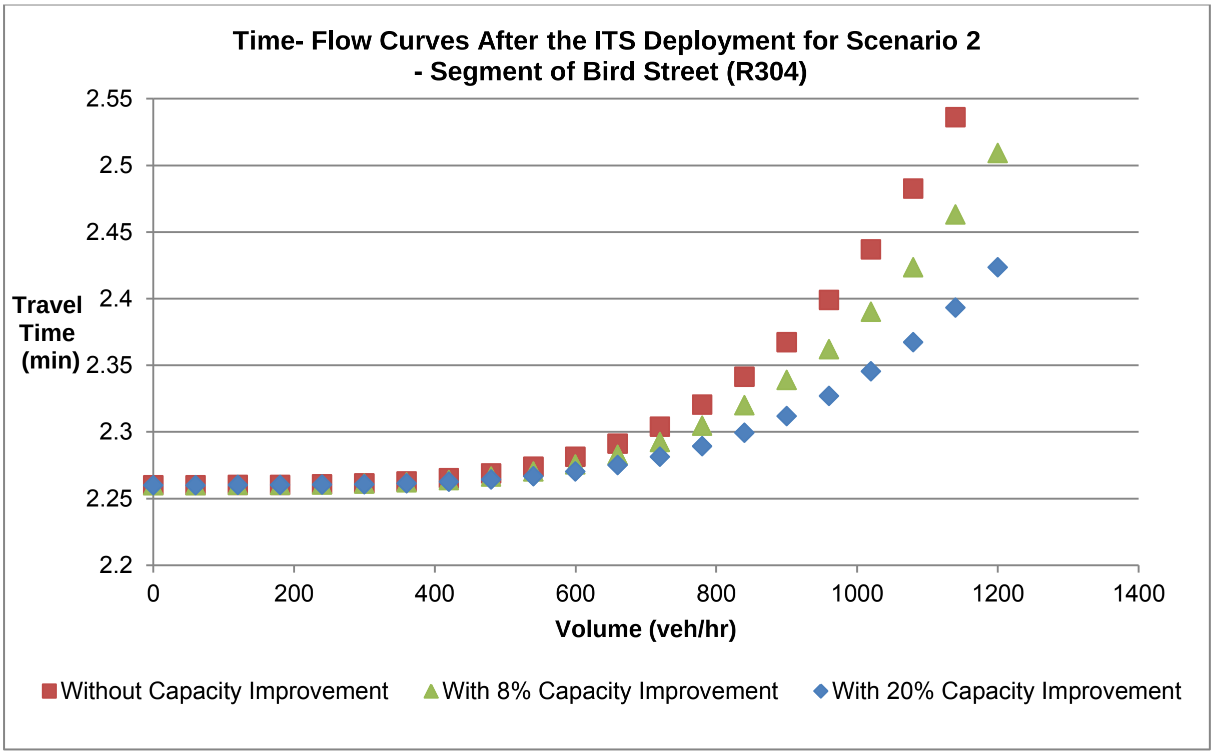



**Figure 4-25: Time-Flow Curves for Improved Capacities for Scenario 2 – Segment on Bird Street (R304)**

### Non-Recurring Time Benefits for Scenario 2 – Segment of Bird Street (R304)

As in Scenario 1 using the curve in Figure 3-6, V/C ratios are used to determine the incident delays that occurred on the segment of road at differenl levels of congestion.

Like in Scenario 1, it can be observed that the incidents delays increase with the increase of the traffic volume, therefore a great number incidents delays is more likely to occur under congested conditions.

Table 4-8 presents the influence of the V/C ratio on the incident delays occuring on the segment of Bird Street (R304).

**Table 4-8: Non-Recurring Travel Time Savings Estimate Using 20% Link Capacity Improvement for Scenario 2 – Segment of Bird Street (R304)**

| Segment Length (km) | Volume (veh/hr) | Capacity (veh/hr/ln) | V/C | Improved V/C at 20% | Incident Delay (hr/veh/km) | Incident Delay(hr) 20% (hr/veh/km) | Save in Incident Delay (hr/veh/km) |
|---|---|---|---|---|---|---|---|
| 1.7 | 0 | 1200 | 0 | 0 | 0 | 0 | 0 |
| 1.7 | 60 | 1200 | 0.05 | 0.04 | -1.10E-03 | -1.06E-03 | -4.37E-05 |
| 1.7 | 120 | 1200 | 0.1 | 0.08 | 3.53E-08 | 3.39E-08 | 1.40E-09 |
| 1.7 | 180 | 1200 | 0.15 | 0.12 | 2.58E-06 | 2.48E-06 | 1.02E-07 |
| 1.7 | 240 | 1200 | 0.2 | 0.16 | 7.99E-06 | 7.67E-06 | 3.16E-07 |
| 1.7 | 300 | 1200 | 0.25 | 0.2 | 1.92E-05 | 1.84E-05 | 7.60E-07 |
| 1.7 | 360 | 1200 | 0.3 | 0.24 | 3.93E-05 | 3.77E-05 | 1.56E-06 |
| 1.7 | 420 | 1200 | 0.35 | 0.28 | 7.20E-05 | 6.92E-05 | 2.85E-06 |
| 1.7 | 480 | 1200 | 0.4 | 0.32 | 1.22E-04 | 1.17E-04 | 4.82E-06 |
| 1.7 | 540 | 1200 | 0.45 | 0.36 | 1.93E-04 | 1.86E-04 | 7.66E-06 |
| 1.7 | 600 | 1200 | 0.5 | 0.4 | 2.93E-04 | 2.81E-04 | 1.16E-05 |
| 1.7 | 660 | 1200 | 0.55 | 0.44 | 4.26E-04 | 4.09E-04 | 1.69E-05 |
| 1.7 | 720 | 1200 | 0.6 | 0.48 | 6.00E-04 | 5.76E-04 | 2.38E-05 |
| 1.7 | 780 | 1200 | 0.65 | 0.52 | 8.25E-04 | 7.93E-04 | 3.27E-05 |
| 1.7 | 840 | 1200 | 0.7 | 0.56 | 1.12E-03 | 1.07E-03 | 4.43E-05 |
| 1.7 | 900 | 1200 | 0.75 | 0.6 | 1.51E-03 | 1.45E-03 | 5.98E-05 |
| 1.7 | 960 | 1200 | 0.8 | 0.64 | 2.09E-03 | 2.01E-03 | 8.29E-05 |
| 1.7 | 1020 | 1200 | 0.85 | 0.68 | 3.09E-03 | 2.97E-03 | 1.22E-04 |
| 1.7 | 1080 | 1200 | 0.9 | 0.72 | 5.09E-03 | 4.89E-03 | 2.02E-04 |
| 1.7 | 1140 | 1200 | 0.95 | 0.76 | 9.55E-03 | 9.17E-03 | 3.78E-04 |
| 1.7 | 1200 | 1200 | 1 | 0.8 | 1.99E-02 | 1.91E-02 | 1.53E-07 |

**Travel Time Saving Valuation**

The recurring travel time and non-recurring travel time were combined to obtain the travel times saved on the segment of the road under different level of congestion. Figure 4-26 illustrates the differences in travel times before and after the deployment of the ITS deployment.

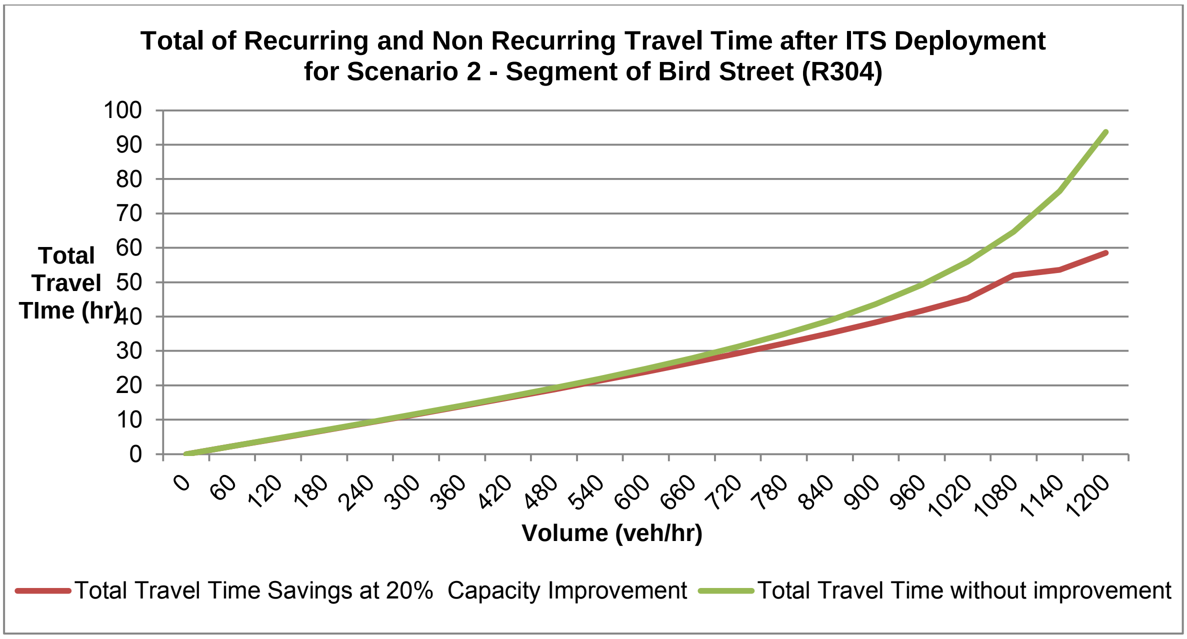



**Figure 4-26: Total Recurring and Non-Recurring Travel Time After ITS Deployment for Scenario 2 - Segment of Bird Street (R304)**

Using a discount rate of 10%, the annual monetised travel time savings benefits resulting from the actuated traffic signal deployment can be expressed as follow in Figure 4-27.

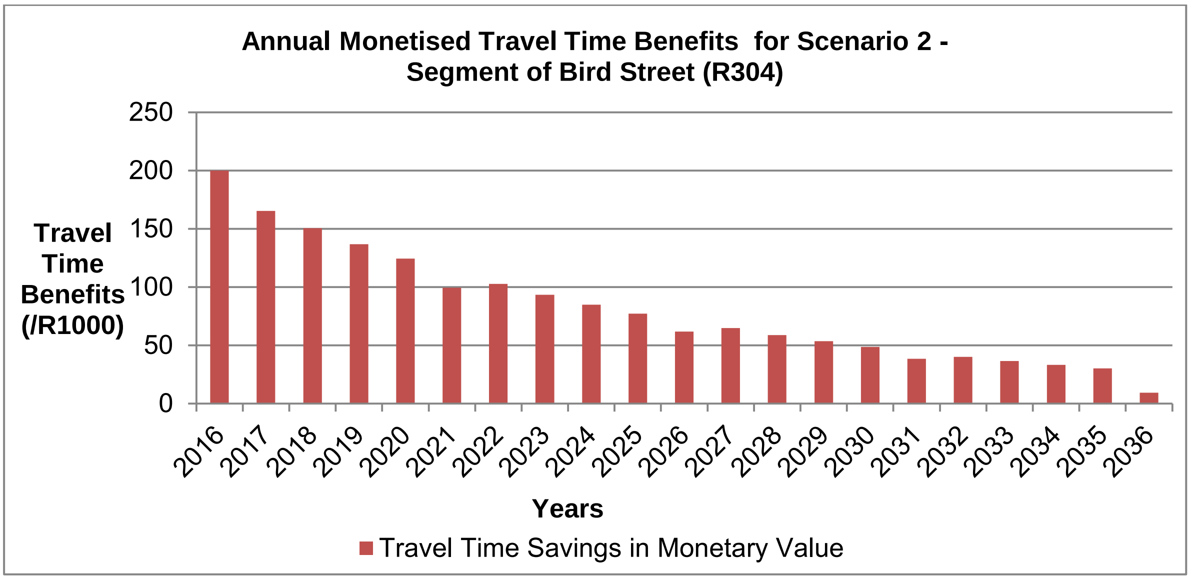



**Figure 4-27: Annual Monetised Travel Time Benefits for Scenario 2 - Segment of Bird Street (R304)**

The Travel Time Benefits for Scenario 2, which is the segment of Bird Road (R304), is calculated as R 165,410.00 in 2017 and R 1,508,514.00 after the 20 years.

### *4.2.2.3. Energy Benefits*

A projected traffic volume was determined to estimate the benefits provided by the Actuated traffic signal over the lifetime. The vehicle type distribution was estimated over the 20 years' time horizon. Figure 4-28 illustrates the forecasted vehicle distribution for the 20 year period considered.

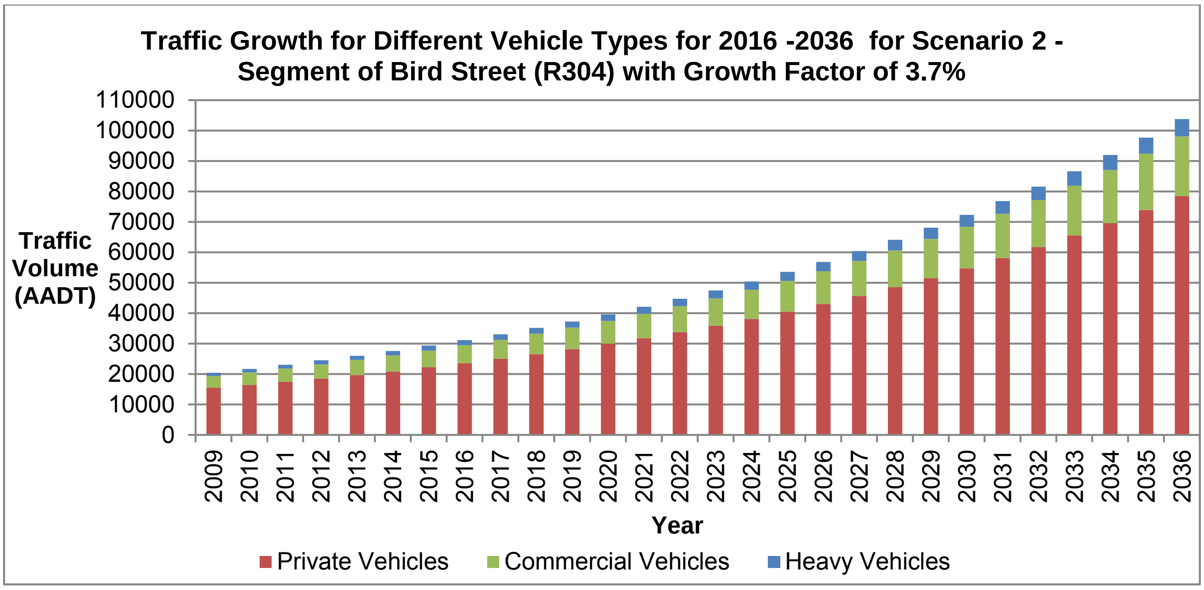



**Figure 4-28: Traffic Growth for Different Vehicle Types for 2016 to 2036 for Scenario 2 - Segment of Bird Street (R304)**

**Vehicle Consumption Distribution**

Fuel consumption on the segment increases with the level of congestion. There is greater fuel consumption under congested conditions than under uncongested conditions. The vehicles stranded in the platoon (queue) experience a high fuel consumption while idling under congested conditions.

Figure 4-29 illustrates the typical trend of fuel consumption of the different types of vehicles on the segment of the road before the actuated traffic signal deployment.

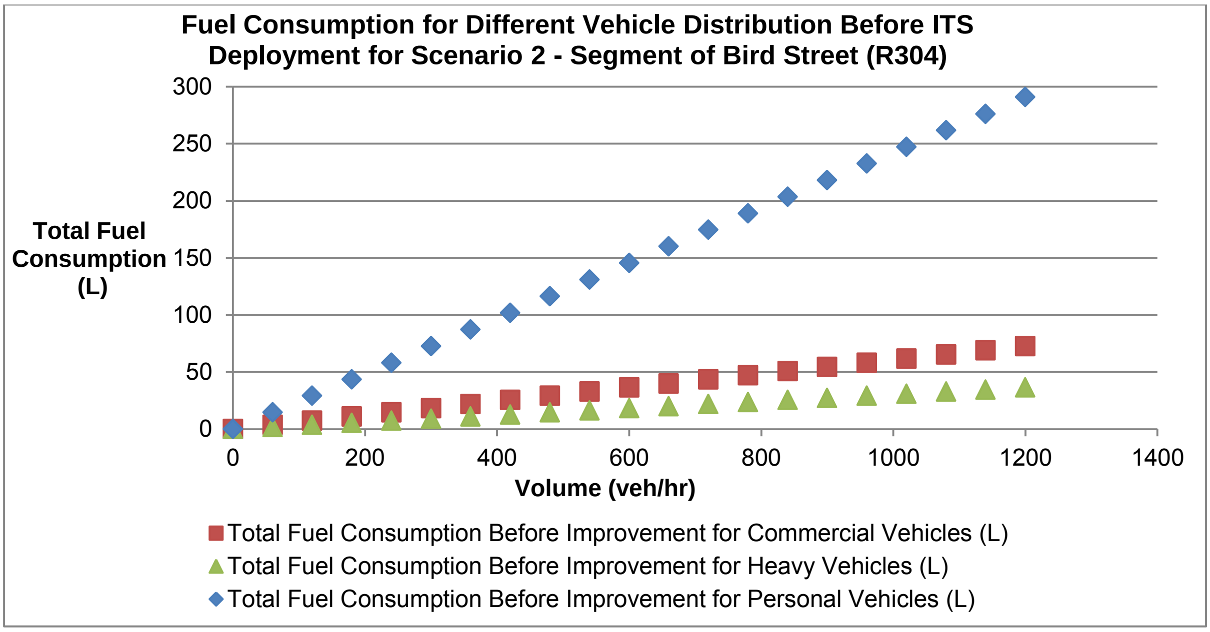



**Figure 4-29: Fuel Consumption for Different Vehicle Distribution Before the ITS Deployment on Scenario 2 – Segment of Bird Street (R304)**

The actuated traffic signal increased the mobility on the road segment and reduced the fuel consumption. The increase of the speed enabled the vehicles to traverse the segment faster under congested conditions than prior to the deployment.

The idling consumption reduced on the segment because the time spent in the queue on the road segment was also reduced.

Figure 4-30 illustrates the improvement of the fuel consumption under-saturated (congested) conditions.

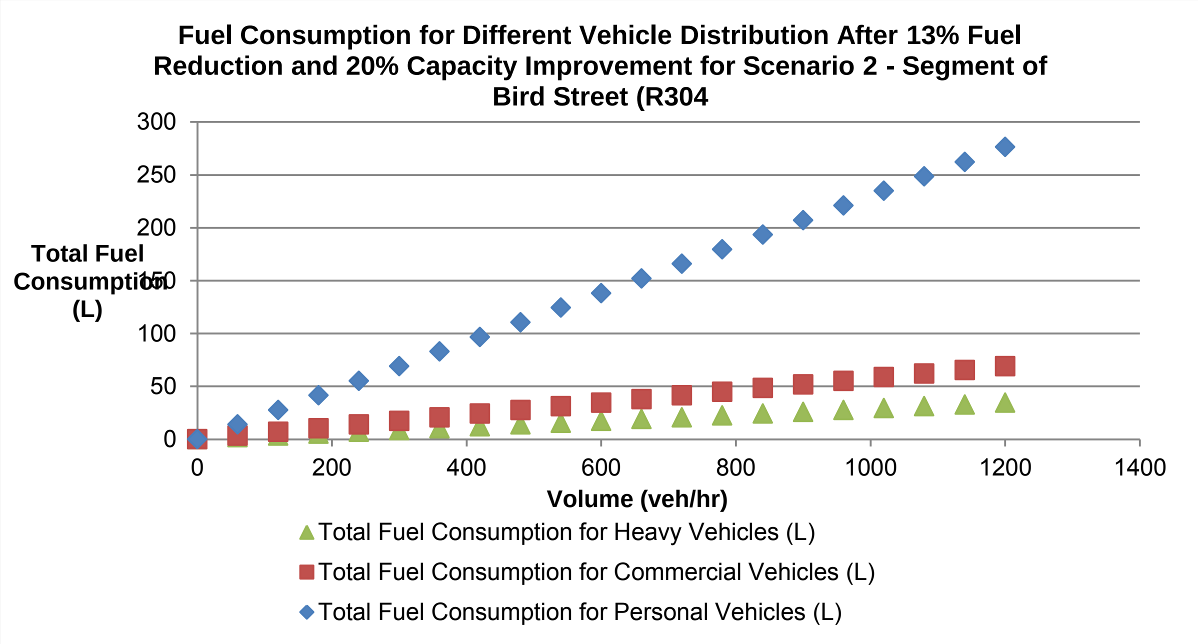



**Figure 4-30: Fuel Consumption for Different Vehicle Distribution After 13% Capacity Improvement for Scenario 2 – Segment of Bird Street (R304)**

However, as the fuel consumption is directly linked to the traffic traversing the segment it can be noted that a greater fuel consumption saving was experienced on the multilane in Scenario 1 than for the single undivided lane in Scenario 2. The fuel saving resulted from the number of VMTs applied on the segment of road, as the volume increases, the number of VMTs increases as well as the fuel saved. Figure 4-31 and Figure 4-32 illustrate the fuel saving on the segment of the road under different level of congest for the different type of vehicles.

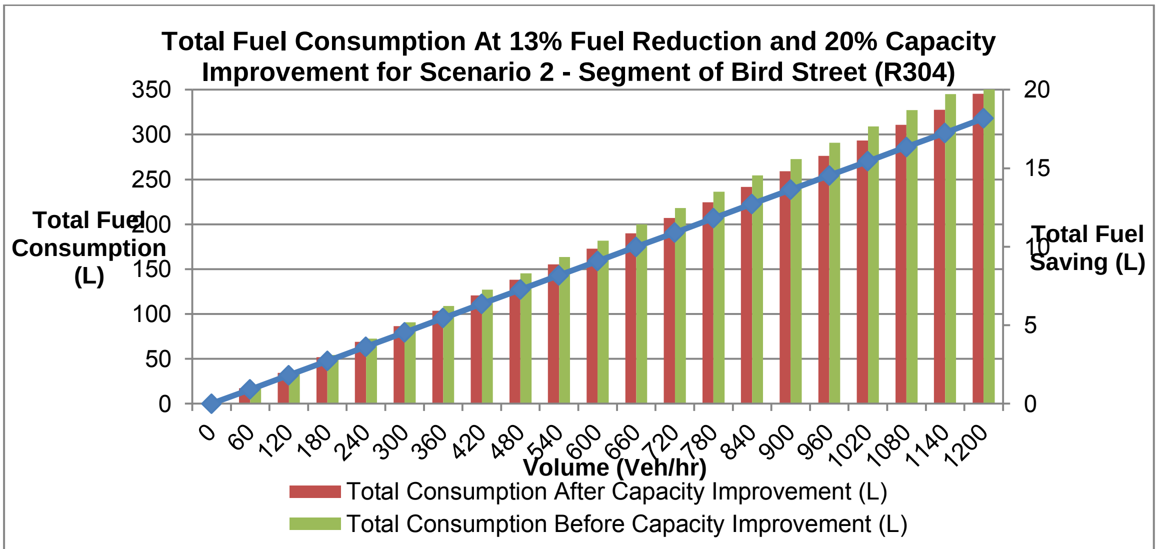



**Figure 4-31: Total Fuel Consumption Saving After Capacity Improvement for Scenario 2 - Segment of Bird Street (R304)**

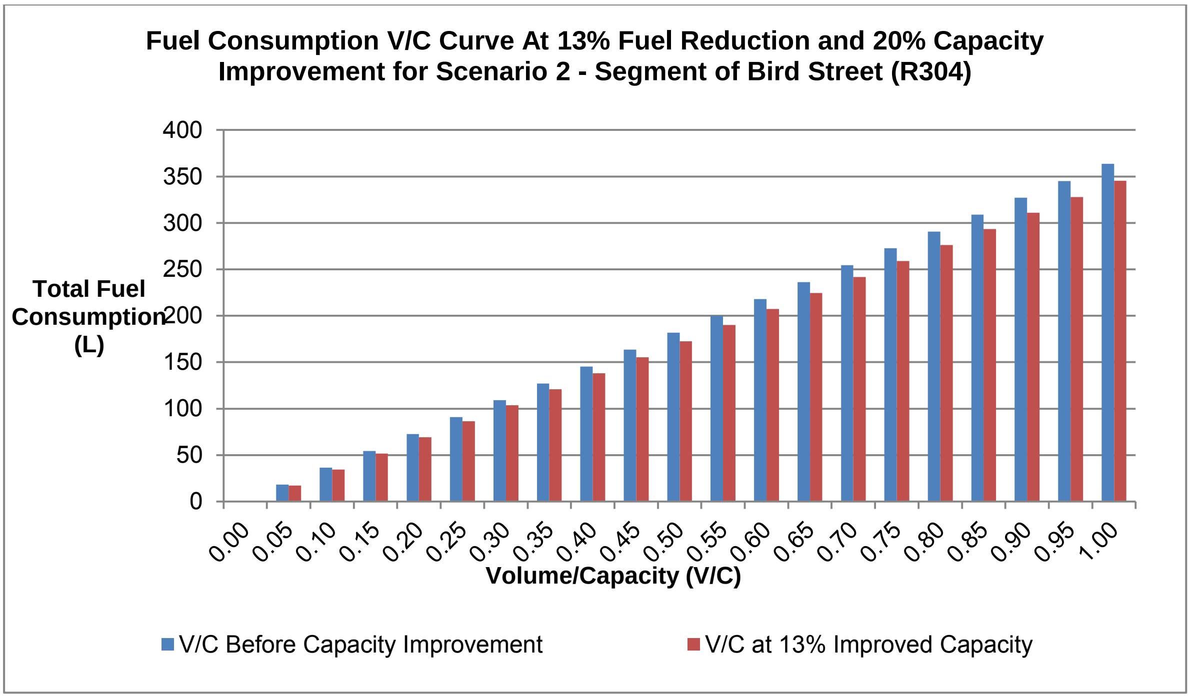



**Figure 4-32: Fuel Consumption V/C Curve After Capacity Improvement for Scenario 2 – Segment of Bird Street (R304)**

The annual monetised fuel saving benefits resulting from the actuated traffic Signal deployment was estimated as follows in Figure 4-33.

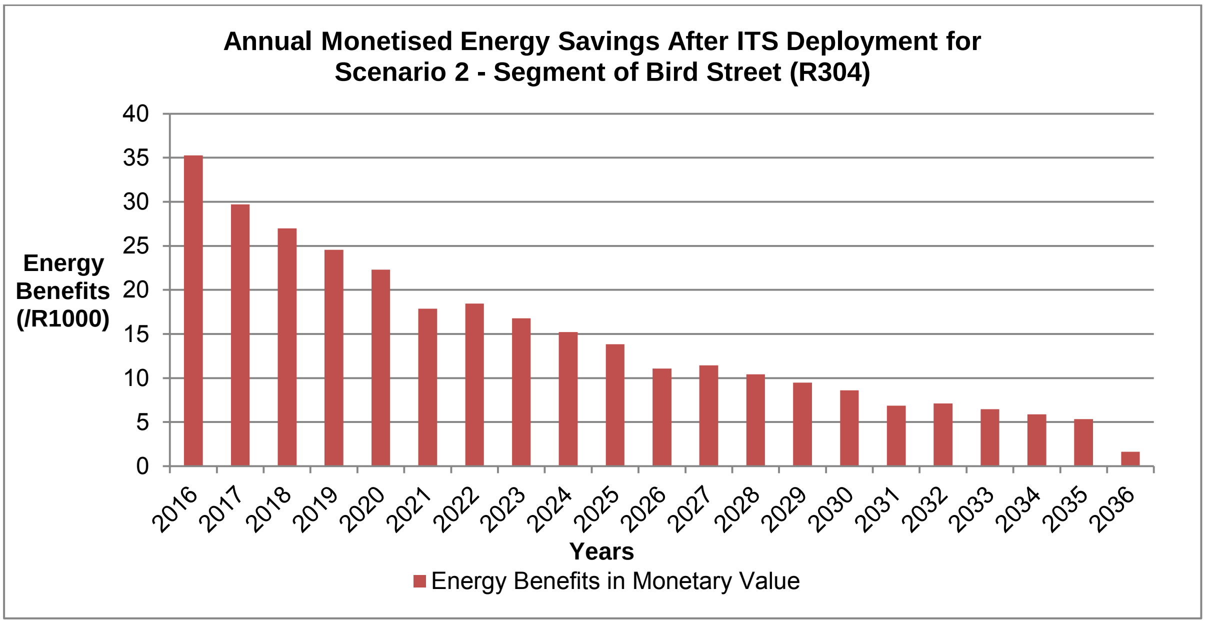



**Figure 4-33: Annual Monetised Energy Savings for Scenario 2 – Segment of Bird Street (R304)**

The Energy Benefits for Scenario 2, the segment of Bird Street (R304) is calculated as R 29,694.00 in 2017 and a total of R 269,962.00 after the 20 years.

### *4.2.2.4. Safety Benefits*

The safety benefits are derived from the applied VKTs in crash occurrence and benefits are express in Crash per million of VKT. This shows how the traffic volume influences the change in the segment under analysis. A greater traffic volume travelling on the segment will give rise to higher possibility collisions. During congested conditions, the drivers have limited possibility of manoeuvres. Figure 4-34 illustrates the typical trend of crash occurrence on the road segment before the deployment of the ITS.

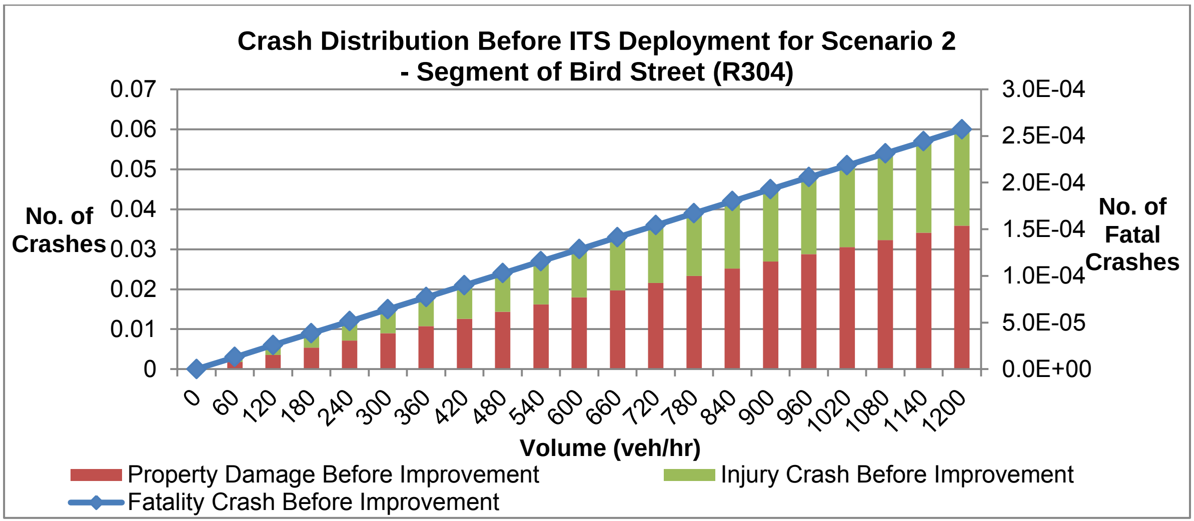



**Figure 4-34: Crash Distribution Before the ITS Deployment for Scenario 2- Segment of Bird Street (R304)**

Similar trend to Scenario 1 is observed for Scenario 2. Figure 4-35 and Figure 4-36 represent the typical trend of crash improvements at differents levels of congestion, using 7% crash reduction rate.

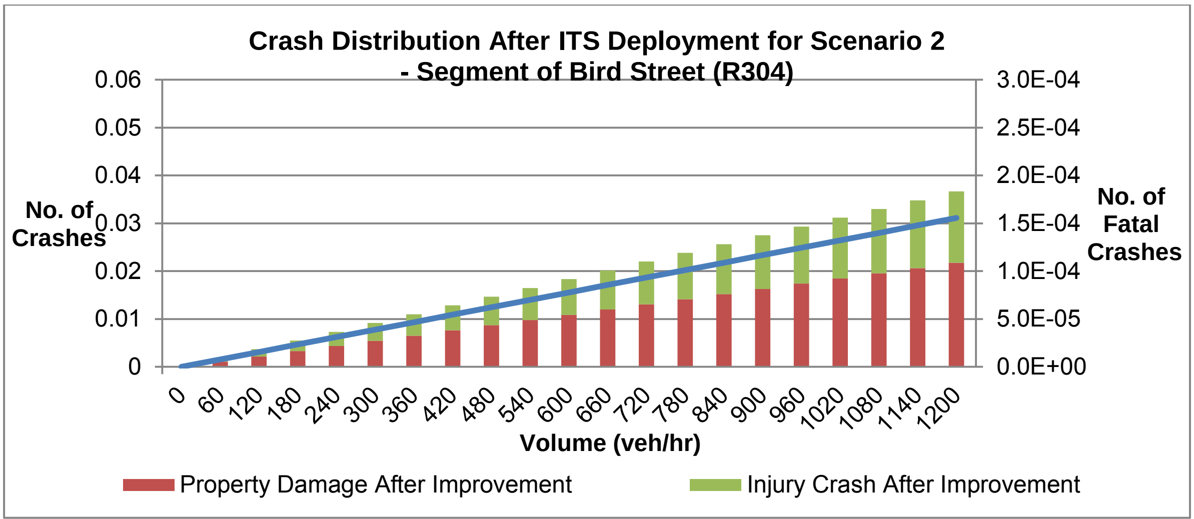



**Figure 4-35: Crash Distribution After the ITS Deployment for Scenario 2- Segment of Bird Street (R304)**

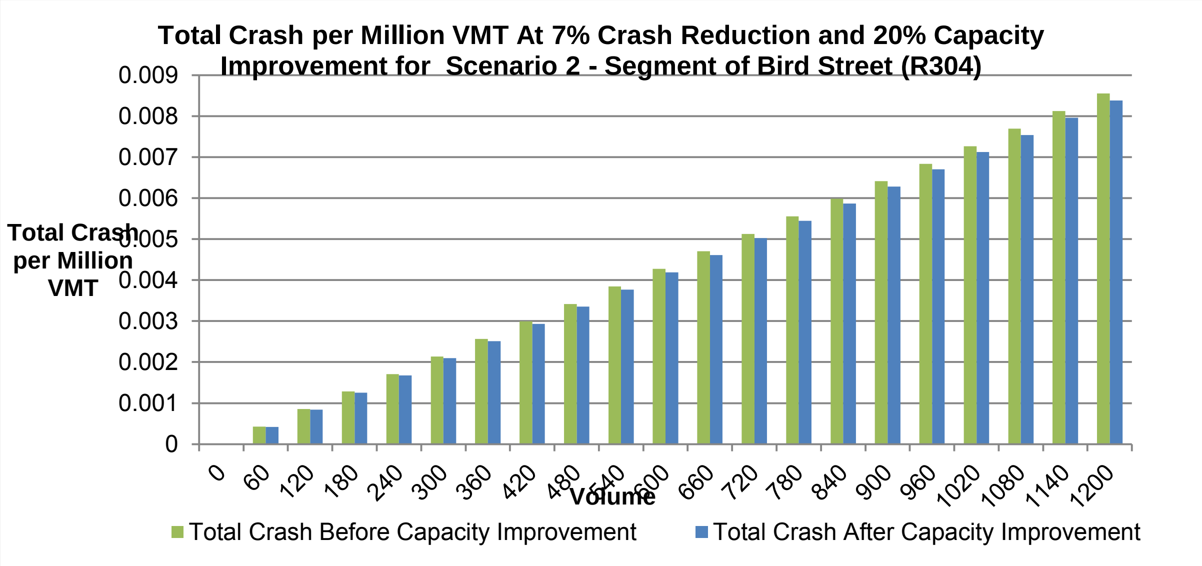



**Figure 4-36: Total Crashes per Million VMT After 20% Capacity Improvement for Scenario 2 – Segment of Bird Street (R304)**

The annual monetised safety benefit using a discount rate of 10% resulting from the actuated traffic signal deployment was estimated as follow in Figure 4-37.

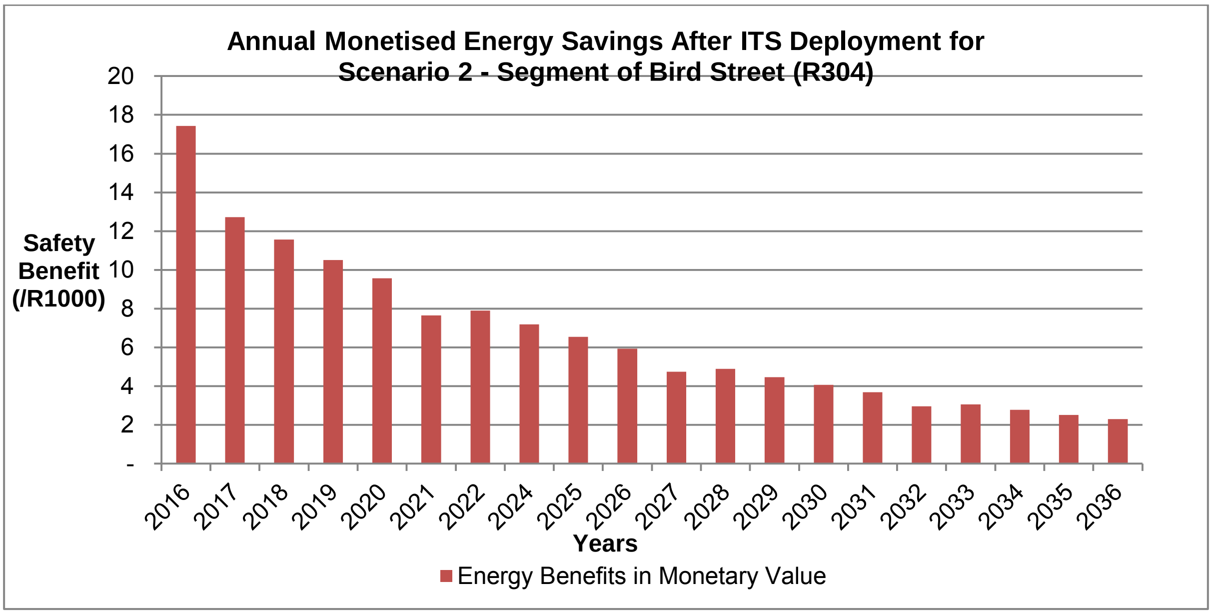



**Figure 4-37: Annual Monetised Energy Savings for Scenario 2 - Segment of Bird Street (R304)**

The Safety Benefits for Scenario 2, which is the segment of Bird Street (R304) is calculated as R 12,726.00 in 2017 and a total of R 115,010.00 after the 20 years.

#### *4.2.2.5. B/C Ratio*

The B/C ratio of Scenario 2 of Actuated Traffic Signal Coordination if approximately 9.2.

## 4.3. Parking Management System

The benefits of the proposed Parking Management System (PMS) for Stellenbosch are directly linked to the facility utilisation. The traffic volume utilising the facility allows for the estimation of the benefits of the deployed strategy. The strategy mostly influences the travel time of the motorists, since they avoid the long search of available parking when parking information is displayed on Variable Message Sign Boards. When the traffic volume passing through the system increases, the percentage of the drivers acting on the information will increase as well and similarly the travel time benefits.

### 4.3.1. Scenario 1: Divided Arterial Lanes – Adam Tas Street

#### *4.3.1.1. Life Cycle Cost Analysis*

The following breakdown of the life cycle costs for the parking management system for Scenario 1 – Adam Tas Street can be seen in Table 4-9.

**Table 4-9: Breakdown of Life Cycle Costs Analysis for Stellenbosch Parking Management System (Per Installation)**

| Estimated Life Cycle Costs of Parking Management System for Stellenbosch | | | | |
|---|---|---|---|---|
| Equipment | Useful Life (Yrs) | Total Capital / Replacement Costs ( R ) | Annual O&M Costs ( R ) | Total Annual Costs ( R ) |
| Basic Infrastructure Equipment | | | | |
| TMC Hardware for Information Dissemination | 5 | 22,400.00 | 1,120.00 | 5,600.00 |
| TMC Software for Information Dissemination | 5 | 45,000.00 | 2,250.00 | 11,250.00 |
| TOTAL Infrastructure Cost | | 67,400.00 | 3,370.00 | 16,850.00 |
| Incremental Deployment Equipment (Per Sign Location) | | | | |
| Communication Line | 25 | 7,000.00 | 8400.00 | 8,860.00 |
| Variable Message Sign | 25 | 25,494.00 | 7,000.00 | 8,020.00 |
| Variable Message Sign Tower | 25 | 28,000.00 | 0.00 | 1,120.00 |
| Entrance/Exit Ramp Meters | 10 | 1,000.00 | 1,680.00 | 1,780.00 |
| Tag Readers | 10 | 1,000.00 | 1,680.00 | 1,780.00 |
| Database and Software for Billing & Pricing | 10 | 75,000.00 | 14,350.00 | 21,850.00 |
| Parking Monitoring System | 10 | 45,000.00 | 0.00 | 4,500.00 |
| TOTAL Incremental Cost | | 182,494.00 | 33,110.00 | 47,730.00 |
| Number of Infrastructure Deployments | 1 | | | 16,850.00 |
| Number of Incremental Deployments | 1 | | | 47,730.00 |
| Year of Deployment | 2016 | | | |
| Average Annual Cost | | | | 64,579.76 |

Figure 4-38 displays the lifecycle costs framework of a traffic actuated for 20 years life time horizon per installation for B/C analysis, for Scenario 1 – Adam Tas Street.

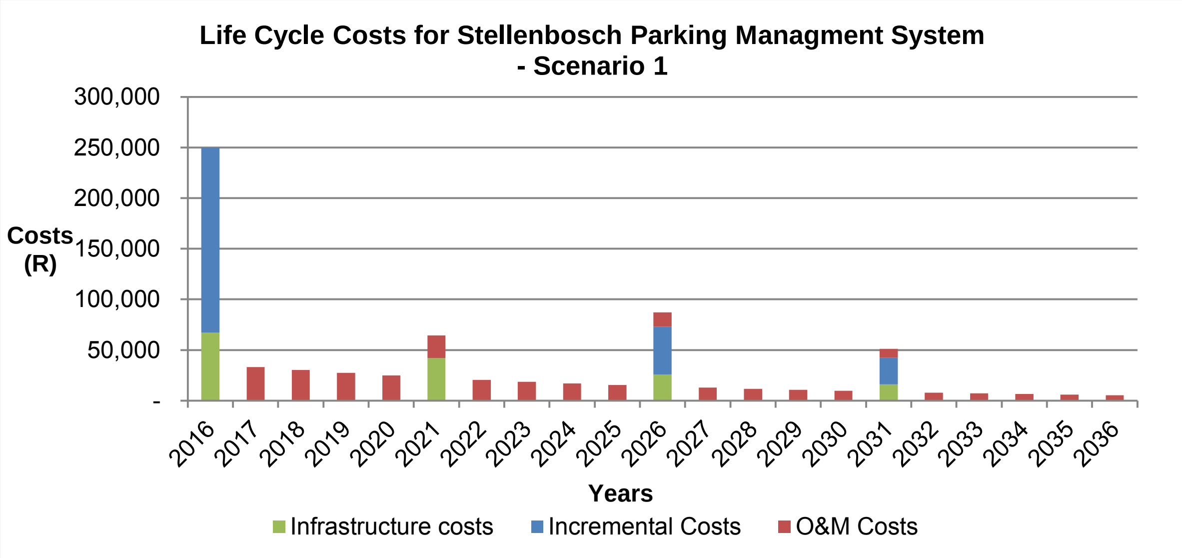



**Figure 4-38: Life Cycle Cost Analysis for Parking Management System for Stellenbosch – Scenario 1**

Table 4-10 presents the various life cycle costs and the resultant Present Worth Cost for the Parking Management System along Adam Tas Road.

**Table 4-10: Breakdown of Life Cycle Costs of Parking Management System - Scenario 1 – Adam Tas Road**

| Year | Infrastructure Costs ( R ) | Incremental Costs ( R ) | O&M Costs ( R ) | Total Costs ( R ) |
|---|---|---|---|---|
| 2016 | 67 400.00 | 182 494.00 | | 249 894.00 |
| 2017 | | | 33 164.00 | 33 164.00 |
| 2018 | | | 30 149.00 | 30 149.00 |
| 2019 | | | 27 408.00 | 27 408.00 |
| 2020 | | | 24 916.00 | 24 916.00 |
| 2021 | 41 850.00 | | 22 651.00 | 64 501.00 |
| 2022 | | | 20 592.00 | 20 592.00 |
| 2023 | | | 18 720.00 | 18 720.00 |
| 2024 | | | 17 018.00 | 17 018.00 |
| 2025 | | | 15 471.00 | 15 471.00 |
| 2026 | 25 986.00 | 47 036.00 | 14 065.00 | 87 087.00 |
| 2027 | | | 12 786.00 | 12 786.00 |
| 2028 | | | 11 624.00 | 11 624.00 |
| 2029 | | | 10 567.00 | 10 567.00 |
| 2030 | | | 9 606.00 | 9 606.00 |
| 2031 | 16 135.00 | 26 142.00 | 8 733.00 | 51 010.00 |
| 2032 | | | 7 939.00 | 7 939.00 |
| 2033 | | | 7 217.00 | 7 217.00 |
| 2034 | | | 6 561.00 | 6 561.00 |
| 2035 | | | 5 965.00 | 5 965.00 |
| 2036 | | | 5 423.00 | 5 423.00 |
| **Present Worth Costs ( R )** | | | | **717 618.00** |

The total monetised value of the life cycle cost analysis amounts to R717,681.00 as indicated in the Table 4-10. This is a new system the infrastructure cost of base year 2016 is included from the analysis.

#### *4.3.1.2. Travel Time Benefits*

The benefits provided by the PMS are composed solely of the travel time saved by the drivers who are using the guidance of the information on parking availability that is disseminated by the Variable Message Sign (VMS) 1.

Figure 4-39 represents the directional average travel time saved by motorists using the guidance from the PMS of Scenario 1, which is the divided arterial lane along Adams Tas Road.

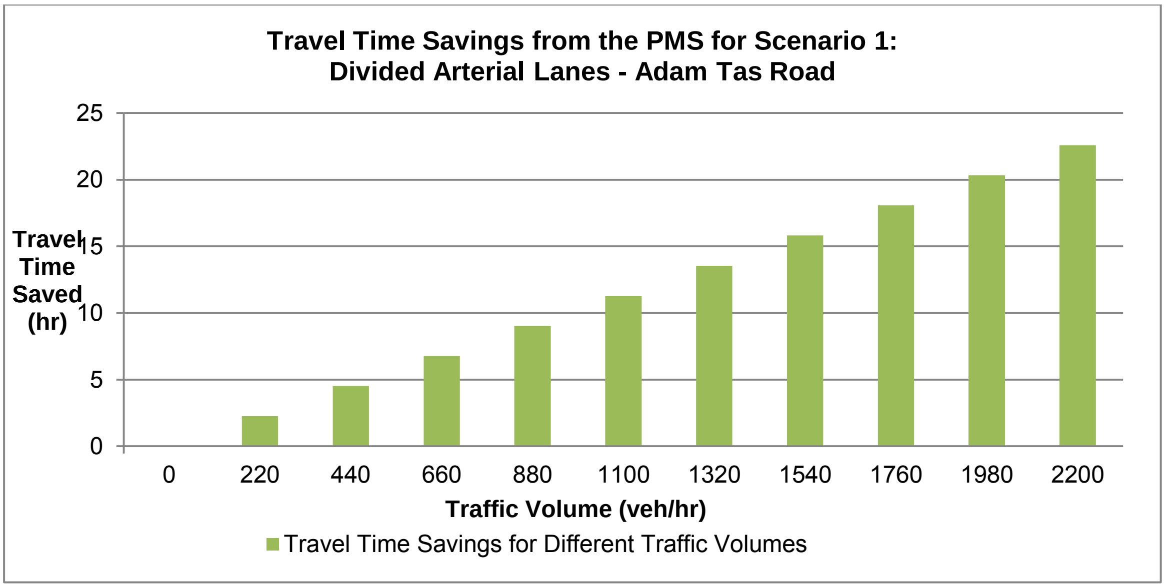



**Figure 4-39: Travel Time Savings for Divided Arterial Lanes - Adam Tas Street**

The traffic from Strand Road (R44) and Polkadraai Road converge on Adam Tas Road toward VMS1. Using the projected DDHV for 2016 from Table 3-6 for the segment of Strand Road (R44) where the VMS1 is located, the travel time benefits were obtained from the assumed 28% of drivers.

The DDHV of the heavy vehicles were ignored and solely the DDHV of the private vehicle were used in the calculation taking into account the assumption that 20% of private vehicles are commercial vehicles.

Figure 4-40 and Figure 4-41 illustrate the typical range of daily and annual monetised travel time savings during the peaks hours for the traffic volume passing by the PMS on Adams Tas Road. The daily and annual monetised travel times are based on the assumption that two-thirds of the traffic volume on Adam Tas Road is travelling in one direction (Northbound) and that the VMS disseminate information that is useful.

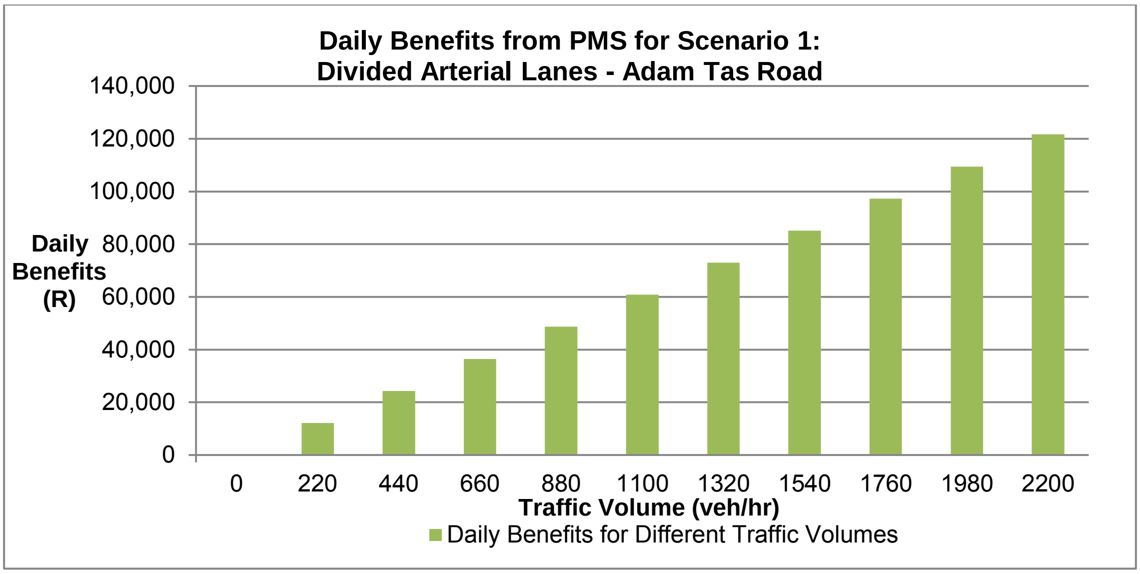



**Figure 4-40: Daily Benefits for PMS - Divided Arterial Lanes - Adam Tas Street**

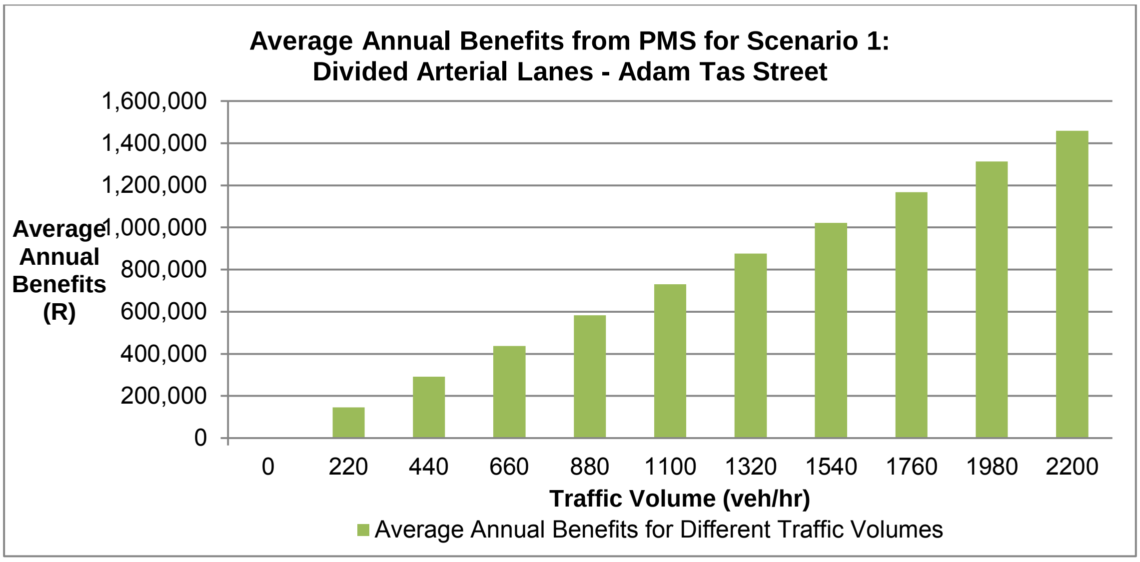



**Figure 4-41: Average Annual Benefits for PMS – Divided Arterial Lanes - Adam Tas Street**

Data was collected during two hours respectively between 7h30 to 8h30 and 12h30 to13h30. Taking into account that South Africa has 237 working days (minus public holidays and weekends), the annual monetised travel time can be expressed as follow in Figure 4-42.

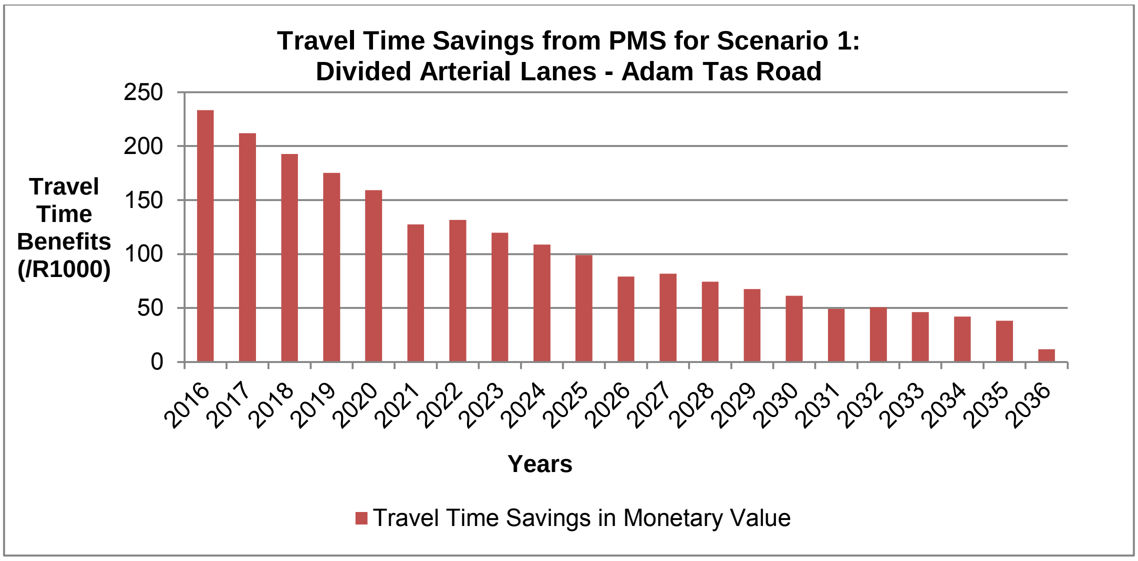



**Figure 4-42: Annual Monetised Travel Benefits for Scenario 1 - Divided Arterial Lanes - Adam Tas Street**

Figure 4-42 above represents the average forecasted annual monetised benefits obtained from the deployment of VMS 1 on Adam Tas Street for parking guidance of the vehicles coming from Strand, Somerset West on the Strand Road (R44) and the vehicles coming from the R310 (Bellville, Kuilsriver, Brackenfell and Eersteriver).

The Present Worth Benefits for the Travel Time Benefits for Scenario 1, which is along Adam Tas Street is calculated as R 212,058.00 for 2017 and a total of R 1,928,080.00 after the 20 years. The B/C Ratio for Scenario 1 is approximately 2.6

##### *4.3.1.3. B/C Ratio of Scenario 1 of PMS*

The B/C ratio of Scenario 1 of the Parking Management System is approximately 2.6.

#### 4.3.2. Scenario 2: Undivided Arterial Lanes – Bird Street

The second VMS as part of the Parking Management Systems Strategy analysed during the research was VMS 3. Conversely, to Scenario 1 where the VMS was deployed on a divided arterial road on Adam Tas Street, VMS 3 is deployed on an undivided lane on Bird Street.

##### *4.3.2.1. Life Cycle Cost Analysis*

The life cycle cost for Scenario 2, which is the undivided arterial lane along Bird Street, will be the same as that for Scenario 1 – Divided Arterial Lanes along Adam Tas Road.

### *4.3.2.2. Travel Time Benefits*

Figure 4-43 present the travel time savings after the PMS for Scenario 2, which is the undivided arterial lane along Bird Street and indicate that the variability of traffic demand influences the travel time savings as a result of the PMS under different levels of congestion.

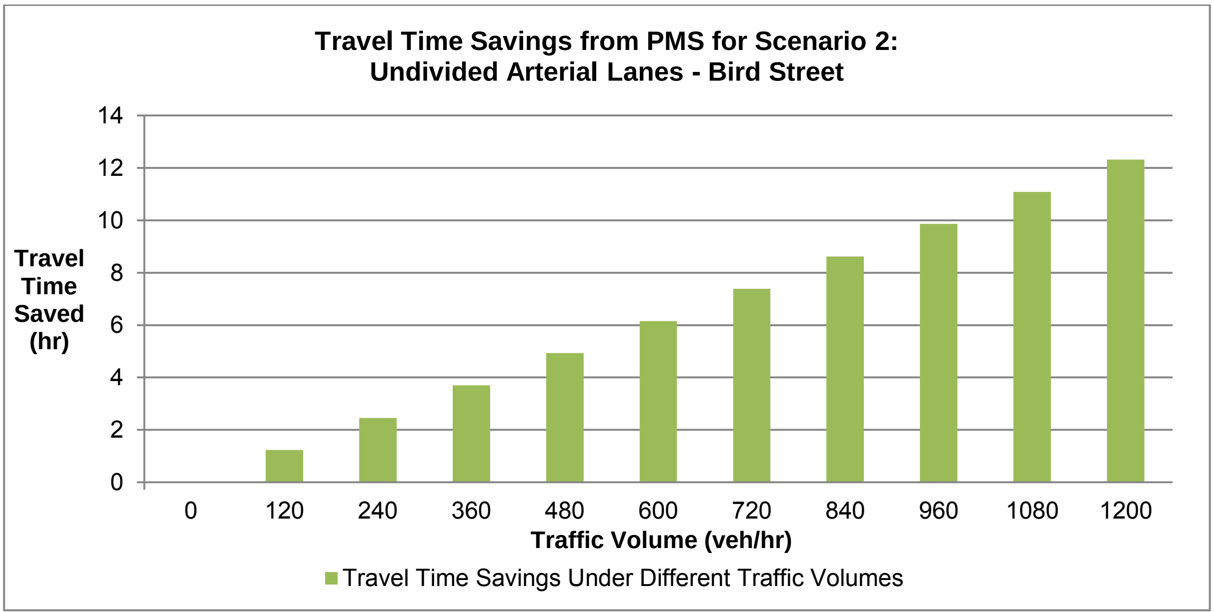



**Figure 4-43: Travel Time Savings for Undivided Arterial Lanes - Bird Street**

Similarly to Scenario 1, Figure 4-44 and Figure 4-45 illustrate the typical range of daily and annual monetised travel time savings obtained during the peaks hours for the traffic volume passing by the PMS on Bird Street. This is also based on the assumption that two-thirds of the traffic volume on Bird Street is travelling in one direction (Southbound) and the VMS disseminate useful information to 20% of drivers and they save.

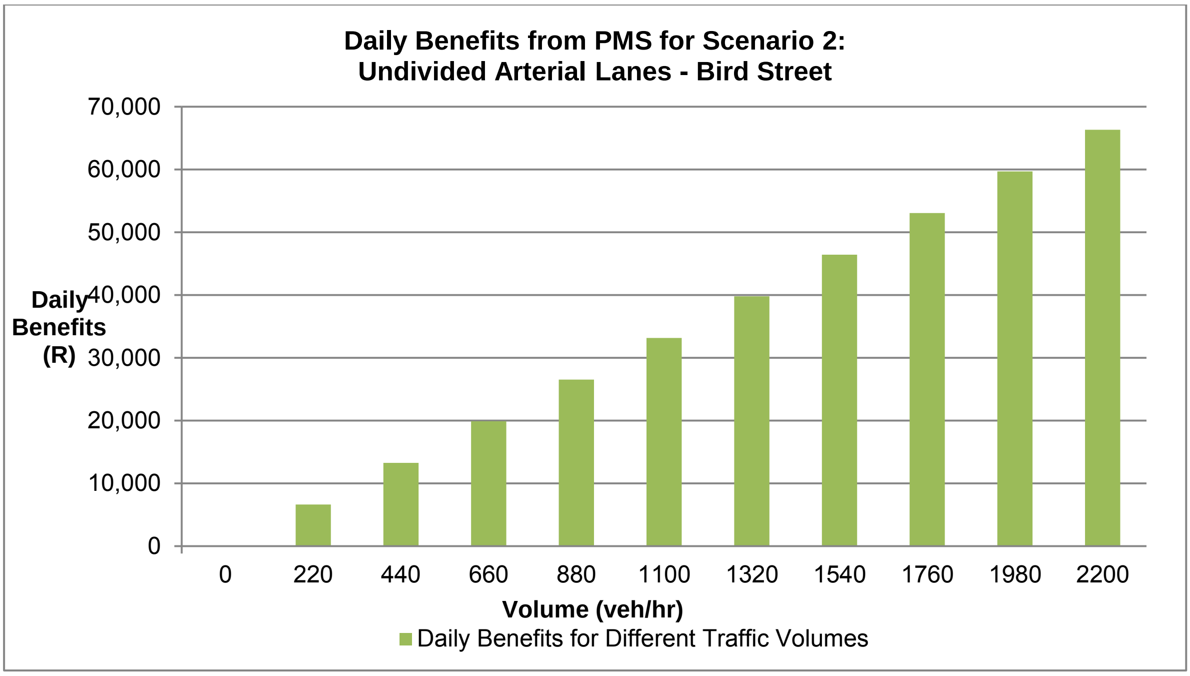



**Figure 4-44: Daily Benefits for Undivided Arterial Lanes – Bird Street**

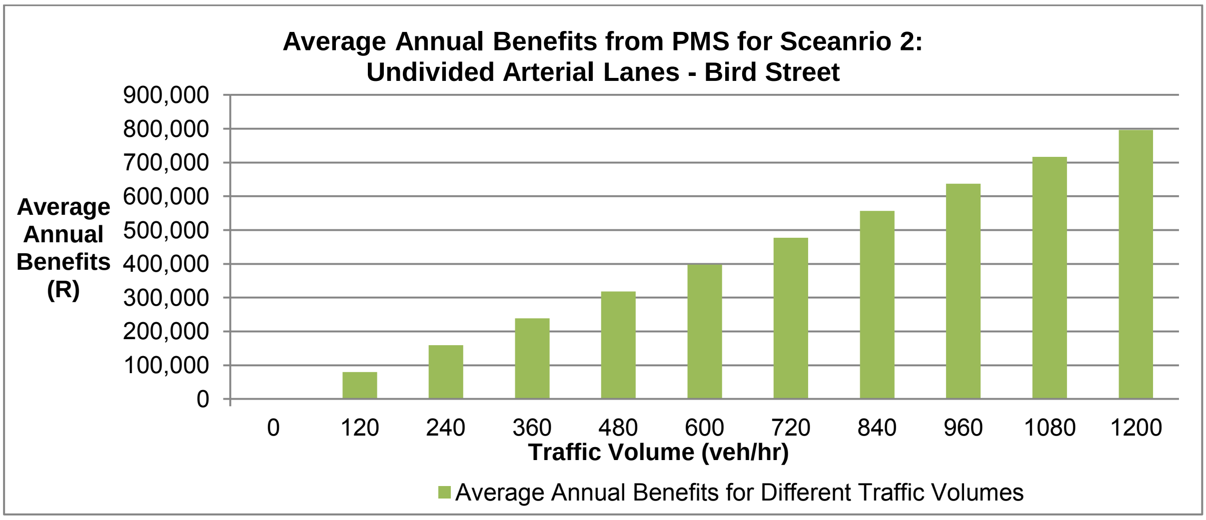



**Figure 4-45: Average Annual Benefits for Undivided Arterial Lanes - Bird Street**

The traffic volume from the R304 and the traffic volume from Paarl (Cloetesville) via Adam Tas (R44) converge on Bird Street towards the VMS3 where the parking management system is deployed. Using the projected DDHV for 2016 obtained in Table 3-13 for the segment of Bird Street where VMS3 is located, the travel time benefits were obtained from the assumed 28% of drivers. The DDHV of the heavy vehicles were ignored and solely the DDHV of the private vehicle were used in the calculation taking into account the assumption that 20%of private vehicles are commercial vehicle.

During the hours of observation parking management, the data were collected during two hours respectively between 7h30 to 8h30 and 12h30 to13h30. Taking into account that South Africa has 237 working day (minus public holidays and weekends), the annual monetised travel time is expressed as follow in Figure 4-46.

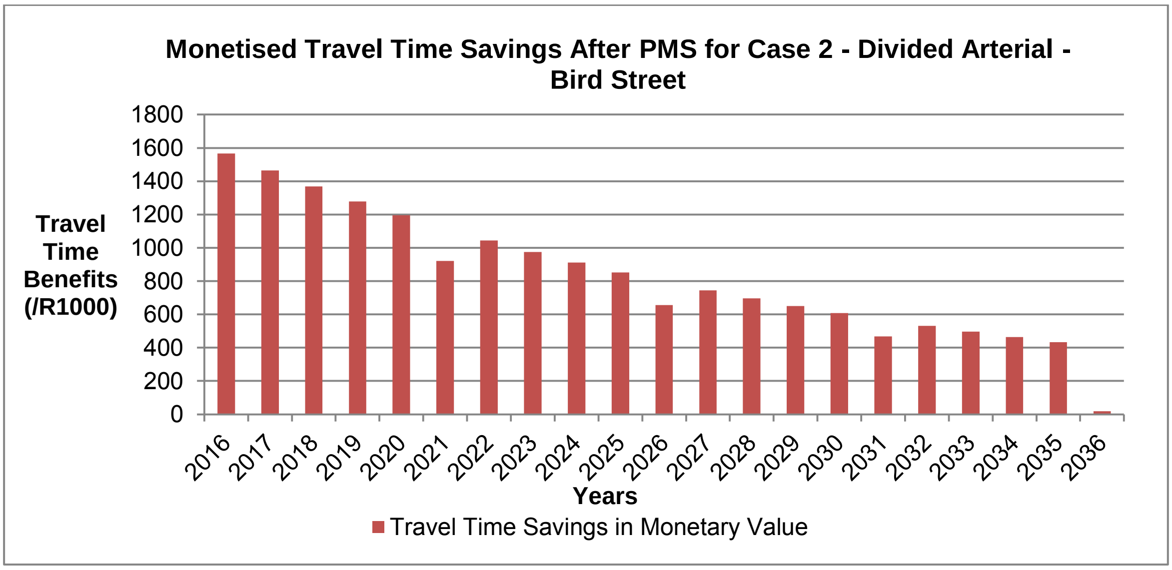



**Figure 4-46: Annual Monetised Travel Benefits for Case 2 - Undivided Arterial Lanes - Bird Street**

The Present Worth Benefits for the Travel Time Benefits for Scenario 2, which is along Bird Street is calculated as R 115,164.00 for 2017 and a total of R 1,078,574.00 after the 20 years.

#### *4.3.2.3. B/C Ratio of Scenario 2 of PMS*

The B/C Ratio for Scenario 2 of the PMS is approximately 1.6.

## 4.4. Alternative 3: Stellenbosch Western Bypass

### 4.4.1. Life Cycle Costs Analysis

This research estimated the life cycle costs of the proposed Western Bypass over a 20 year period, by carrying out a preliminary construction cost estimate. The cost estimate included only the costs of construction of the pavement layers required to carry the anticipated traffic on the Western Bypass. The costs of surveying, designing and construction supervision were therefore excluded from the life cycle cost analysis as seen in Table 4-11.

**Table 4-11: Life Cycle Costs Analysis of Stellenbosch Western Scenic Bypass**

| Pavement Structure | Unit Cost/m³ (2016) | Initial Costs/m² | Maintenance | Initial Costs/m² | Discounted Maintenance |
|---|---|---|---|---|---|
| | | | | | **10%** |
| 50mm Asphalt | - | 400.00 | 30mm Asphalt (11 yrs) | 350.00 | 315.00 |
| 150mm G1 | 300 | 45.00 | 35mm Asphalt (20 yrs) | 375.00 | 337.50 |
| 300mm C3 | 200 | 60.00 | | | **652.50** |
| | | **505.00** | | | |
| **Present Worth of Costs/m²** | | | | | **1157.50** |
| **Present Worth of Costs/1 000 000 ( R )** | | | | | **252.68** |

The 16.8km bypass will have extensive earthworks, drainage and atleast four major intersections. The PWOC of the bypass will be in excess of the PWOC reported in Table 4-11. Assuming a current rate of R 30 million/km, this thesis estimates that the bypass will cost approximately R 354 million.

### 4.4.2. Travel Time Benefits

Since there is reduction of the traffic on the Stellenbosch arterial during the peak hours, mobility had drastically improved as well as the vehicles speed. Drivers are able to manoeuvre freely with lower accident risk. The total travel time saved is the sum of the travel time saved by each driver using the arterial system. Figure represents the monetised travel time benefits during the peak hours from the Arterial system after construction of the Stellenbosch Western Bypass.

Figure 4-47 presents the influence of the Western Bypass on the Stellenbosch Arterial Network. The monetised travel time benefits (R 1,897,168.00) are lower than the travel time benefits produced by the arterial management system (R 5,725,888.00 for Scenario 1 but higher than that of Scenario 1 (R 1,508,514.00).

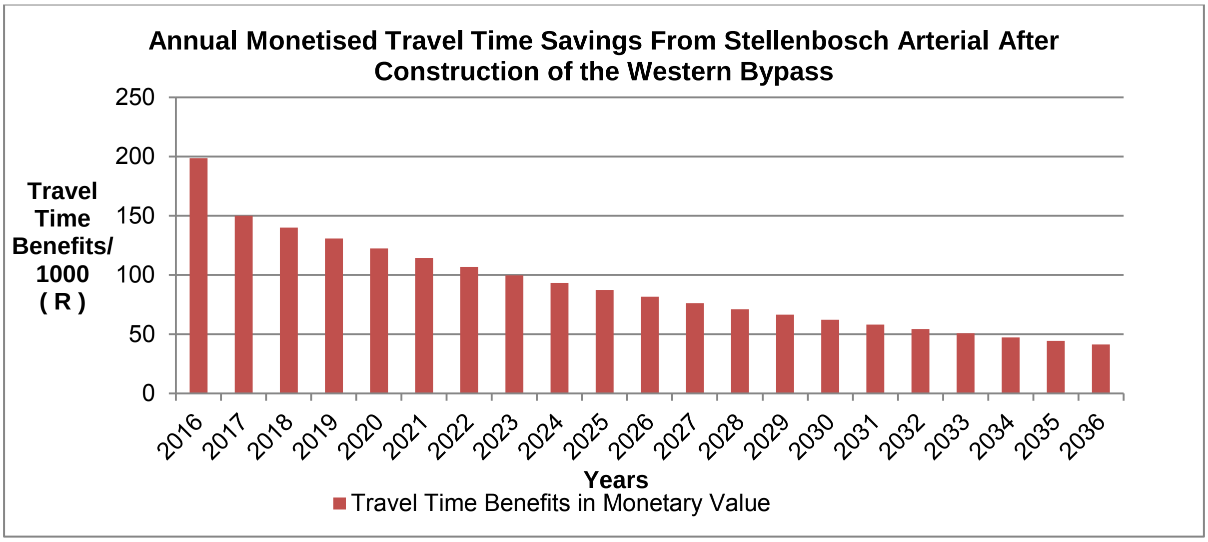



**Figure 4-47: Annual Monetised Travel Time Savings From Stellenbosch Arterial After Construction of the Western Bypass**

### 4.4.3. Energy Benefits

With construction of the bypass, the volume of traffic traveling the Stellenbosch's arterial system is radically reduced. The motorists spend less time to travel on the segment of the R44, R304 and R310 and reach their destination. The vehicles operating costs are reduced as well as the fuel consumption. Fuel consumption is directly linked to number of VKT travelled on the network, thus the reduction of traffic volume on the network as result of the bypass as alternative route had also influenced the fuel consumption. The total fuel Saved is the sum of the fuel saved by the motorist traveling on the network during the peak hours.

Figure 4-48 represents the average estimated annual monetised benefits over the 20 year lifetime horizon for the fuel saved on the Stellenbosch Arterial system during the analysis, which is equal to R 2,231,950.00, which is higher than that of the arterial management system (R 1,019,914.00 for Scenario 1 and R 269, 962.00 for Scenario 2).

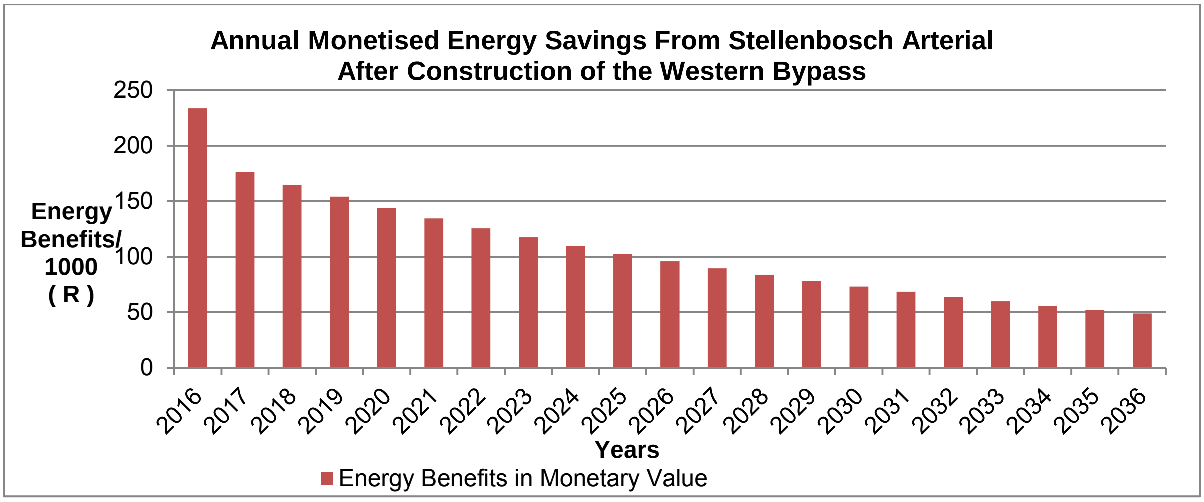



**Figure 4-48: Annual Monetised Energy Benefits From Stellenbosch Arterial After Construction of the Western Bypass**

### 4.4.4. Safety Benefits

The risk of collision will reduce during the peak hours after construction of the Bypass. The motorists have now enough space to manoeuvre as well as better sight distance. Motorists now travel a better speed and with appropriate gap. Reduction of traffic volume as reduced traffic congestion. Figure 4-49 illustrates the average annualized monetised safety benefits, which is equal to R 7,053,102.00, which is higher than the arterial management system (R 437,080.00 for Scenario 1 and R 115,710.00 for Scenario 2).

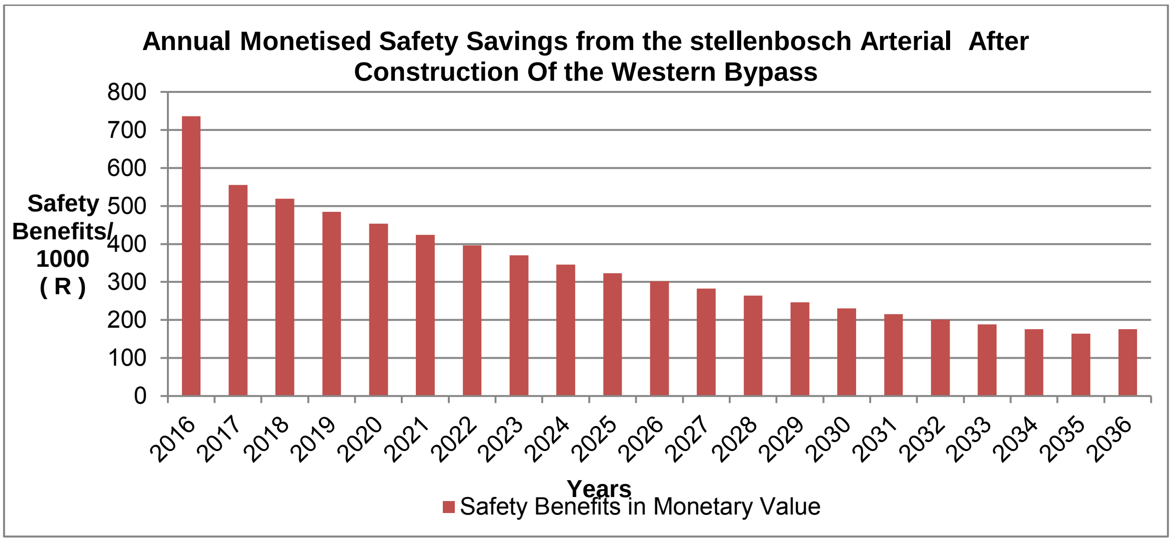



**Figure 4-49: Annual Monetised Safety Benefits From Stellenbosch Arterial After Construction of the Western Bypass**

### 4.4.5. B/C Ratio of Stellenbosch Western Bypass

The B/C ratio for the Stellenbosch Western Bypass is approximately 0.03.

## 4.5. Summary of Results

Table 4-12 provides a summary of the benefit/cost analysis that was performed for the Arterial Management for Scenario 1, which is the segment of Strand Road (R44). It can be seen that the travel time benefits made the greatest contribution to the Present Worth Benefits, the Net Present Value and ultimately the B/C ratio.

**Table 4-12: Summary of B/C Analysis for Scenario 1 per intersection - Segment of Strand Road (R44)**

| Year | Travel Time Benefits/ (R1000) | Energy Benefits/ (R1000) | Safety Benefits/ (R1000) |
|---|---|---|---|
| **2016** | 0.00 | 0.00 | 0.00 |
| **2017** | 623.27 | 111.87 | 47.95 |
| **2018** | 566.61 | 101.70 | 43.58 |
| **2019** | 515.10 | 92.46 | 39.62 |
| **2020** | 468.27 | 84.06 | 36.02 |
| **2021** | 371.46 | 66.67 | 28.57 |
| **2022** | 387.00 | 69.47 | 29.76 |
| **2023** | 379.82 | 63.15 | 27.06 |
| **2024** | 319.83 | 57.41 | 24.60 |
| **2025** | 290.75 | 52.19 | 22.37 |
| **2026** | 230.65 | 41.40 | 17.74 |
| **2027** | 240.30 | 43.13 | 18.48 |
| **2028** | 218.46 | 39.21 | 16.80 |
| **2029** | 198.59 | 35.64 | 15.27 |
| **2030** | 180.54 | 32.41 | 13.89 |
| **2031** | 143.21 | 25.70 | 11.02 |
| **2032** | 149.21 | 26.78 | 11.48 |
| **2033** | 135.65 | 24.35 | 10.43 |
| **2034** | 123.31 | 22.13 | 9.49 |
| **2035** | 112.10 | 20.12 | 8.62 |
| **2036** | 71.76 | 10.05 | 4.31 |
| **Benefits ( R )** | **5 725 888.00** | **1 019 914.00** | **437 080.00** |
| **PWB** | | | **7 182 882.00** |
| **PWC** | | | **301 390.00** |
| **NPV** | | | **6 881 492.00** |
| **B/C** | | | **23.8** |

Table 4-13 provides a summary of the benefit/cost analysis that was performed for the Arterial Management for Scenario 2, which is the segment of Bird Street (R304). It can be seen that the travel time benefits made the greatest contribution to the Present Worth

Benefits, the Net Present Value and ultimately the B/C ratio. Scenario 1 yielded the higher B/C ratio since it was performed for the segment with multilanes, which carry a greater volume of traffic.

**Table 4-13: Summary of B/C Analysis for Scenario 2 per intersection - Segment of Bird Street (R304)**

| Year | Travel Time Benefits/(R1000) | Energy Benefits/ (R1000) | Safety Benefits/ (R1000) |
|---|---|---|---|
| **2016** | 0.00 | 0.00 | 0.00 |
| **2017** | 165.41 | 29.69 | 12.73 |
| **2018** | 150.36 | 26.99 | 11.56 |
| **2019** | 136.70 | 24.54 | 10.51 |
| **2020** | 124.26 | 22.30 | 9.56 |
| **2021** | 99.41 | 17.85 | 7.64 |
| **2022** | 102.70 | 18.44 | 7.90 |
| **2023** | 93.37 | 16.76 | 7.18 |
| **2024** | 84.88 | 15.23 | 6.54 |
| **2025** | 77.17 | 13.85 | 5.94 |
| **2026** | 61.73 | 11.09 | 4.75 |
| **2027** | 64.60 | 11.45 | 4.90 |
| **2028** | 58.72 | 10.40 | 4.47 |
| **2029** | 53.38 | 9.46 | 4.06 |
| **2030** | 48.52 | 8.60 | 3.68 |
| **2031** | 38.33 | 6.87 | 2.95 |
| **2032** | 40.11 | 7.11 | 3.05 |
| **2033** | 36.46 | 6.47 | 2.77 |
| **2034** | 33.14 | 5.88 | 2.52 |
| **2035** | 30.13 | 5.33 | 2.30 |
| **2036** | 9.14 | 1.64 | 0.70 |
| **Benefits ( R )** | **1 508 514.00** | **269 962.00** | **115 710.00** |
| **PWB ( R )** | | | **1 894 186.00** |
| **PWC ( R )** | | | **206 374.00** |
| **NPV ( R )** | | | **1 687 812.00** |
| **B/C** | | | **9.2** |

Table 4-14 provides a summary of the benefit/cost analysis that was performed for the Parking Management System. It can be seen that the travel time was the only benefit obtained in the Parking Management System and therefore the sole contributor towards the

Present Worth Benefits, the Net Present Value and ultimately the B/C ratio. Case 1 yielded the higher B/C ratio since it was performed for the segment with multilanes, which carry a greater volume of traffic.

**Table 4-14: Summary of B/C Analysis for the Parking Management System per installation**

| Year | Travel Time Benefits/(R1000) | |
|---|---|---|
| | Case 1 - Adam Tas Road | Case 2 - Bird Street |
| 2016 | 0.00 | 0.00 |
| 2017 | 212.06 | 115.16 |
| 2018 | 192.78 | 104.71 |
| 2019 | 175.25 | 95.19 |
| 2020 | 159.32 | 86.53 |
| 2021 | 127.46 | 78.67 |
| 2022 | 131.67 | 71.51 |
| 2023 | 119.70 | 65.02 |
| 2024 | 108.82 | 59.09 |
| 2025 | 98.92 | 53.73 |
| 2026 | 79.14 | 48.85 |
| 2027 | 81.76 | 44.41 |
| 2028 | 74.33 | 40.36 |
| 2029 | 67.56 | 36.69 |
| 2030 | 61.43 | 33.36 |
| 2031 | 49.14 | 30.32 |
| 2032 | 50.76 | 27.57 |
| 2033 | 46.14 | 25.06 |
| 2034 | 41.96 | 22.79 |
| 2035 | 38.14 | 20.72 |
| 2036 | 11.73 | 18.83 |
| **PWB (R )** | **1 928 080.00** | **1 078 574.00** |
| **PWC ( R )** | **467 724.00** | **467 724.00** |
| **NPV ( R )** | **1 460 356.00** | **610 850.00** |
| **B/C** | **2.6** | **1.6** |

Table 4-15 provides a summary of the benefit/cost analysis that was performed for the Stellenbosch Western Scenic Bypass. It can be seen that the benefits obtained were derived from the resultant improvement to the Stellenbosch Arterial System, which made up the

Present Worth of Benefits. The Present Worth of Costs considered only the costs for the proposed pavement structure, derived from the anticipated traffic on the Western Bypass.

Due to the high traffic volume that will pass along the bypass, a high pavement structure with a high bearing capacity is required, which will result in the costs outweighing the benefits.

**Table 4-15: Summary of B/C Analysis for the Construction of the Stellenbosch Western Bypass**

| Year | Travel Time Benefits/1000 ( R ) | Energy Benefits/1000 ( R ) | Safety Benefits/1000 ( R ) |
|---|---|---|---|
| **2016** | 198.646 | 233.702 | 736.176 |
| **2017** | 149.842 | 176.288 | 555.296 |
| **2018** | 140.042 | 164.752 | 518.98 |
| **2019** | 130.872 | 153.972 | 485.016 |
| **2020** | 122.318 | 143.892 | 453.292 |
| **2021** | 114.31 | 134.484 | 423.64 |
| **2022** | 106.834 | 125.692 | 395.92 |
| **2023** | 99.848 | 117.46 | 370.02 |
| **2024** | 93.31 | 109.774 | 345.814 |
| **2025** | 87.206 | 102.592 | 323.19 |
| **2026** | 81.508 | 95.886 | 302.05 |
| **2027** | 76.174 | 89.614 | 282.282 |
| **2028** | 71.19 | 83.748 | 263.816 |
| **2029** | 66.528 | 78.274 | 246.568 |
| **2030** | 62.174 | 73.15 | 230.426 |
| **2031** | 58.114 | 68.362 | 215.362 |
| **2032** | 54.306 | 63.896 | 201.264 |
| **2033** | 50.75 | 59.71 | 188.104 |
| **2034** | 47.432 | 55.804 | 175.798 |
| **2035** | 44.338 | 52.15 | 164.29 |
| **2036** | 41.426 | 48.748 | 175.798 |
| **Benefits ( R )** | **1 897 168.00** | **2 231 950.00** | **7 053 102.00** |
| **PWB ( R )** | | | **11 182 220.00** |
| **PWC ( R )** | | | **354 000 000.00** |
| **NPV ( R )** | | | **-342 817 780.00** |
| **B/C Ratio** | | | **0.03** |

# 5. Conclusions and Recommendations

## 5.1. Conclusions

Congested roadways are negatively affecting the quality of life for society on a daily basis. Intelligent Transportation Systems (ITS) are one of the approaches that aim to reduce traffic congestion and provide socio-economic, environmental, and safety benefits. In order to encourage decision makers to proceed with new ITS investments on transportation infrastructures, it is crucial to present their impacts in a holistic manner.

The original primary objective of this thesis was to provide a better understanding of the ITS application areas within the Stellenbosch context, by quantifying the benefits and costs that will result from the deployment of an integrated ITS and operations strategies in Stellenbosch, i.e. appropriate deployment that make sense from an economic perspective.

This chapter summarizes the most important conclusions of the research undertaken. These deductions focuses on the influence of improved capacity on certain corridors with respect to changes in travel time, travel time reliability, number and severity of crashes, vehicle emissions and fuel use. Due to various limitations encountered, recommendations for future research are also provided.

### 5.1.1. Suitability of ITS Deployment in Stellenbosch

This study found that a number of ITS services will be applicable in Stellenbosch, but only two strategies were chosen to form the basis of the research analysis. These two are Actuated Traffic Signal Coordination as part of Advanced Transportation Management System and Parking Information Systems as part of Advanced Traveller Information Systems. These two strategies were chosen because it was anticipated that their benefits will have a significant effect on reducing congestion along the Stellenbosch arterial as well as in the town of Stellenbosch.

It was also found that Stellenbosch has a serious problem with lack of proper and safe public transport and non-motorised transportation facilities, but due to their system dependency and cultural complexity, these were not considered for the economic evaluation in this thesis.

### 5.1.2. Applicability of TOPS-BS

TOPS-BS was found to be a simple analysis tool, which incorporated various default values from literature in its program. The program however does allow default values to be overwritten and updated data to be entered as input values.

It was furthermore found that the definition of the baseline was critical in order to produce a meaningful analysis, since the benefit-cost analysis in TOPS-BC compares alternatives to a baseline condition.

### 5.1.3. Proposed ITS Strategies

- Life Cycle Cost Analysis

From the life cycle cost analysis for the Arterial Management System it can be concluded that the present worth of costs would be similar for each intersection considered along the designated corridors, since similar equipment would be present at each intersection. It is therefore evident that the longer corridor (more intersections along the segment of road) will ultimately account for a higher present worth of cost.

Similarly, for the life cycle cost analysis of the Parking Management System, the present worth cost is the same for each sign location. The number of sign locations along each segment of road considered will likewise influence the total present worth cost.

- Travel Time Benefits

For the Arterial Management System it is evident that the travel times benefits accounted for the greatest part of the benefits produced by the ITS strategy, since the ITS strategy accelerated the throughput movement on the segments and reduced travel times. Improvements to signal timing plans therefore reduce average peak period facility travel times.

For the Parking Management System, the only benefits were those of travel time and indicated that when drivers saw important parking information displayed and reacted accordingly that they experienced a travel time saving. This study also indicated that the travel time benefits are dependent on the type of arterial road (multilane or single lane); since both yielded different travel time benefits, as different traffic volumes passed through the Parking Management System.

- Energy Benefits

For the Arterial Management System, the energy benefits were greatly influenced by the volume of traffic, with the level of congestion directly linked with the fuel consumption, since it required a longer travelling time. With the improvement in capacity, higher speeds were possible, which reduced travel times and also fuel consumption. Multilanes carry higher traffic volumes and will therefore yield higher benefits as well.

Traffic volumes were derived from the future traffic projection, which was greatly influenced by the traffic growth rate. It can thus be concluded that a higher traffic growth rate will yield higher energy benefits.

- Safety Benefits

Safety benefits for the Arterial Management System were greatly influenced by the traffic volume. It can be concluded that higher levels of congestion introduced less possibility of avoiding crashes and that severity of crashes were higher on multilanes. Multilanes carry higher traffic volumes and will therefore yield higher safety benefits as well.

### 5.1.4. Proposed Stellenbosch Western Scenic Bypass

- Life Cycle Cost Analysis

From the life cycle cost analysis for the proposed Stellenbosch Western Scenic Bypass, it can be seen that the anticipated traffic that will be diverted from Stellenbosch, will require a pavement structure with a significantly high bearing capacity, which will have high cost implications. The life cycle analysis only considered the costs of the pavement structure, which suggests that the total costs will be even greater.

- Travel Time Benefits

For the Stellenbosch Western Scenic Bypass it is evident that the travel times benefits accounted for the lowest part of the benefits produced by the Traditional Transportation strategy, since the traffic volumes within the Stellenbosch Arterial Road System is expected to reduce significantly. Travel time benefits are calculated per vehicle miles travelled, if less vehicles travel, lower travel time benefits will be derived.

- Energy Benefits

A significantly higher benefit is expected for the energy benefits for the Western Bypass compared to the Arterial Management, since the traffic volumes within the Stellenbosch area will be reduced by the Stellenbosch Western Scenic Bypass and result in lower vehicle fuel consumption and ultimately higher energy benefits.

- Safety Benefits

The highest benefit in monetary value can be expected for the safety benefits, since Stellenbosch with significantly reduced traffic volumes will result in less crash incidents. When compared to the Arterial Management System, safety benefits are slightly higher, due to the reduction in traffic in Stellenbosch.

#### 5.1.5. Overall B/C Results

The overall B/C results indicate that the deployment of the proposed ITS strategies within the Stellenbosch Arterial Management System and with the Stellenbosch Parking Management System is anticipated to yield the highest benefit/cost ratio, 23.8 and 9.2 respectively. The Stellenbosch Western Scenic Bypass compared significantly with a B/C ratio of 0.61. It will therefore be more beneficial for Stellenbosch to deploy these two ITS strategies, than to have a roadway bypassing Stellenbosch, when considering the need to decongest Stellenbosch.

### 5.2. Discussion of Challenges

Due to the lack of details on the crash rates provided in the Stellenbosch Master Plan, the rate of crashes were joined with the default TOPS-BC rates to estimate the safety benefits for this analysis.

A total calculation of present worth of costs for the Stellenbosch Western Scenic Bypass will have an in depth investigation of design factors for the proposed bypass, which was beyond the scope of this research study.

### 5.3. Future Research

The study strongly recommends that updated traffic counts be performed to reflect the new traffic conditions for future actuated traffic deployment. Future studies are also required on crash rate estimation under oversaturated traffic conditions.

This thesis furthermore focused solely on the throughput movement with rates for various delays incorporated. The influence of intersection delay was not investigated independently and can provide more realistic travel times for the focus area.

Future studies could possibly consider a full depth investigation on the benefits and costs that can be derived from the proposed Stellenbosch Western Scenic Bypass, since it derived significantly high safety benefits.

It was shown that a number of ITS strategies will be applicable for the area, these need to be investigated, particularly strategies to improve the current public transport and non-motorised travelling system in Stellenbosch.

TOPS-BC is one of many analysis tools for economic evaluation; future studies can consider comparing different tools.

Lastly, not all benefits are easily quantifiable; qualitative descriptions of items like “improved quality of life” can provide authorities and the public with a better understanding of what is accomplished by project deployment. Future studies can consider these benefits as well.

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# Appendices

## Appendix 1 - B/C Analysis Methods

The following methods are used in B/C analysis of this research.

1. Net Present Value (NPV)

The NPV determines the value of a future improvements project expressed in monetary value. It relies on the concept of opportunity cost to place a value on the benefit in current monetary value resulting from the initial cost of the investment. The NPV is a Discounted Cash Flow (DCF) technique where cash inflows expected in future years are discounted back to their present value.

The NPV method is suitable for both the assessment of new investments as well as the comparison of investment alternatives. The investment with the higher net present value is the more favourable alternative. The surplus of the total benefit (B) over the total cost (c) known as the Net Social Benefit is represented by the NPV of the project. After quantification of the benefit (B) and the cost (c) for the estimated duration of the project, the NSB is calculated as follows:

$$NSB = B - C \tag{18}$$

To determine the NPV of the project, we need to apply a discount rate to the quantified benefits and costs.it very important to costs and benefits occurring in the future relatively to those occurring in the present. This is because the money received now can be invested and generates large interest. The basis for NPV method is the assumption that one rand today is worth more than one rand will be worth tomorrow.

Projects with positive NPVs usually are economically viable and exhibit an efficient use for the community's resources. Where all projected costs and benefits are valued in real terms, they should be discounted by a real discount rate. The NPV is calculates as follows:

$$NPV = \sum_{t=k}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{j} \frac{C_t}{(1+i)^t} \tag{19}$$

Where:

| | |
|---|---|
| $B_t$ | = Sum of benefit accruing during the year |
| $C_t$ | = Sum of the implementation costs occurring within the year t |
| $n$ | = Number of year in the analysis period |
| $k$ | = Year in which benefit start to occur |
| $j$ | = Last year of implementation |
| $t$ | = Any particular year in the analysis period |
| $i$ | = Annual discount rate as a decimal function |
| $NPV$ | = Net Present Value of benefits |
| $\sum_{t=k}^{n} \frac{B_t}{(1+i)^t}$ | = Present worth of benefits |
| $\sum_{t=0}^{j} \frac{C_t}{(1+i)^t}$ | = Present worth of investment (i.e. implementation) costs |

Another result from B/C analysis is the Net Benefit, which is the sum of all benefit minus the sum of all cost of a project. Net benefit can be useful in ranking projects with similar B/C ratios. When a great number of alternatives are provided and tested in the cost-benefit analysis, the best alternative to take into account is the alternative with the largest benefit.

2. Present Worth of Cost (PWOC)

The PWOC selects the lowest cost alternative among mutually exclusive projects. All economic costs associated with the provision, maintenance and use of each possible alternative project are discounted to their present growth. The alternative that presents the lowest PWOC is regarded as the most beneficial proposal (Bester, 2013). In case of the null alternative, PWOC is equal to the present worth facility maintenance cost and users cost only. This method can be express as follows:

$$PWOC = \sum_{t=0}^{j} \frac{C_t}{(1+i)^t} + \sum_{t=k}^{n} \frac{(M-U)_t}{(1+i)^t} \tag{20}$$

Where:

$PWOC$ = Present worth of cost

$\sum_{t=0}^{j} \frac{C_t}{(1+i)^t}$ = Present worth of all project implementation costs

$\sum_{t=k}^{n} \frac{(M-U)_t}{(1+i)^t}$ = Present worth of facility maintenance costs and users costs

3. Benefit/Cost (B/C) Ratio

This method provides an economic evaluation in order to determine the most advantageous project among projects alternative. B/C determines the ratio between the present worth of the future project benefits and the present worth of the project investment cost. When the value of the B/C ratio is 1 or greater the project is consider as efficient investment. When mutually exclusive projects are compared I, projects with the highest B/C ratio would be ranked as the most efficient (Bester, 2013). The B/C ratio method can be expressed as follows:

$$B/C = \sum_{t=k}^{n} \frac{B_t}{(1+r)^t} = \sum_{t=0}^{j} \frac{C_t}{(1+i)^t} \qquad (21)$$

## Appendix 2 - Worksheets from TOPS-BC Tool

### FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2

***What would you like to do today?***


**TOPS-BC V 1.2 is a sketch-planning level decision support tool developed by the FHWA Office of Operations. It is intended to provide support and guidance to transportation practitioners wanting to conduct benefit/cost analysis of the wide range of Transportation System Management and Operations (TSM&O) strategies. The TOPS-BC tool was developed in parallel with the FHWA's Operations Benefit / Cost Desk Reference.**

**http://www.ops.fhwa.dot.gov/publications/fhwahop12028/**

**If you have questions or comments on the TOPS-BC tool, please contact Jim Hunt with FHWA (Jim.Hunt@dot.gov).**

**Opening Screen of TOPS-BC Tool**

**Navigation**

- Back
- OPENING SCREEN
- GENERAL TOOL OVERVIEW
- LIST OF ALL WORKSHEETS
- 1) INVESTIGATE IMPACTS
- 2) METHODS AND TOOLS
- 3) ESTIMATE COSTS
  - *Traveler Information*
    - DMS
    - HAR
    - Pre-Trip Traveler Info
  - *Traffic Signal Coordination Systems*
    - Preset Timing
    - Traffic Actuated
    - Central Control
    - Transit Signal Priority
  - *Ramp Metering Systems*
    - Central Control
    - Traffic Actuated
    - Preset Timing
  - *Other Freeway Systems*
    - Traffic Incident Management
  - *Other Strategies*
    - ATDM Speed Harmonization
    - Employer Based Traveler Demand Mgmt
    - ATDM Hard Shoulder Running
    - ATDM High Occupancy Toll Lanes
    - Road Weather Management
    - Work Zone
  - *Supporting Strategies*
    - Traffic Management Center
    - Loop Detection
    - CCTV
  - Costs Summary
- 4) ESTIMATE BENEFITS
  - Parameters
  - Generic Link Model
  - *Arterial Strategies*
    - Signal Coordination
  - *Freeway Strategies*
    - Ramp Metering
    - Traffic Incident Management
  - *Traveler Information*
    - Dynamic Message Sign
    - Highway Advisory Radio
    - Pre-Trip Traveler Information
  - *ATDM*
    - HOT Lanes
    - Hard Shoulder Running
    - Speed Harmonization
  - Road Weather Management
  - Work Zone Systems
  - MY DEPLOYMENTS

# FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2

MORE INFO

### *What is TOPS-BC?*

TOPS-BC is a spreadsheet based decision support tool developed by the FHWA Office of Operations. It is intended to provide support and guidance to transportation practitioners wanting to conduct benefit/cost analysis of the wide range of Transportation System Management and Operations (TSM&O) strategies. The TOPS-BC tool was developed in parallel with the FHWA's Operations Benefit / Cost Desk Reference [ http://www.ops.fhwa.dot.gov/publications/fhwahop12028/index.htm ].

Click here to access the latest Operations Benefit/Cost Desk Reference Document

### *What are the capabilities of TOPS-BC?*

TOPS-BC provides four key support capabilities to practitioners wanting to conduct benefit/cost analysis. These capabilities include (click on the hyperlinks below to be taken directly to the listed capability):

1) Investigate the Range of Expected Values Associated with Various TSM&O Strategies
*Provides the ability for users to investigate the expected range of impacts associated with previous deployments and analyses of many TSM&O strategies. Data is presented in look-up tables organized by strategy and impact, and represents impacts that have been observed in regions nationally and internationally that have deployed and/or analyzed the TSM&O strategies.*

2) Map Different B/C Methodologies to Your Organizations Needs
*Provides a screening mechanism to help users identify appropriate tools and methodologies for conducting a B/C analysis based on their analysis needs. Criteria used in mapping to a methodology include geographic scope, TSM&O strategies, desired confidence in analysis results, and measures of effectiveness.*

3) Estimate Lifecycle Costs of TSM&O Strategies
*Provides a framework and default cost data to estimate the lifecycle costs of various TSM&O strategies, including capital, replacement, and continuing operations and maintenance (O&M) costs.*

4) Conduct Simple Spreadsheet-Based Benefit/Cost Analysis for Selected TSM&O Strategies
*Provides a framework and suggested impact values for conduct simple B/C analysis for selected TSM&O strategies.*

In addition to these four key capabilities, TOPS-BC also maintains a rich dataset of default information and links to data sources useful to practitioners conducting benefit/cost analysis of TSM&O strategies.

### *Operational basics:*

The TOPS-BC workbook is set up in a modular format with each of the capabilities provided on their own (or own collection of) worksheets. The worksheet tabs are color coordinated according the capabilities provided (and as presented on the "OPENING SCREEN" tab). For capabilities with more than one devoted worksheet a navigation / instruction sheet is provided as the first worksheet with the assigned tab color. The mapping of capabilities to worksheet **tab color** includes:

| | |
|---|---|
| (blue) | 1) Investigate the Range of Expected Values Associated with Various TSM&O Strategies |
| (orange) | 2) Map Different B/C Methodologies to Your Organizations Needs |
| (light green) | 3) Estimate Lifecycle Costs of TSM&O Strategies |
| (lavender) | 4) Conduct Simple Spreadsheet-Based Benefit/Cost Analysis for Selected TSM&O Strategies |

Within the individual worksheets, color is also used **within individual cells to highlight** the source of the data in the cell according to the following convention:

| | |
|---|---|
| (yellow) | Yellow cells represent default data maintained by the tool. |
| (blue) | Blue cells represent data or outputs calculated internally within the tool. |
| (green) | Green cells represent user defined input. These cells may represent mandatory user inputs, which are typically indicated by the word "INPUT" along the left hand side of the sheet. Green cells may also represent optional user input. Note: inputting a value into an optional user input cell will override the values shown in the default data or calculated data cells in all subsequent analysis; however, the default or calculated values will still appear in those cells as a check on the user input value. |

**Information Tab of TOPS-BC Tool**

# FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2
## List of All Worksheets

### *Worksheets Within TOPS-BC*

TOPS-BC is designed to provide analysis capability within a standard spreadsheet environment. This tool was developed in this manner in order to be comfortable for practitioners familiar with spreadsheets, and also provide the capability for users to easily modify and copy worksheets with minimal knowledge of computer programming. Due to these needs, the resulting tool is comprised of multiple worksheets and this can make it difficult to navigate through the tool as all the available worksheets are not simultaneously visible (as tabs) when viewing the tool. All individual worksheets have a hyperlink listed in the Navigation Menu on the left hand side of each worksheet. This navigation menu may be modified to provide additional hyperlinks as new worksheets are added. See the User's Manual for additional detail.

TOPS-BC provides four key support capabilities to practitioners wanting to conduct benefit/cost analysis. These capabilities are provided on individual, or in many case multiple worksheets. The first two capabilities are provided as individual worksheets within TOPS-BC that may be accessed via the hyperlinks below. The last two capabilities for estimating lifecycle costs and benefits are comprised of multiple worksheets, containing an introductory worksheet followed by a series of worksheets providing analysis capabilities for individual TSM&O strategies. The introductory/instructional worksheet for these capabilities may be accessed by clicking on the hyperlink for the capability heading listed in the Navigation Menu on the left hand side of the screen. The worksheet for any individual TSM&O strategy may be accessed by clicking on the hyperlink with the strategy name following the capability heading.

**List of Worksheets in TOPS-BC Tool**

## FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2

**RESEARCH AVAILABLE ANALYSIS METHODS AND TOOLS**

**Instructions**: Please indicate the needs of your analysis associated with the following options. As you select the options, a list of appropriate methodologies will be displayed to the right. Hyperlinks are provided for those tools with current websites. Tools/methods without a current website are denoted with an asterisk (*).

**INPUT CRITERIA**

What is the geographic scope of the analysis? (Select 1)

- ( ) No Preference
- ( ) Statewide
- ( ) Regional
- (•) Corridor
- ( ) Isolated Location
- ( ) Other

What is the desired level of confidence of the analysis results? (Select 1)

- (•) No Preference
- ( ) High (extremely accurate)
- ( ) Medium
- ( ) Low (order of magnitude)

What TSM&O strategy(ies) do you want to analyze? (Choose Multiple)

- [ ] No Preference
- [x] Arterial Corridor Traffic Signal Coordination Strategies
- [ ] Traffic Signal Priority Strategies
- [ ] Ramp Metering Strategies
- [ ] Traffic Incident Management Systems
- [ ] Transit AVL and Automated Scheduling
- [ ] Pre-Trip Traveler Information
- [ ] En-Route Traveler Information
- [ ] HOT Lanes
- [ ] Speed Harmonization
- [ ] Road Weather Management
- [ ] Work Zone Management
- [ ] Travel Demand Management - Employer Based
- [ ] Supporting Systems (Surveillance, TMC, Communications)

What are the key measures of effectiveness you want to see? (Choose multiple)

- [ ] No Preference
- [x] Travel Time
- [x] Travel Time Reliability
- [x] Safety
- [ ] Emissions
- [x] Energy
- [ ] Agency Efficiency
- [ ] Vehicle Operating Cost Savings
- [x] Lifecycle Costs

What travel modes do you want include in your analysis? (Choose multiple)

- [ ] No Preference
- [x] Auto
- [x] Auto High Occupancy Vehicles
- [x] Truck/Freight
- [ ] Transit Bus
- [ ] Transit Rail

What is the level of resources available to support the analysis? (Select 1)

- ( ) No Preference
- ( ) High
- (•) Medium
- ( ) Low

What data/tools are available to support the analysis? (Choose multiple)

- [ ] No Preference
- [x] Basic speed and volume data only
- [ ] Travel demand model data
- [ ] Simulation model data
- [ ] Automated archived data system

**Suggested Methodologies:**

| Tools meeting ALL criteria | Also Consider: Tools meeting ALL BUT 1 criteria |
|---|---|
| TOPS-BC * | FITSEval * |
| IDAS | |

### Methods and Tools Available in TOPS-BC Tool

# FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.2

## ESTIMATE LIFE-CYCLE COSTS

### *Purpose*

Purpose**:** The purpose of the Lifecycle Cost Estimation Tool is to provide the capability to quickly estimate the costs of various TSM&O strategies. The tool is developed to provide scalable costs dependent on the scope of the user's anticipated deployments. The lifecycle cost estimates include both up front capital costs as well as on-going operations and maintenance (O&M) costs. The tool is also capable of displaying average annual costs and the expected stream of costs over time.

### *Inputs Needed*

Inputs Needed: The tool was developed to include most of the data needed to estimate the costs of the various strategies. This data is maintained as defaults in the tool. The user is generally only required to provide minimal information on their deployments, including: size/scope of the deployment (e.g., how many ramp meters will be deployed), the implementation date of the deployment, and any desired time horizon for the analysis itself. The user is encouraged to review the default data and make appropriate changes to these data elements as well, including: Equipment mix associated with any strategies, the unit costs of equipment, the anticipated useful life of equipment elements, and the discount rate.

### *Outputs*

Outputs: The outputs from the tool include an **Average Annual Cost** and a forecasted **Stream of Costs**. The Average Annual Cost represents a snapshot of the average level of funding that would be required to deploy and operate the TSM&O strategy. In the calculation of Average Annual Costs, the capital cost deploying of equipment is amortized over its anticipated useful life. The Stream of Costs represents the year-by-year anticipated expenditures needed to deploy and operate the strategy. Costs are forecast from the deployment date to the year 2100. Costs necessary for replacing obsolete equipment are realized at the anticipated end of the equipment's useful life. Additionally, from the Stream of Costs, the **Net Present Value** (NPV) of the costs may be calculated.

Note: All costs shown in the individual strategy cost sheets and SUMMARY worksheets are displayed in year 2010 constant dollars. The user is given the option of viewing these costs in another year dollars within the benefit/cost comparison shown in the Benefits Module.

### *Directions*

To estimate the lifecycle costs for a single strategy, the user should select the worksheet for that strategy from the tabs at the bottom of the workbook. Once in the correct worksheet, the user should enter the year in which the strategy will be deployed as well as enter the relevant the number of **Infrastructure** and **Incremental** units to be deployed.

**Infrastructure** equipment represents those pieces of backbone infrastructure necessary to support the roadside components. Examples of infrastructure components include the TMC hardware, system integration and software necessary to operate a traffic signal system. **Incremental** equipment represents those elements that need to be deployed to implement one additional roadside unit. Incremental equipment is often deployed on a location-by-location basis, and the tool will specify the unit to be entered (e.g., number of intersections, number of vehicles, etc.) depending on the strategy being deployed.

Once this information is entered in the green cells within WORK AREA 1 of the strategy worksheet, and the user has reviewed and edited the default unit equipment cost assumptions (including reviewing the useful life assumptions) the Average Annual Costs will calculate automatically and display at the bottom of WORK AREA 1 in the worksheet. The Stream of Costs will also automatically display in WORK AREA 2 of the worksheet and the Net Present Value will be calculated based on default analysis parameters. The user may change the assumed discount rate and time horizons for the NPV analysis if desired. The default parameters are highlighted in yellow in the worksheet. The user should enter their preferred parameters in the green cells only. Similar to all other areas of the Ops B/C Decision Support Tool, entering a value in the green cell will override the use of the default parameter; however, the default parameter will still be shown for informational purposes.

To estimate the lifecycle costs for multiple strategies, the user should fill out the identical information for any and all of the strategies they want to include in the analysis. The lifecycle cost information for the individual strategies will be displayed on the individual strategy worksheets. The SUMMARY tab will compile the Average Annual Cost and Stream of Costs information from the individual worksheets in a single table. The ability to estimate NPV of the costs of the combined strategies is provided on the SUMMARY page.

**Life Cycle Costs Analysis in TOPS-BC Tool**