Investigating the Sustainability of the Freeway Management System and Feasibility of Implementing a Connected Vehicle Environment in the Western Cape

Conceptual Design of a Connected Vehicle Environment in Cape Town

by
Aadil Kriel

Thesis presented in fulfilment of the requirements for the degree of Master of Science in the Faculty of Engineering at Stellenbosch University

Supervisor: Dr. Johann Andersen
Department of Civil Engineering

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By submitting this research project electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

This investigation considered the effect that Connected Vehicles may produce within the local environment with the use of two Connected Vehicle applications focused on the improvement of efficiency within South Africa, with specific focus on Cape Town.

The technology investigated was Dedicated Short Range Communication (DSRC), a communications device designed specifically for use in vehicular communication. DSRC provides the latency requirements necessary for real-time safety applications. While safety was not the focus of this investigation, the potential effect that may be produced as a result of the technology would reach beyond the improvement of efficiency in the network.

The applications tested for this investigation was Speed-Harmonization and Queue-Warning to determine if an improvement in congestion was possible and the extent thereof. These applications were tested with a simulation software program called VISSIM by the PTV Group. These applications were tested under Free-Flow conditions, under the occurrence of an Accident or Crash and in Congested traffic conditions. Thereafter, the applications were combined in two distinct ways with the aim of providing the effect of Cellular communication and DSRC communication capabilities. The Cellular implementation was considered for 100% market penetration, while the DSRC alternative was determined for varying penetrations of Connected Vehicles into the existing vehicle fleet within the design area. Overall, the following benefits were determined from the simulations:

- Average improvement in Travel Time of 12%
- Improvement in Fuel consumption and CO2 emissions reduction of 2% per day
- Average reduction in delays of 18%

These benefits however would result in costs to both users and traffic management agencies. The following costs and benefits were determined for users and traffic management agencies respectively in the compilation of a cost benefit analysis

Benefits to Road Users

Decision	Option	Total Present Cost (Minimum) (R)	Total Present Cost (Maximum) (R)	Total Present Benefit (R)	Benefit Cost Ratio (Min)	Benefit Cost Ratio (Max)
Alternative 0	-	-	-	-	-	
Alternative 1	Option 1: Added to Vehicle	132 725.54	242 043.90	182 215	1.37	0.75
	Option 2: Aftermarket	118 234.75	156 717.36	182 215*	1.54	1.16
	Option 3: Retro-fitted	122 292.12	231 609.48	182 215	1.49	0.79
	Option 4: Self-Contained	120 285.72	229 603.08	182 215	1.51	0.79
	Option 5: VAD	112 928.92	222 246.28	182 215*	1.61	0.82
	Option 6: Standard Equipment (SE)	160 888.24	270 205.60	182 215*	1.13	0.67
	Option 7: SE with Video	386 179.15	495 496.51	182 215*	0.47	0.37
Alternative 2	1: Min. Delay	40 099.90	75 554.20	158 730.30	3.49	1.77
	2: Max. Delay	40 099.90	75 554.20	101 324.80	2.53	1.34

Benefits to Traffic Agencies

Decision		Total Present Cost (Design Area)	Total Present Benefit	Total Net Benefit
Alternative 0	From 2015	- R1 601 055	-	- R1 601 055
Alternative 1	40%	- R13.928 mil	R17.22 mil	R3.295 mil
	50%		R20.73 mil	R6.80 mil
	60%		R23.96 mil	R10.03 mil
Alternative 2	At 2020	-R430 970	-	-R430 970
	At 2025	-R702 652	-	-R702 652
	At 2030	-R949 875	-	-R949 875

It was found that the benefits under minimal conditions would exceed the initial costs committed to either alternative. Furthermore, according to the simulated models, a similar effect may be achieved in utilizing Cellular technology or DSRC technology. It may therefore be more sustainable for South Africa to consider the use of existing technology to reduce costs and reduce the time of deployment of the technology

OPSOMMING

Hierdie ondersoek beskou as die effek wat verbind Voertuie binne die plaaslike omgewing met die gebruik van twee Verbinde Voertuig (VV) toepassing gefokus op die verbetering van doeltreffendheid in Suid-Afrika kan produseer, met spesifieke fokus op Kaapstad.

Die tegnologie ondersoek was Toegewyde Kort Afstand Kommunikasie (TKAK), 'n kommunikasie toestel wat spesifiek ontwerp is vir gebruik in voertuie kommunikasie. TKAK bied die tyd vermindering vereistes wat nodig is vir ware tyd veiligheid programme. Terwyl veiligheid nie die fokus van hierdie ondersoek was nie, sal die potensiële uitwerking wat gebruik kan word geproduseer as gevolg van die tegnologie bereik as die verbetering van doeltreffendheid van verkeer in Kaapstad.

Die toepassings wat in hierdie ondersoek getoets was, was Spoed-Harmonisering en Tou-Waarskuwing om te bepaal of 'n verbetering in opeenhoping moontlik was en die omvang daarvan. Hierdie toepassing is getoets met 'n simulasie sagteware program genaamd VISSIM deur die PTV Groep. Hierdie aansoeke is getoets onder Vry-Vloei voorwaardes, onder die voorkoms van 'n ongeluk of ineenstorting en in dig verkeer omstandighede. Daarna is die aansoeke gekombineer in twee verskillende maniere met die doel om die effek van Sellulere kommunikasie en TKAK kommunikasie vermoëns. Die Sellulere implementering beskou vir 100% markpenetrasie, terwyl die TKAK alternatiewe vasbeslote was om wisselende meng van Verbinde Voertuie in die bestaande voertuigvloot in die ontwerp gebied. Algehele, is die volgende voordele te sien van die simulasies:

- Gemiddelde verbetering in Reistyd van 12%
- Verbetering in Brandstofverbruik en CO_2-emissies verminder 2% per dag
- Gemiddelde vermindering in vertragings van 18%

Hierdie voordele sal egter lei tot koste vir beide gebruikers en verkeer bestuur agentskappe. Die volgende koste en voordele is vasgestel vir gebruikers en verkeer bestuur agentskappe onderskeidelik in die samestelling van 'n koste-voordeel-ontleding:

Koste en Voordele aan Gebruikers

Besluit	**Opsie**	**Totaal Huidige Koste (Minimum) (R)**	**Totaal Huidige Koste (Maksimum) (R)**	**Totale Huidige Voordeel (R)**	**Kostevoordeel Verhouding (Min)**	**Kostevoordeel Verhouding (Maks)**
Alternatief 0	-	-	-	-	-	
Alternatief 1	Keuse 1:	132 725.54	242 043.90	182 215	1.37	0.75
	Keuse 2:	118 234.75	156 717.36	182 215*	1.54	1.16
	Keuse 3:	122 292.12	231 609.48	182 215	1.49	0.79
	Keuse 4:	120 285.72	229 603.08	182 215	1.51	0.79
	Keuse 5:	112 928.92	222 246.28	182 215*	1.61	0.82
	Keuse 6:	160 888.24	270 205.60	182 215*	1.13	0.67
	Keuse 7:	386 179.15	495 496.51	182 215*	0.47	0.37
Alternatief 2	1: Min. Vertraging	40 099.90	75 554.20	158 730.30	3.49	1.77
	2: Maks. Vertraging	40 099.90	75 554.20	101 324.80	2.53	1.34

Koste en Voordele vir Bestuur Agentskappe

Besluit		**Totaal Huidige koste (Ontwerp Omgewing) (R)**	**Totale Huidige Voordeel (R)**	**Totale Netto Voordeel**
Alternatief 0	Van 2015	- R1 601 055	-	- R1 601 055
Alternatief 1	40%	- R13.928 mil	R17.22 mil	R3.295 mil
	50%		R20.73 mil	R6.80 mil
	60%		R23.96 mil	R10.03 mil
Alternatief 2	By 2020	-R430 970	-	-R430 970
	By 2025	-R702 652	-	-R702 652
	By 2030	-R949 875	-	-R949 875

Daar is bevind dat die voordele onder 'n minimale voorwaardes van die aanvanklike koste verbind tot óf alternatief sou oorskry. Verder, volgens die gesimuleerde modelle, 'n soortgelyke effek bereik kan word in die benutting van Sellulere tegnologie of TKAK tegnologie. Dit kan dus meer volhoubaar wees vir Suid-Afrika om die gebruik van bestaande tegnologie om koste te verminder en die vermindering van die tyd van die ontplooiing van die tegnologie te oorweeg.

ACKNOWLEDGEMENTS

Throughout my investigation into Connected Vehicles and the existing traffic network, I felt as if I had mountains to climb in terms of information required and software that was needed to determine the results I needed to prove the feasibility of my study. I therefore feel a moral obligation to mention the following individuals for helping me complete the ascent to the top of the mountain.

To Christoff Frick, Anton Struwig, David Sampson, Christo Bester and Marion Sinclair, thank you for all of the information that was provided to me, for dealing with all of my questions and for taking time out of yours and your colleagues day to provide me with assistance. I am entirely grateful for the interaction and the assistance that allowed me to complete my thesis in a manner that I am proud of.

Thank you Dr. Johann Andersen, for providing excellent guidance through work and the provision of this great topic. I took this topic without knowing anything about Connected Vehicles, and now I am in disbelief that it has not yet become commonplace on the road network. With all of the stress and sleepless nights, I thoroughly enjoyed working on this topic every day in the hopes of making a new contribution to the work. Thank you for the strict commentary on the work I produced. I learnt a great deal during the completion of this study, life lessons that I will hold for the greater portion of my life.

Thank you Megan Bruwer for your kindness and eagerness to assist with every question I had. I was never under the impression that I was a nag in terms of requesting information and I appreciate that, thank you for everything.

I was completely overwhelmed about how I would complete the investigations and upon stumbling on your videos, I was able to complete the simulations with the desired results. Thank you Matyas Lemer for your assistance.

There are many other individuals whom I am not mentioning and kindly request your forgiveness for not mentioning your name. Your assistance provided me with insight, belief in the potential of improvement in South Africa, and a document that I am proud of. A simple thank you feels insulting for the great level of assistance that I was fortunate to have had. I hope that each of you feel a sense of achievement along with me for submitting my findings.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACCRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADAS	Advanced Driver Assistance System
AV	Autonomous Vehicle
CACC	Cooperative Adaptive Cruise Control
CAMP	Crash Avoidance Metrics Partnership
CCTV	Closed Circuit Television
CoCT	City of Cape Town
CV	Connected Vehicle
DSRC	Dedicated Short Range Communication
ESS	Environmental Sensor System
FHWA	Federal Highway Administration
GPS	Global Positioning System
MDOT	Michigan Department of Transport
OBU	On-Board Units
PGWC	Western Cape Provincial Government
Q-WARN	Queue-Warning
RSE	Roadside Equipment
RSU	Roadside Unit
SAE J2735	Society of Automotive Engineers
Sanral	South African National Road Agency Ltd.
SPD-HARM	Speed-Harmonization
TCT	Transport for Cape Town
TMC	Traffic Management Centre
USDOT	United States Department of Transport
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VDS	Vehicle Detection System
VMS	Variable Message Sign

CHAPTER 1 : INTRODUCTION

This study will investigate the efficiency of travel of private vehicles in Cape Town. In this Chapter, a brief description of Connected Vehicles will follow to provide basic context of the elements involved with this technology. Thereafter, the Freeway Management System (FMS) will be considered, more specifically focussing on the goals and aims of Sanral. A discussion on the Traffic Management Centre (TMC) will be presented to provide context to the existence of the FMS. Subsequently, the current situation of traffic in the Western Cape will be discussed. This will be done to present the grounds for establishing the effect that the systems in place may have produced to date. Thereafter, a correlation between the information presented will be drawn i.e. the FMS in its current state along with the current plan in place. With the FMS state and traffic situation described, a possible solution or alternative to address the above mentioned information will be given. The thesis then, under the consideration of the above facts, proposes an alternative approach to managing traffic flow - The Connected Vehicle and Connected Vehicle applications. The future of transportation, the consideration of the benefits and the problems that this may alleviate. Thereafter, an outline of the approach to investigating the research statement will be briefly described.

1.1 EFFICIENCY AND ITS IMPORTANCE TO THE GROWTH OF AN ECONOMY

Transportation plays a crucial part in the development of economies, providing access to different locations, accessing products and moving people to and from areas of productivity – this level of production is used to determine the wealth and related living standard of a country, indicated as the Growth Domestic Product (GDP) (OECD, 2016). In the Sanral Strategic Plan 2015/2016 – 2019/2020 (2015: Page 12 of 111), it is conveyed that the mobility transportation establishes is linked to the level of economic output, employment and the income of any national economy, directly impacting the development of the population. The importance of an effective transportation system is thus far reaching and critical to the development and progress of a country.

Transportation assists with productivity by improving accessibility to areas, with the aim of doing so in a safe and time-effective manner. To this effect, a transportation network would be directly affected by the efficiency of its operation, since an inefficient transportation network would impede the progress and development of a country. The Strategic Plan 2015/2016 – 2019/2020 further states that “a key objective of South Africa is to ensure a sustainable transport sector which is efficient and provides economic and social opportunities”, clarifying that the transportation network is key to a nations development. This efficiency in the transportation network, is the focus of this investigation within the current operation of the traffic network

An efficient transport network therefore directly affects the productivity of any economy. By enhancing the efficiency of a traffic network, an economy's productivity may directly be improved in a similar proportion and, according to the above mentioned statements, may produce an improvement in social and environmental well-being.

1.2 WHAT IS A CONNECTED VEHICLE?

A Connected Vehicle differs from standard motorised transportation in its ability to not only establish communication, but to do so between different technological avenues. The communication that these vehicles establish is to provide information to the surrounding environment about its condition and status in real-time. The information that these vehicles are able to send relate to the operating condition of the vehicle, the geometry of the vehicle, the engine statistics, driver response and input data and vehicle mobility information. The vehicle's operating-condition information relates to the operation of the engine, the geometry relates to the dimensions of the vehicle and trajectory predictions (the path the vehicle is anticipated to follow), the engine information refers to operation of the engine components and their status, driver details refers to throttle response and braking status and mobility refers to the heading (direction in which vehicle is moving) and speed information – the detail of the information provided will be discussed in *Chapter 2* of this investigation. This information could be beneficial to vehicle users, traffic management agencies and vehicle manufacturers as it may be utilised for the development of a traffic network that operates in a predictable, reliable, safe and efficient manner. With regards to the technological avenues, information may be transmitted to other vehicles (Vehicle-to-Vehicle communication (V2V)), infrastructure (Vehicle-to-Infrastructure communication (V2I)), internal communication with the vehicle's sensors (Vehicle-to-sensor (V2S)) and communication to the internet and pedestrians (Vehicle-to-Pedestrian communication (V2P)). Collectively, the communication with these devices is referred to as Vehicle-to-everything (V2X). Figure 1.1 provides a graphical description of the communications:

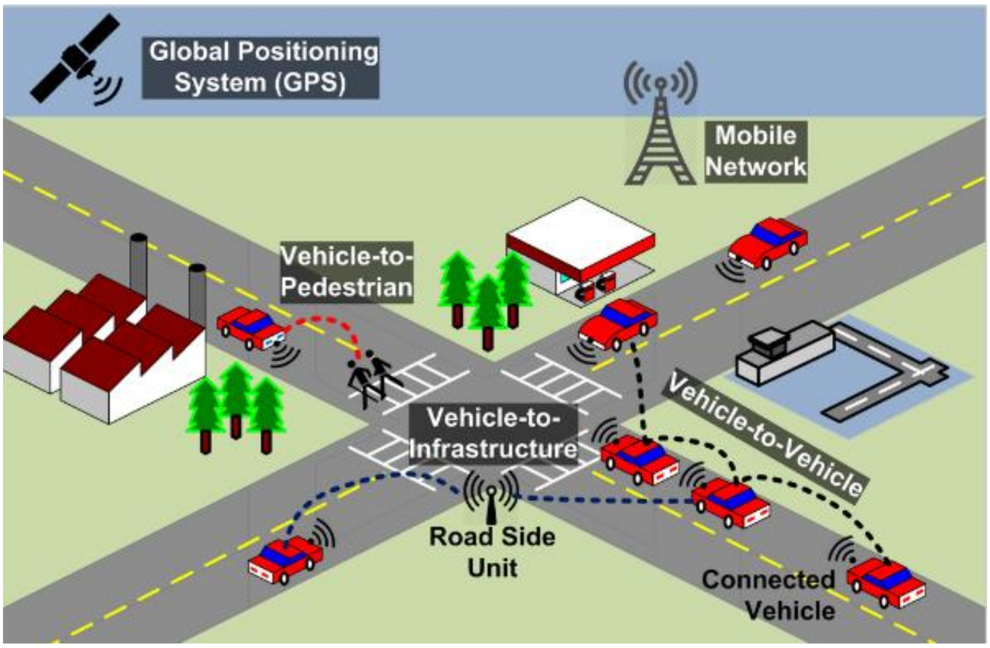


Figure 1.1: Communication between vehicles (V2V), infrastructure (V2I) and pedestrians (V2P) ((Hamida, Noura and Znaidi., 2015:384)

According to the USDOT (www.its.dot.gov, 2016), Connected Vehicles make use of on-board Dedicated Short-range Radio Communication (DSRC – discussed further in *Chapter 2*) devices to transmit information (such as speed, heading and brake status) to other vehicles; while vehicles with advanced on-board sensors, cameras and radar devices provide drivers with safety assistance, Connected Vehicles add value due to the data-transfer range that may be achieved by DSRC devices (www.its.dot.gov, 2016) - with the combination of V2V and V2I communication, safety may be enhanced along with travel efficiency. Connected Vehicles will therefore provide benefits for the surrounding environment while providing benefits specific to each user.

1.3 BACKGROUND: TRAFFIC MANAGEMENT CENTRE OPERATIONS

The Traffic Management Centre (TMC) as known today was achieved through the implementation of multiple forms of infrastructure, a plan designed and approved by multiple stakeholders in 2008. These stakeholders include the City of Cape Town (CoCT), the South African National Roads Agency Ltd. (Sanral), Western Cape Provincial Government (PGWC), the National Department of Transport (NDoT), along with the South African Police Service (SAPS). The intention of the TMC was to create a system for monitoring the traffic network, to respond to traffic incidents and to improve the flow of traffic both economically and efficiently (Pollack, M. 2009). Initially, management of the traffic network was achieved through awareness of the traffic systems; navigation devices (GPS) were in the initial phases and had begun to affect the market but were not entirely accurate and trustworthy at that stage (Lendino, J. 2012). Additionally, GPS navigation devices were only available to those who could afford the devices, geographical map guides were still generally in use. The services envisioned to be addressed include Transport Network Operations, Integrated Rapid Transit (IRT), Transport Information Centre, Metropolitan Police and Traffic Services (illustrated in Figure 1.2).

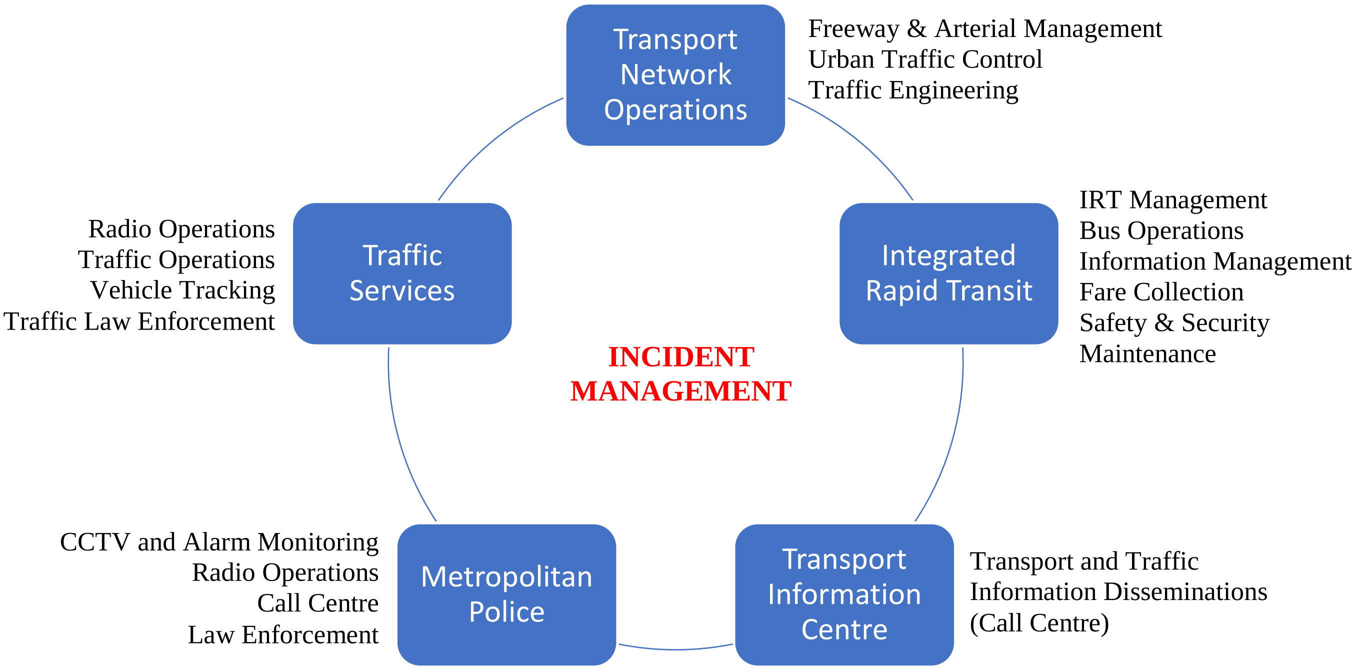


Figure 1.2: Services to Accommodate within the Traffic Management Centre (Nell, F. 2009)

Since commencement of operations within the TMC in 2010, the FMS has achieved positive results with a major improvement of management over the transportation network. According to the City of Cape Town, 90% of the incidents that occurred on the roads were first identified by the operators at the TMC (Nell, F. 2012). With immediate identification of incidents, response teams could be deployed to remove any obstructions preventing the flow of traffic. Additionally, road users are provided with traveller information along the route of travel through Variable Message Sign (VMS) notices, information with the i-traffic web application (which provides route warnings and images from road-side camera-feed of the street-view which is continuously updated) and warnings via social media avenues such as Twitter and Facebook.

The improvement of traffic flow conditions achieved within the Western Cape may extend to the improvement of time spent travelling, users to make more informed decisions, earlier incident responses and returning traffic to normal flow conditions (Pollack, M. 2009), fulfilling the initial intention of the system. The improvement after 2012 has been a change in clearance time of almost 2 hours (1 hour and 5 minutes), ranging from 3 hours and 43 minutes before 2012 to approximately 2 hours (Figure 1.3, page 1.5).

The FMS has presented an opportunity to monitor the road network, respond to the occurrence of incidents and independently take action in more severe situations and has positively impacted the traffic network. Enhanced traveller information systems, significant reduction in incident response and clearance times with an overall improvement in safety through clearance of incidents on the roads not only signifies the importance of the TMC both functionally and operationally, but the power that this institution possesses over the transportation network. Any further significant improvements over this network will be achieved through the operations within the TMC, with the potential to provide a more elaborate and inclusive transportation system.

LATEST RESULTS PROVIDED CONCERNING FREEWAY MANAGEMENT SYSTEM PROGRESS

At present, Sanral has implemented various technologies and infrastructure (Intelligent Transportation System (ITS)) to reduce congestion and improve driver awareness on the roads. Since the completion of the traffic management facility in 2010, Sanral has engaged in tremendous improvements within the traffic network with the Freeway Management System. These improvements include the deployment of devices such as Variable Message Signs (VMSs), Vehicle Detection Systems (VDSs), Environmental Signal Systems (ESSs) and CCTV surveillance. The VMS provides traveller information (for example, the time it will take to traverse a section of the Freeway currently travelled by users), the VDS detect vehicles for probe data and traffic information, the ESS obtains weather information to assist with real-time travel information and the precautions that should be initiated, and CCTV surveillance is used for detection of and response to incidents. The following figures prove that the use of these devices has attained positive results with congestion mitigation and maintaining traffic flow.

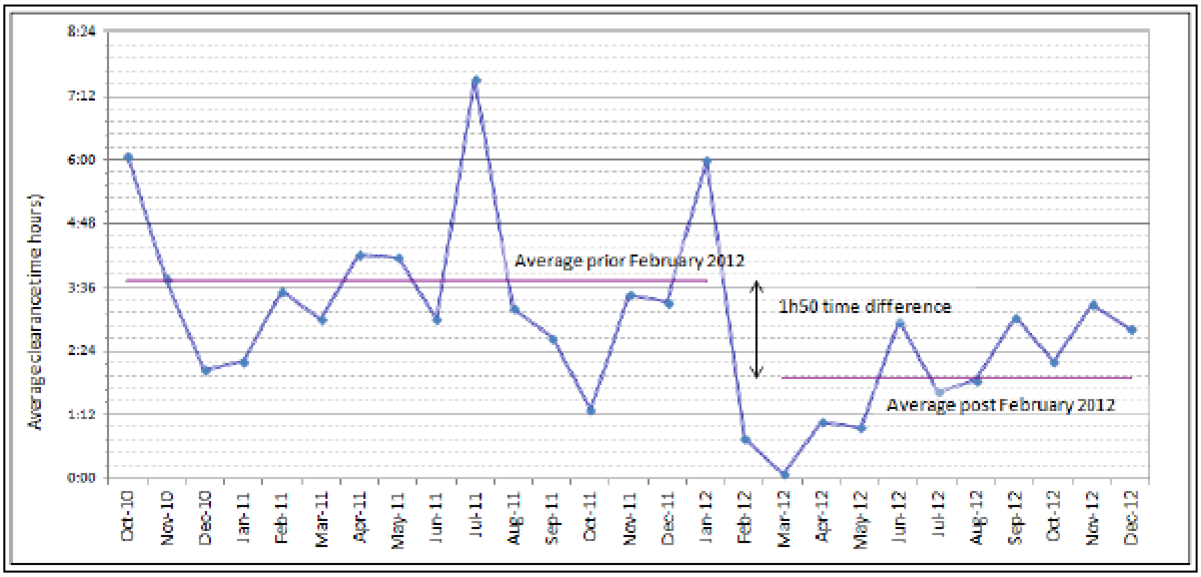


Figure 1.3: Difference in clearance times for accidents in the Western Cape (Krogscheepers, C. et al 2013)

Figure 1.3 as previously mentioned, illustrates the improvement in clearance times achieved from 2010 and 2012. This improvement is clearly a result of the ability to monitor the network and the manner in which it operates (Krogscheepers, C. et al 2013).

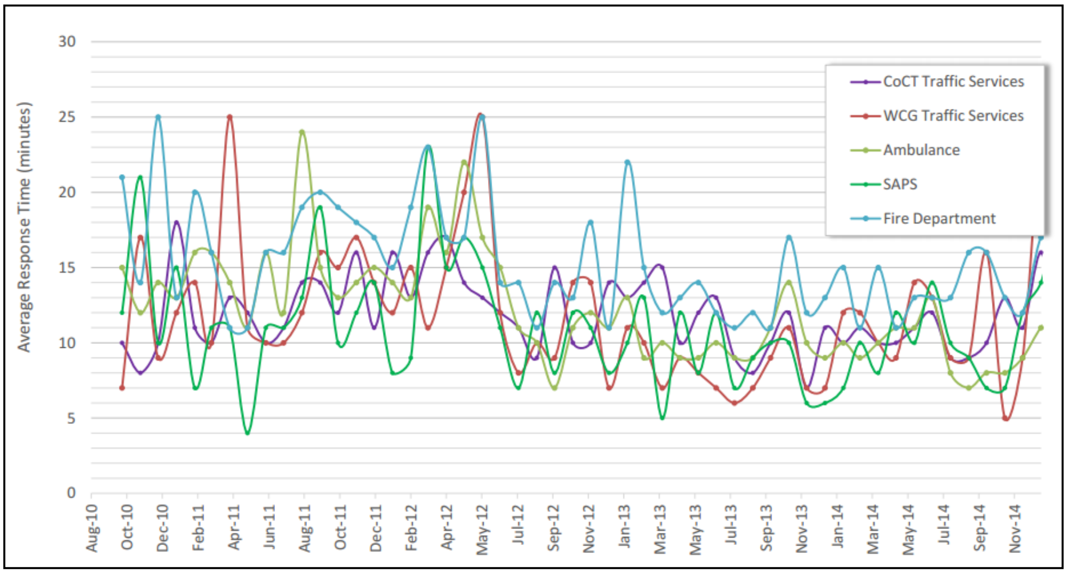


Figure 1.4: Average response times of emergency services (Cable, R. 2015)

Figure 1.4 indicates an improvement in response times for all emergency service (in the Western Cape) which can be attributed to the success of the FMS operations and the infrastructure implemented to monitor the traffic network. This level of awareness creates the immediate responses and analysis of shorter routes necessary for improvement of traffic flow and reduction of congestion.

1.4 PROBLEM STATEMENT: NECESSITY OF AN ALTERNATIVE APPROACH TO MANAGEMENT OF TRAFFIC IN CAPE TOWN

The existence of a Freeway Management System inherently means that a system is in place to establish some form of control over the operation and flow of traffic through means that are determined according to traffic managing agencies – i.e. with substantial motivation and available funding, specific infrastructure may be deployed, such as incorporating Vehicle Detection Systems (VDSs) to conduct automatic traffic counts for improved traffic planning. Infrastructure across different regions and countries may therefore vary according to the requirements of the traffic agencies involved, the available funding and the influence of the environment (areas with consistent visually limiting scenery, such as trees, winding roads, overcast weather or unfavourable lighting, may require more powerful camera capabilities). However, this variation in equipment requirement exists to accomplish certain objectives that are conventional to Freeway Management Systems globally (NevadaDOT, 2005), which include:

- Reducing the impacts of recurring congestion on the freeway system;
- Minimizing the duration and effects of nonrecurring congestion on the freeway systems;
- Maximizing the operational safety and efficiency of travelling public while using the freeway system;

- Providing facility users with information necessary to aid them in making effective use of the freeway facilities and to reduce their mental and physical stress;
- Providing a means of aiding users who have encountered problems while travelling on the freeway system.

Additionally, national agencies incorporate objectives and aims specific to their environment. In a presentation conducted by (Bester, 2013) on behalf of Sanral, the following aims were highlighted:

- Reduce impact of congestion
- Improve road safety
- Provide users with real time information

It can be seen that these aims of Sanral with regards to the Freeway Management System, correlate well with the general objectives of a Freeway Management System in addressing the fundamental aspects of transportation, namely mitigation of congestion, enhancement of road safety and provision of traffic information to road users. These areas will therefore be discussed to determine if the aims of Sanral are indeed tending towards achievement.

REDUCING CONGESTION

Congestion in South Africa, particularly in Cape Town is continuing to increase according to the trend-line produced, illustrated in Figure 1.5. The congestion information was obtained from the TomTom Index (www.tomtom.com/trafficindex, 2016) in which the average annual level of congestion for Cape Town was determined, ranking 47th in severity in comparison to 174 countries. On average, it currently takes approximately 30% longer (in comparison to free-flow conditions) to gain access to a destination within the City. Figure 1.5 illustrates the trend in congestion in Cape Town:

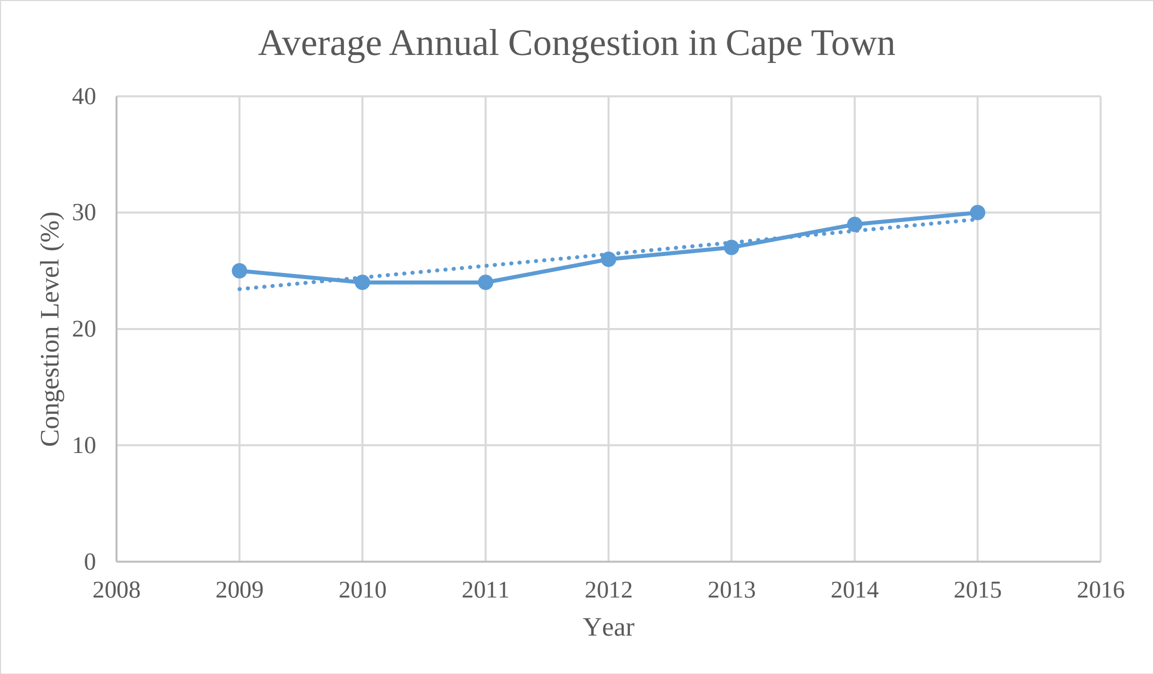


Figure 1.5: Annual Congestion in Cape Town compared to Free-Flow Conditions (www.tomtom.com, 2016)

The figure indicates that congestion is increasing in Cape Town (the **Congestion Level (%)** axis was limited to 40% to highlight the uptrend). For a 20-year period (from 2015 till 2035), the trend indicates that the anticipated level of congestion may be in the range of 41 to 49%. While this is the case for the average travel time on a daily basis, the weekday travel times portray a more severe picture of the travel times in Cape Town as a result of congestion. Figure 1.6 indicates the extra travel time during the morning peak period.

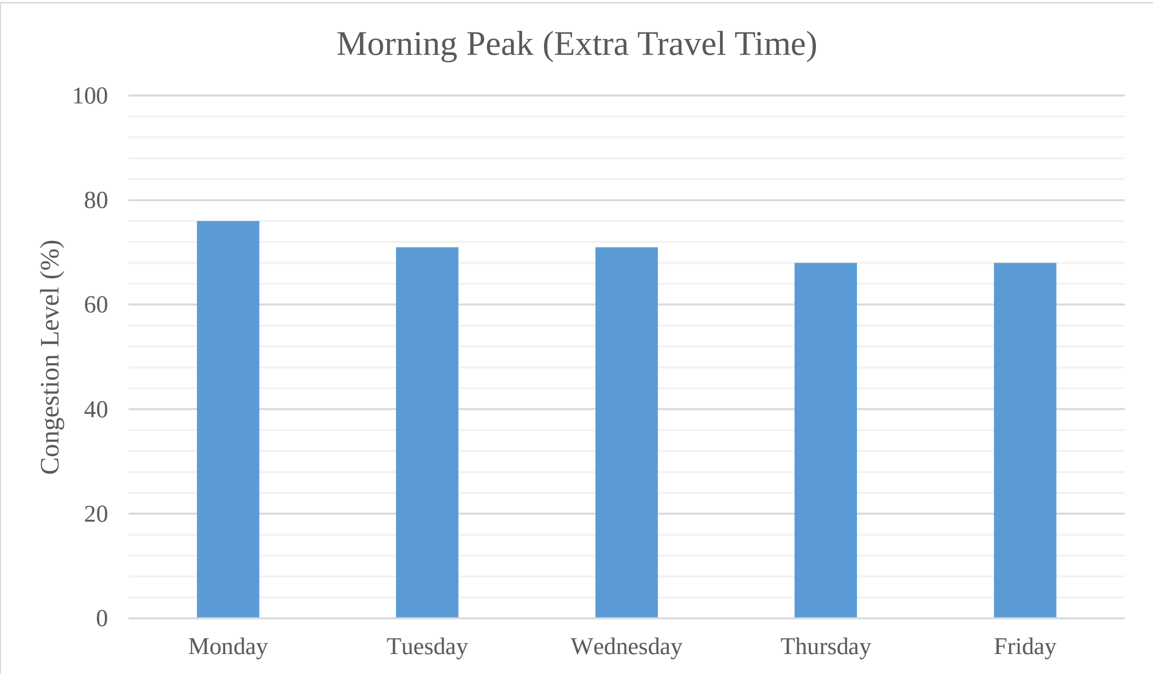


Figure 1.6: Morning Peak Congestion Levels per day in Cape Town (www.tomtom.com, 2016)

Figure 1.6 indicates the highest level of congestion on a Monday at 76% during the 07:00-08:00 AM period, while the congestion on a Friday morning during this period is 68%. Additionally, Figure 1.7 indicates the congestion levels for the evening peak period:

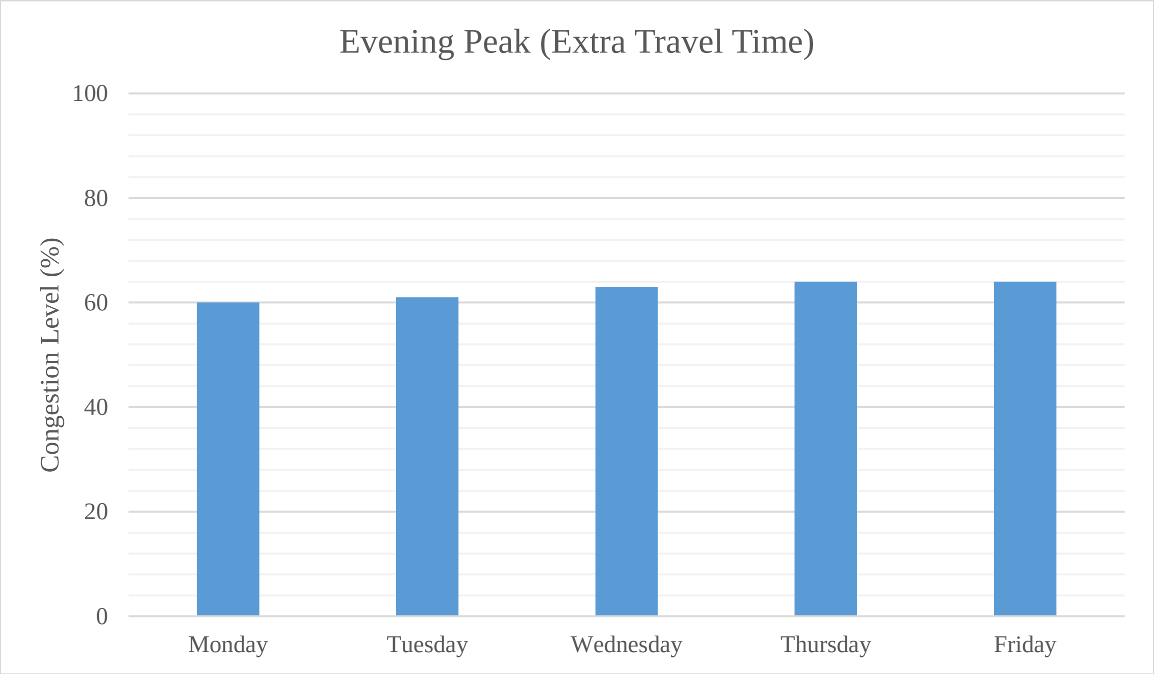


Figure 1.7: Evening Peak Congestion Levels per day in Cape Town (www.tomtom.com, 2016)

From Figure 1.7, the congestion levels for the evening peak period is 60% on Monday between 17:00 and 18:00 PM and 64% on a Friday between 16:00 and 17:00 PM. From Figure 1.6, it takes an average of 71% longer to travel in comparison to free-flow conditions, and 62% longer to travel in the evening. In addition to the current congestion levels discussed above, the traffic network is growing at a rate of 0.35% per year from 2009 (enatis.com, 2016). Figure 1.8 indicates the growth of the traffic network in the Western Cape (enatis.com, 2016):

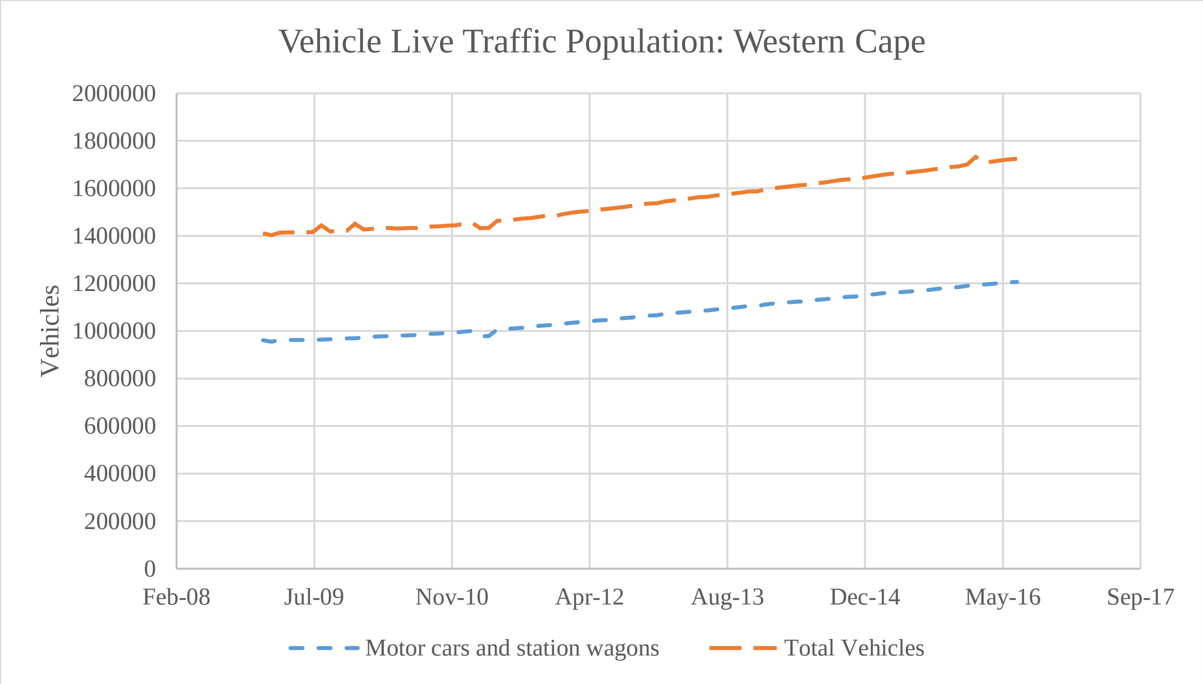


Figure 1.8: Live Vehicle Population in the Western Cape (enatis.com, 2016)

It is clear from the figure that the vehicle population is increasing. The private vehicles (indicated by the Motor cards and station wagons dashed-line) accounts for approximately 70% of the live traffic population, and approximately 88% including SUVs and single/double-cab vehicles. With this information, it may be inferred that traffic congestion may continue to increase at the current rate – this does not reflect Sanral's aim of reducing congestion.

IMPROVING ROAD SAFETY

South Africa, according to a study conducted in 2013 (WHO 2015), ranks 39th out of 180 for the death rates per 100 000 people. According to Steyn, L (2013), South Africa was ranked as the worst out of 36 countries for road fatalities, with a rate of 27.6 per 100 000 inhabitants. The meaning of this statistic is that it costs the economy approximately R307 billion rand. Sanral's road safety audit revealed that during 2007 and 2008, South African road users were being killed by a rate of 1 every 36 minutes (SANRAL Road Safety Audit 2010). The latest information produced by the World Health Organisation (WHO 2014) rates South Africa as 37th for the number of road accident death rates, the rate being 24.64 which (according to the study) is a high death rate. The measures currently in place (the existing road infrastructure – VMSs, VDSs, and social media notifications) may therefore, not have produced the desired improvement in road safety. In support of this statement, the following graph indicates the latest trend in crashes on the freeways (Coetsee and Krogscheepers, 2015).

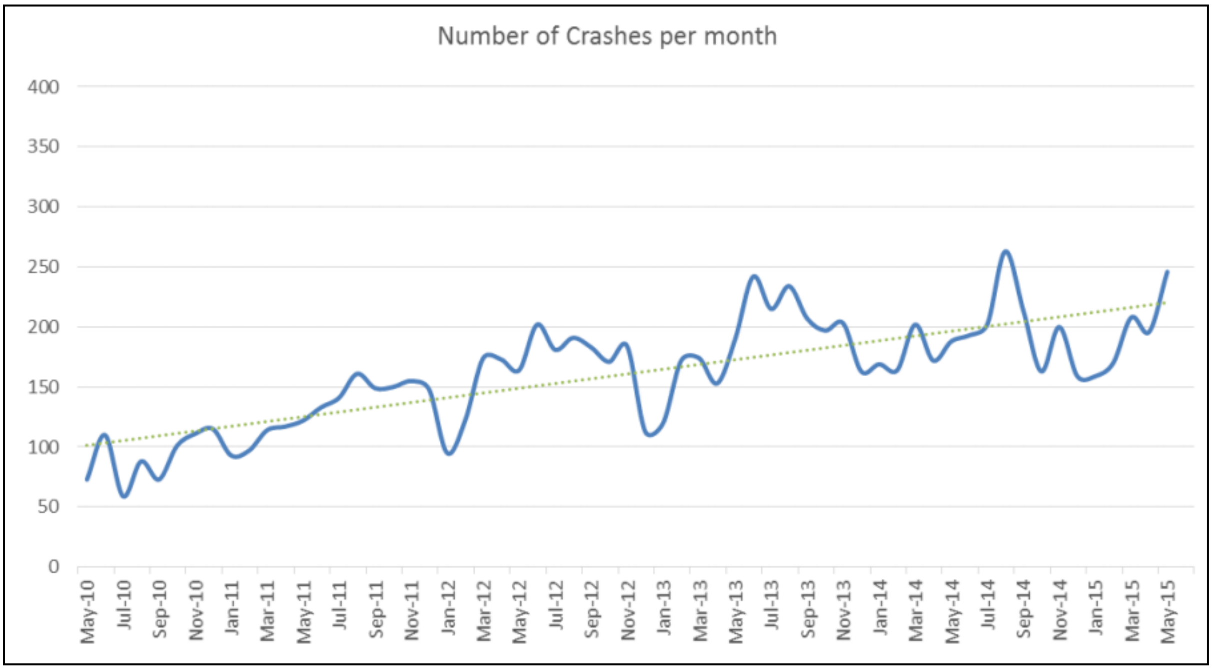


Figure 1.9: Crashes in the Western Cape from May 2010 to May 2015 (Coetsee and Krogscheepers, 2015)

The figure indicates a rising trend in accidents from 2010 up to 2015. One of the aims of ITS, it can be seen that the desired effect of road safety may not be as effective as is necessary. However, is should be noted that_Sanral and the Department of Transport in Johannesburg and Cape Town hope to pursue more stringent measures of enforcing road users to comply with safety, such as a proposed implementing of a decrease in the speed to be travelled on South African roads (Writer, S. 2015). The approach is to be more aggressive and strict towards drivers such as checking the road worthiness of vehicles and implementing a dragger (screening to check for use of alcohol). Additionally, Ishmael Mnisi (spokesperson for the Department of Transport) stated that a 40 km/h speed limit was not only proposed but was to be expected on South African roads at the end of 2015 (Writer, S. 2015). Furthermore, heavy-vehicles (9 tonnes and greater) were proposed to be allowed on the roads during specific times of the day as a means of allowing the traffic to flow more efficiently.

At present, these measures have yet to be implemented and, although in conjunction with Sanral, is not specifically an extension to the Freeway Management System operations. Based on the accident statistics mentioned on page 1.12 and the figure indicating the trend in crashes, it may be deduced that the number of crashes will increase, and does not conform to Sanral's aim of improving road safety.

TRAVELLER INFORMATION

One of the advantages of FMS, with the assistance of ATMS and ATIS (Advanced Traffic Management System and Advanced Traveller Information System respectively, discussed in *Chapter 2 Section 2.1.5 and Section 2.1.6 respectively*) is that users can be provided with real-time traveller information via displays on Variable Message Signs, through user based information from the i-Traffic website, alerts via Twitter (of which they have nearly 30 000 users) and Facebook (with more than 120 000 unique users in combination with Twitter users). The argument that can be made however, is that the information, while strategically placed on VMS boards and provided via social media, is not user specific (with the exception of the i-traffic application), is not provided directly to the user (unless smartphone is mounted) and assumes that the user is familiar with the entire network and would be able to navigate the use of an alternative route once the user is on the road un-aided by navigation applications.

Educating travellers widely and more consistently about conditions of traffic, alternative routes and travel times, as well as leveraging existing mobile software capabilities may create opportunities for users to gain access to alternative routes and may optimise the system in a better light. With the multiple avenues of providing traveller information considered, it can be reasoned that Sanral's aim of providing users with real-time traveller information is currently accurate and has been maintained and improved (with regards to social media acceptance and development of the i-traffic application). However, this is an aspect that can be improved, which will be illustrated in this investigation.

Based on the discussion above, it is clear that supporting or alternative approach managing the flow and operation of traffic. With the increasing numbers of vehicles on the roads and crashes, producing adverse effects of increasing congestion and carbon dioxide emissions, it is crucial that a more effective and sustainable approach to traffic management be investigated.

1.5 CONSISTENCY OF SANRAL'S GOALS AND OBJECTIVES VERSUS CURRENT SITUATION

To determine if any improvement is indeed necessary, consideration must be given to the intentions that Sanral state are their goals and objectives for the management of the traffic network according to the Strategic Plan 2015/2016 – 2019/2020. The following statement appears in Sanral's Strategic Plan 2015/2016 – 2019/2020 (2015), stating that the following policy provided guidance for the existing strategic plan:

The White Paper's vision is "to provide safe, reliable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers at improving levels of service and cost in a fashion which supports government strategies for economic and social development whilst being environmentally and economically sustainable". (Strategic Plan, 2015: Page 8 of 111)

Furthermore, the White Paper of 1996 adds a number of goals of which six were presented in the Strategic Plan, the fourth goal being:

"*to improve South Africa's competitiveness and that of its transport infrastructure and operations through greater effectiveness and efficiency to better meet the needs of different customer groups, both locally and globally"* (Strategic Plan 2015/2016 – 2019/2020, 2015: Page 9 of 111)

In both statements, Sanral mentions the provision of improved traffic operations and infrastructure to meet customer needs – this may be understood as the commitment to improve traffic and travelling conditions. Although Figure 1.3 and Figure 1.4 provide positive feedback of the results obtained as a direct result of the infrastructure (response and clearance times improved substantially), Figure 1.5 (congestion) and Figure 1.8 (increasing traffic network) indicate increasing traffic congestion and a growing fleet of vehicles. Furthermore, the rate of accidents (Figure 1.9) appears to be increasing as well. It is therefore not clear that the presence of the ITS infrastructure on the freeways have produced a positive effect on efficiency and safety. Additionally, the clearance and response times result from the occurrence of crashes on the freeway and can therefore not be an indication of an improvement in efficiency and safety when compared to free-flow and peak-flow conditions.

In the Strategic Plan it is stated, as part of the visionary 2011 National Deployment Plan (NDP) for 2030, that *"SANRAL's philosophy has always been to maintain its assets first and only then allocate funds towards upgrades or new infrastructure"* (Strategic Plan 2015/2016 – 2019/2020, 2015: Page 10 of 111). With the consideration of this statement, along with the motivation for maintaining the existing equipment mentioned, it is reasonable to assume that SANRAL would be willing to invest in an approach that may reduce the current issue of congestion in South Africa, provided the suggestion establishes the necessary support for government strategies of social and economic development and considers the maintenance of the existing assets. This can be further motivated with the following extract from the Strategic Plan:

"*a key objective of South Africa is to ensure a sustainable transport sector which is efficient and provides economic and social opportunities and benefits that result in positive multiplier effects such as better accessibility to markets, employment and additional investments."* (Strategic Plan 2015/2016 – 2019/2020, 2015: Page 12 of 111)

It is therefore clear that the intention of Sanral is to establish an all-encompassing transport network that is safe and efficient whilst considering the best interest of the population itself. Furthermore, the effect of congestion is also addressed, with special focus on its social impact, along with the environmental impact of congestion, resulting in the following being stated: *"The social impact of congestion cannot be calculated in monetary value, but manifests in the social health of families"* and *"In addition to the social impact of congestion above, it also has a negative environmental load, which cannot be ignored."* (Strategic Plan 2015/2016 – 2019/2020, 2015: Page 12 of 111). Alleviating congestion through the enhancement of efficiency in the transport network is therefore of utmost importance for a developing country such as South Africa.

In closing, the following statement outlines further motivation for the proposal of an alternative or additional solution to the current systems in place for the managing the traffic network:

"Sanral is committed to the principles outlined in the national policy guidelines as previously mentioned, and is of the view that efficient and sustainable transport infrastructure is fundamental to the promotion of economic development, service delivery, good governance, social cohesion and improving the standard of living of all South Africans." (Strategic Plan 2015/2016 – 2019/2020, Page 12 of 111).

With this in mind, the focus of this investigation will be driven toward the consideration of a means to improve travel efficiency in South Africa, with particular focus on Cape Town.

1.6 RESEARCH OUTLINE AND OBJECTIVES

This section discusses the intention of the research and elaborates on the research statement. The motivation for considering a Connected Vehicle environment is presented and thereafter leads into the limitations of the study, concluding with the outline of the investigation.

1.6.1 RESEARCH STATEMENT

Connected Vehicle technology has the ability to reduce traffic congestion and improve traffic flow in the network, and presents a more effective alternative to expansion and maintenance of the existing Freeway Management System.

1.6.2 WHY CONSIDER CONNECTED VEHICLES?

With consideration of the factors mentioned in the *Problem Statement* (reducing congestion, improving road safety, providing real-time traveller information), Connected Vehicle technology has the potential to address each of the factors relevant to a progressive traffic network, that is, to improve the levels of congestion by possibly improving travel times, to improve the environmental impact through the possible reduction of emissions levels and to improve the availability and provision of traveller information with direct access to each user.

Connected Vehicle technology aims to provide users with real-time information of the traffic situation along their route and within the surrounding network, and is more specific to each user in comparison the general provision of travel times along specific routes, such as VMS boards for example. Road users are currently provided with traveller information via VMS boards, the i-traffic web application, notifications on Twitter and similarly on Facebook. However, VMS boards are only located on the Freeway and at specific points (although the placement of these VMSs were strategically designed) and the use of social media for traffic information reached approximately 120 000 users (Stop-over.co.za, 2016); if each of these users own vehicles, this would be less than 8% of private vehicle owners (refer to Appendix A for live traffic information). Connected Vehicle technology allows for traffic information to be sent directly to a user – with access to immediate and consistently updated information, users would be able to rapidly adjust their travel route if necessary. Although alternative routes are suggested with the current system in place, this would only be effective if the user was familiar with the network and was aware of the conditions on the alternative routes. Connected Vehicle technology may bridge this gap with the provision of alternative routes and the associated travel times for the user to be fully aware of their options within the network.

With the reduction of congestion, according to the aims of the FMS, this may be addressed with the distribution of traveller information as discussed above. With users aware of the alternative route choices, arrival times based on their location and road conditions, immediate decisions concerning the chosen route of travel can be made – this may result in reductions in overall delays, if the information is used correctly.

A further aim of Sanral with the Freeway Management System was to improve road safety. However, with the exception of road design, it may be evident that road safety is not actively addressed with the current layout and selection of ITS infrastructure in the Cape Town network – Figure 1.9 (page 1.13) indicates that, although the FMS infrastructure has been deployed and active since 2010, along with extensions of the FMS network (Strategic Plan 2015/2016 – 2019/2020, 2015), the accident rate has continued to increase. It is evident that passive safety measures have been taken, such as creating awareness of road safety with VMS safety messages, billboard messages and broadcasted messages; once again, Figure 1.9 (page 1.13) suggests that this may not be the most effective approach for improving road safety. Connected Vehicle technology presents an opportunity for active safety to be executed. The applications available with Connected Vehicle technology (these applications will be discussed in *Chapter 3 Section 3.4*) focus on driver safety, providing warnings and notifications of traffic conditions, keeping the driver aware of the environment at all times – Connected Vehicles add value in comparison to vehicles with advanced technology by communicating with other Connected Vehicles and the surrounding environment (its.dot.gov/cv_basics, 2016).

It should therefore be clear that Connected Vehicles have the potential to establish the desired environment for traffic operations that offers efficiency and safety, with the possibility of alleviating congestion by providing traveller information and reducing accident rates by providing users with warnings and notifications.

1.6.3 RESEARCH OBJECTIVES

The primary objectives of this investigation may be summarised as follows:

- To determine the effect of Connected Vehicles and the development of a Connected Vehicle environment on the flow of traffic and the presence of congestion.
- To determine if this is a more sustainable solution in comparison to expanding the network through increasing the amount of infrastructure on the freeway.

The secondary objectives of this investigation are:

- To complete a cost-benefit analysis for the existing network and a proposed network to provide an indication of the level of commitment that would be placed on a connected vehicle environment;
- To provide reference to appropriate starting points for possible development of local pilot studies by providing a detailed study of the necessary equipment.

1.6.4 SCOPE AND LIMITATIONS

The investigation went as far as possible within the time-frame to incorporate and consider all applications currently available according to the USDOT (iteris.com, 2016). Since the focus of this study was the efficiency of traffic and the possible effect that Connected Vehicles may have within the network, the investigation attempted to consider the effect of two Connected Vehicle applications, with recommendations for further consideration of suggested applications. While safety is not the focus of this study, it is a recurring element and one of the core objectives of Connected Vehicles (its.dot.gov/pilots, 2016) – this was not particularly explored as it was not within the scope of this investigation, but is mentioned throughout this document as it coincides with the aims of Sanral for the Freeway Management System.

The conceptual design of the infrastructure required for a connected environment was limited to Cape Town and does not include all of the current ITS infrastructure. Additionally, the construction costs that may be involved were not considered since the intention was to provide an indication of the possible costs to be considered.

It is stated multiple times in this study that the Connected Vehicle environment is in a state of maturity. This is meant to indicate that the technology, the necessary environment and the extent of the impact are currently under multiple investigations and testing, according to the *CV Pilot Deployment Program* issued by the USDOT concerning the test-beds (refer to Appendix A for the CV development progress and status).

With the implementation of Connected Vehicles being relatively new (investigations began in 2005 (MDOT, 2012:3) while Connected Vehicle applications were fully defined in 2011(Fehr and Krueger, 2013:2). Testing is currently in Phase 2, concluding in 2018 to the start of Phase 3 (Appendix A)), the study was limited by access to real-life studies, availability of equipment locally and cost information of the necessary equipment. For this reason, the study relied heavily on the research, results and investigations conducted by the USDOT in terms of equipment, infrastructure, applications tested and systems architecture (elaborated on later in this document) and made use of traffic simulations to conduct the testing. Further limitations will be addressed within the study at the appropriate locations.

1.7 RESEARCH PROPOSAL

According to the STRATEGIC PLAN 2015/2016 – 2019/2020 (2015), Sanral may be willing to pursue the improvement of traffic flow, efficiency, safety and the overall operation of the network. While there are multiple facets of consideration depending on the focus of improvement, the focus in this study is foremost the improvement in efficiency. It should be noted that, according to the Strategic Plan 2015/2016 – 2019/2020 (2015), the intention in relation to the FMS is to expand and optimise the system with the following inclusions (Page 36 of 111):

- Implementation of traffic demand strategies and active management on the existing FMS network;
- Identify "strategic corridors" to implement ITS (Intelligent Transportation Systems);
- Implement centre to centre links to existing FMS centres;
- Implement centre to centre links with adjacent network operators and concessionaires.

While the extension of the FMS is in effect (Strategic Plan 2015/2016 – 2019/2020, 2015: Page 36 of 111), and the response times have improved, TomTom data reveals that congestion levels are on average 30% in Cape Town – refer to Figure 1.5 (page 1.10) (www.tomtom.com, 2016). In addition to this, an article from *News24* titled "Traffic congestion costs SA over R1bn – Joburg mayor" (Wakefield, 2015) mentions that, as the title implicates, congestion costs South Africa approximately 1bn per annum, excluding the adverse effects on social and environmental sectors. Although the article was sourced for Johannesburg, it may be inferred that Cape Town is a contributor to this extensive cost of congestion, given that the congestion in Cape Town exceeds that of Johannesburg (30% compared to 27% respectively, (www.tomtom.com, 2016)). The trend (Figure 1.5, page 1.10) indicates increasing congestion, which at some point, may reach a level at which the intended effects of the FMS system are nullified – that is, the provision of traveller information for route planning and assistance with Emergency Response Units. If this were to occur, the monthly and annual licence and maintenance payments to keep the existing ITS infrastructure in place may result in further financial costs to the economy without the intended benefits.

Based on these points, the author proposed an investigation into the feasibility of implementing Connected Vehicles in South Africa, with initial focus directed towards Cape Town in the Western Cape. The effect on traffic flow and operations of these vehicles should be considered in this environment and the possible improvements that may be achieved. To this effect, the following layout is proposed for the consideration of a detailed investigation into the feasibility of this system and technology, as well as the sustainability of this system.

1.8 RESEARCH LAYOUT

The following information provides a summary of the content to be expected in the chapters mentioned and highlights the flow of the investigation with the aim of attaining a rational outcome.

Chapter 2: Literature Review

The literature review will consider any and all information relevant to the Connected Vehicle (CV) and will explore areas requiring further development before the CV can be utilised for improvement.

Chapter 3: Research Design

This section will consider details of the research as highlighted in the Research Proposal. Specifically, creating a Connected Environment and the required infrastructure to ensure that the impact will influence the safety of road users. Further research will delve into implementing applications for use by the stakeholders of the TMC.

Chapter 4: Methodology

The methodology will attempt to strictly follow the Research Design with the aim of attaining information from existing pilot studies and assessing the possible impact in a South African context.

Chapter 5: Results

The results obtained from the study will be summarised in this section with the aim of concluding the necessity of further investigation into this technology.

CHAPTER 2 : LITERATURE REVIEW

The literature review discusses the Freeway Management in South Africa and focusses attention on the milestones achieved and current endeavours of the Traffic Management Centre (TMC) in Goodwood, Cape Town. Thereafter, the study introduces the Connected Vehicle (CV) and the required environment in which this technology may flourish. Additionally, a discussion of the by-products of CV technology follows, as the influence they present are significant to the study. These by-products include Big Data, Dedicated Short Range Connectivity (DSRC) and Probe Data. Furthermore, a brief discussion of Autonomous Vehicle (AV) technology will be given in this text based on its significance to the transportation environment. It should however be understood that AV technology is not the focus of this study.

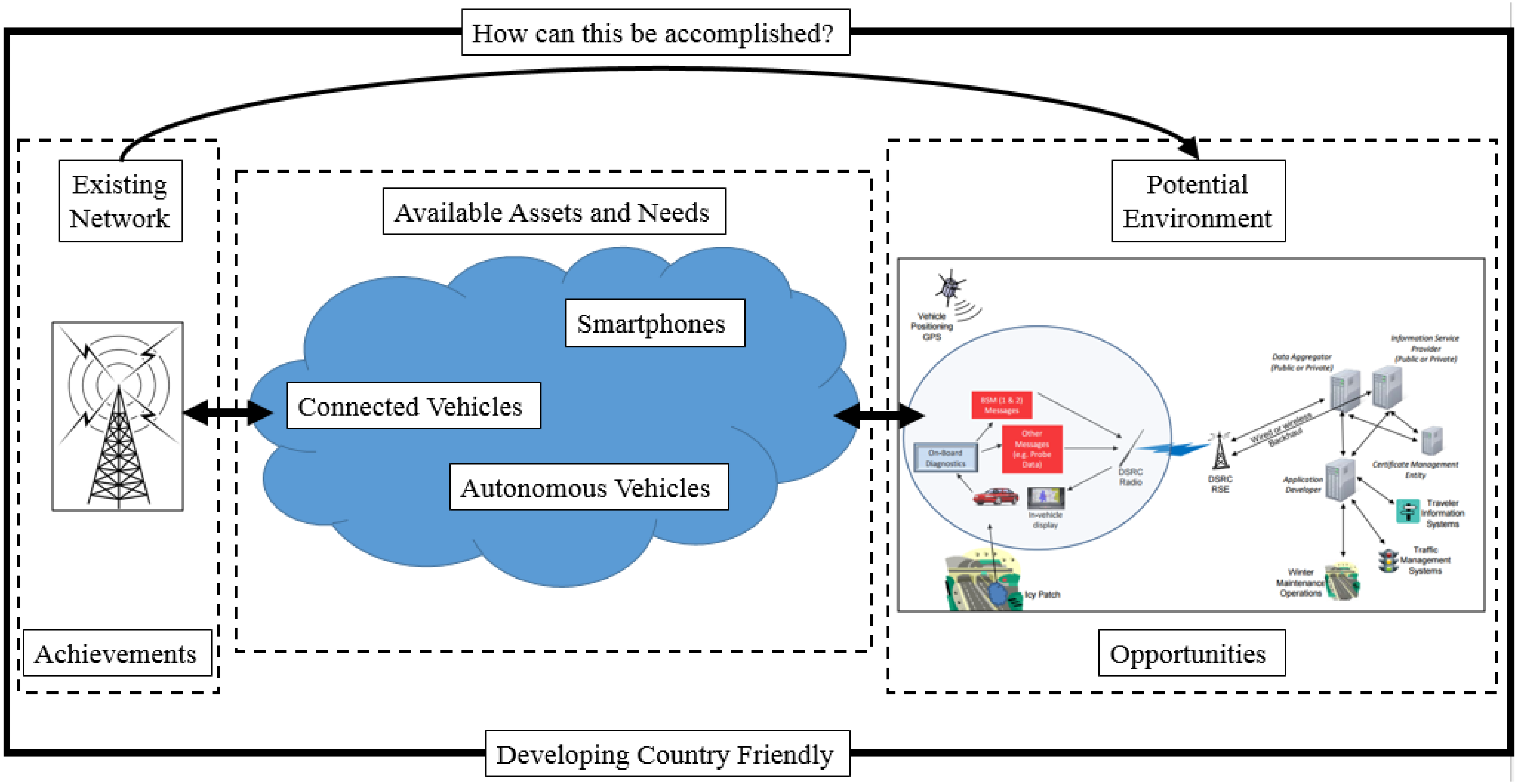
The literature review considers the vast number of applications presented by CV technology and the environment required to utilise the information provided by these vehicles. CV applications currently identified will be briefly discussed to provide an impression of the progress achieved thus far. The study will later consider which applications are relevant in a South African context.

The aim of this literature review is to highlight the current steadiness in progress of the Freeway Management System and portray the possibility of a solution that may alleviate the issues of efficiency and safety on South African roads, with particular focus on the Western Cape.

The following diagram illustrates the manner in which this chapter will be approached, with the eventual goal of understanding an environment that may provide the most potential for South Africa while remaining conscious of a developing country perspective. The approach taken attempted to provide answers to the following questions before any investigation was initiated:

- What is the existing situation with regards to Intelligent Transportation Systems (ITS) Infrastructure, operation of the Freeway Management System (FMS) to manage the freeways in the Western Cape and the road related issues (such as road safety, travel efficiency etc.) that this system was intended to address?
- What would a suitable ITS Infrastructure environment comprise to address road related issues discussed in Chapter 1?
- With the understanding and viewpoint that South Africa is a developing country, are there existing systems, strategies and equipment available to lead the transportation network in the Western Cape, in the direction of the proposed environment?
- What needs to be addressed (in terms of road users, management, equipment, strategies etc.) to steer the Western Cape, and eventually South Africa, to (possibly) a more reliable transportation network?

The process outlined in the diagram does not specifically indicate the order of the information presented in this Chapter, but provides an illustration of the connection between the research conducted and the transition into conducting a relevant investigation.


How can this be accomplished?
Existing Network
Available Assets and Needs
Potential Environment
Smartphones
Connected Vehicles
Autonomous Vehicles
Achievements
Opportunities
Developing Country Friendly

2.1 FREEWAY MANAGEMENT SYSTEM

In the Western Cape SANRAL, in partnership with the City of Cape Town (CoCT) and the Western Cape Provincial Government (PGWC), currently operates 236 CCTV cameras, 51 Variable Message Signs (VMSs), while 84 Vehicle Detector Stations (VDS) as well as 10 Environmental Sensor Stations (ESS). These communication devices have been commissioned (SANRAL Annual Report 2014) and are used to monitor the transportation network, known as the Freeway Management System (FMS). The FMS became operational in 2010, in which the management of infrastructure was initiated (nra.co.za/Press Releases, 2016). The purpose of the infrastructure was to be able to monitor the traffic network in order to ensure the safety and efficiency of the transportation network in its entirety.

The construction of the Traffic Management Centre (TMC) in the Western Cape was completed in 2010 and has since produced commendable results in terms of response times to incidents due to the ability to see their occurrence in real-time. According to the report *FREEWAY MANAGEMENT AND THE IMPACT ON RESPONSE AND CLEARANCE TIMES*, the response to incidents has improved from approximately 12 minutes in 2010 to 10 minutes in 2013. Although this may appear to be partially insignificant, it is an improvement of 17% and assists by reducing the overall time of stand-still traffic, allowing vehicles to resume flow in a reduced period of time (from the beginning of the incident to the clearance of the event). Minister Ben Martins referred to the quicker response time as the ‘golden hour’, stating that it is the critical time period in which lives could be saved in the case of a serious incident (Safety greatly boosted by N1/N12 interchange upgrade – SANRAL 2013). Figure 2.1 indicates the CCTV cameras and VMSs on the road network.

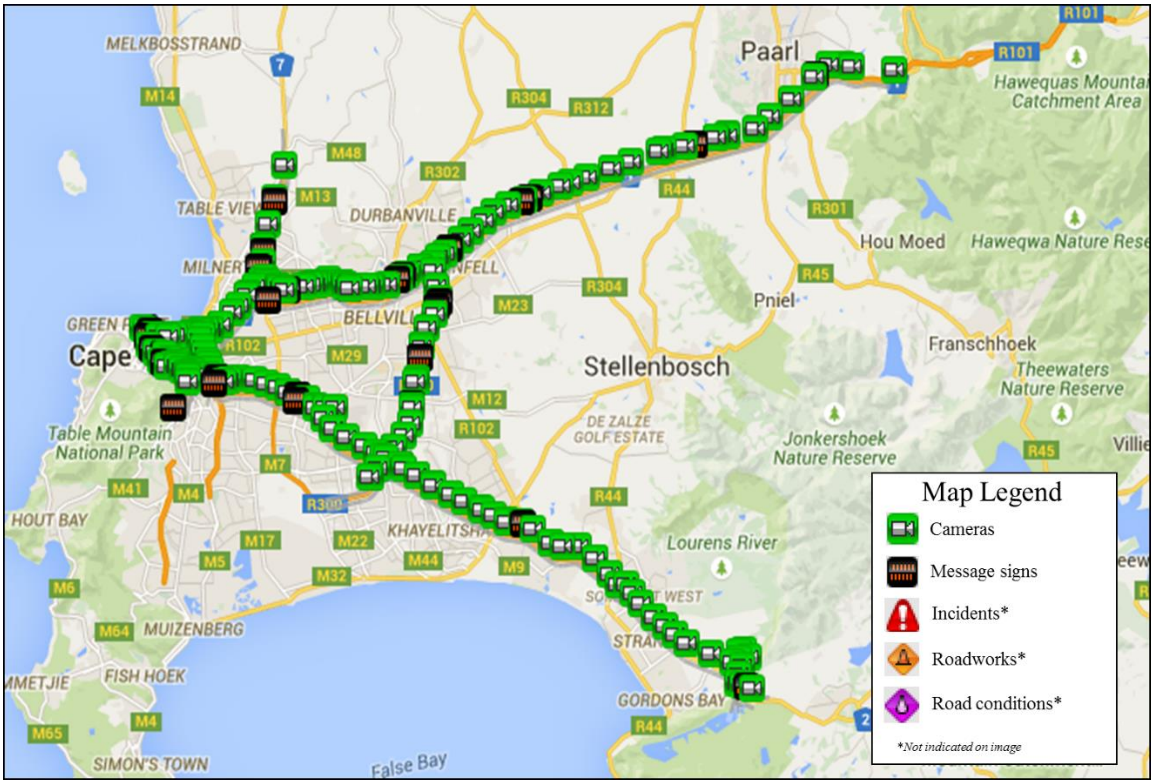


Figure 2.1: CCTV Camera (Green) and VMSs (Black) in the Western Cape (www.i-traffic.co.za, 2016)

A study conducted by Sanral indicates the influence of the deployed infrastructure on response times of the respective emergency response services. Figure 2.2 shows this progression.

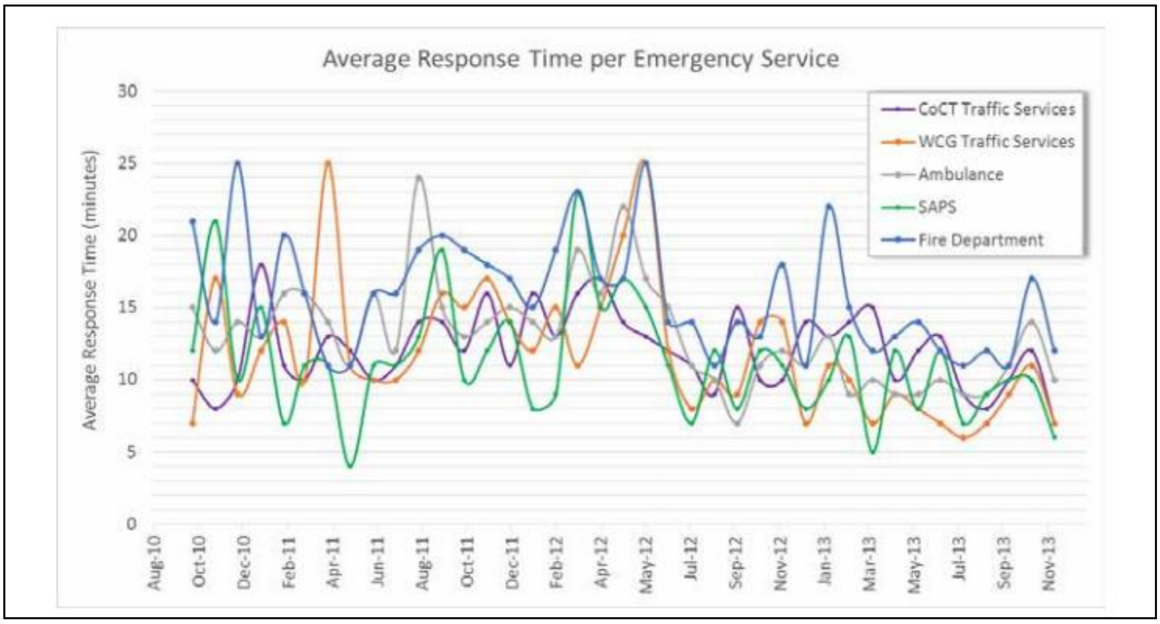


Figure 2.2: Response Time per Month per Emergency Service (SATC, 2014)

Figure 2.2 shows a clear decline in the response times for every emergency service since the completion of the Traffic Management Centre (TMC). The average response time has decreased to a response time of approximately 10 minutes.

Based on the information and statistics given, Sanral, the Western Cape government and the City of Cape Town have strengthened the efficiency of the transportation network due to the management and expansion of infrastructure, which in turn relates to the ability to identify incidents. The privilege of identifying the incidents as they occur has produced an efficient system in which the concerns experienced on the road could be viewed without a physical site visit. This would provide a clear increase in productivity in the operations centre and would thus allow for more incidents to be addressed.

In addition to the effect on incidence response, an improvement over the safety of drivers and pedestrians has occurred as a result of the refined interaction with the public – not only has this led to an improvement in the response times, but has enhanced the provision of valuable traveller information. This may be attributed to the implementation of the VMSs, i-Traffic website and information received via social media such as Facebook and Twitter. Both infrastructure and communication has led to an improved performance for the TMC.

2.1.1 THE FREEWAY MANAGEMENT SYSTEM IN SOUTH AFRICA

The transportation industry in South Africa has seen major changes that have taken place due to the improvement of infrastructure and the use of technology to improve the driving conditions on the road. This improvement however, has come at a price. The price in this case is the overall cost of infrastructure, whether it is the infrastructure itself, the construction to erect the required items or the maintenance and operational costs involved.

Although the cost factor is crucial for consideration (it would be costly to implement additional infrastructure), increasing the network of infrastructure will be based perceivably on dated means of monitoring traffic – at present, the technology is current and updated; it does not however, correlate to the global trend of acquiring traffic information (i.e. establishing communication with vehicles). Even though this current implementation of the FMS has proven to be an improvement to the traffic network, simply continuing with the use of this form of technology and dated monitoring methods may lead to criticism of its sustainability and progressive effect.

In addition, this form of technology requires an immense storage capacity. Due to this required level of storage, the information concerning video footage of the traffic cannot be archived for extensive time-periods. According to the employees at the Traffic Management Centre (TMC) in Goodwood, Cape Town, all video footage is stored for two to three months before it is over-written; major incidents however (particularly accidents and criminal activity) are archived for 5 years.

It is vital to understand the traffic management industry and the transportation sector in order to identify potential drawbacks, improvements as well as to understand the need for a change in the current systems used. The following items described are intended to provide a basic understanding of the current situation and the technology that is available.

2.1.2 HOW INTELLIGENT TRANSPORTATION SYSTEMS (ITS) IS INCORPORATED

Intelligent Transportation Systems (ITS) is the use of advanced technology in order to improve the transportation network in such a way that it allows the users to make educated decisions with reference to their use of transport, as well to make the users aware of their immediate environment.

ITS at its basis, means the incorporation of the systems in which information and communication technologies are applied in transportation. This not only includes the infrastructure, vehicles and users, traffic and mobility management, but also the interfaces of other modes of transport (Intelligent transportation systems (Wikipedia) 2015).

Because ITS in general is understood as information and communication technologies, ITS could be dated back to the construction of the first road and first implementation of road signage (the use of signboards to give direction to the users of the roads) (Intelligent transportation systems (Wikipedia) 2015). The origin of the initial use of technology to establish control over the transport network however, according to (TransNav, 2012), states that the use of Intelligent Transportation Systems was approved in the United States and Japan in 1991, and later in 1994 in Europe. The improvement of ITS is however directly related to the progression of technology – ITS is thus a field that is assured to expand innovatively.

At present, ITS has progressed from storage on single systems to cloud based storage in countries such as the United States and England. Furthermore, users have been provided with improvements such as real-time information via applications and websites (Waze, Google Traffic, TomTom internationally, and i-Traffic by Sanral locally for example), provision of traffic maps and information regarding the arrival times based on the route taken and traffic conditions on that particular route.

ITS is a domain in which constant expansion and innovative methods and applications are frequently developed. The aim hereof is to improve the transportation network in terms of safety and efficiency. Vast opportunities therefore exist for improvement of the entire network within this field.

2.1.3 SANRAL INCORPORATING ITS INFRASTRUCTURE INTO FMS NETWORK

This section provides a brief description of the current FMS network in the Western Cape and the intended operation of incident management.

2.1.3.1 SANRAL

Implementing additional infrastructure would extend the Freeway Management System's visibility over the freeway, which would provide a greater improvement in terms of the response to incidents and the provision of traveller information. In Part B of Sanral's Strategic Plan (Strategic Objectives), the first objective is to *manage the national road network effectively* (Strategic Plan 2012). Within this objective, the first requirement stated on their behalf is to establish growth in infrastructure. The following networks were identified for the regions in which this growth would be required to take place (adapted from Sanral: Strategic Plan 2012):

- **Core Strategic Network -** the most important roads in South Africa identified based on a list of criteria. Total length was approximately 9200 km
- **Secondary Strategic Network -** Additional roads required to complement the Core Strategic Network and alternative routes. Total length of the network identified was approximately 9600 km
- **Primary Road Network -** Additional roads that act as the primary feeder network to the Strategic Road Network. Total length of the network identified was approximately 14 000 km

The Core and Secondary Strategic Network were combined to form the network that falls under Sanral's jurisdiction which was calculated to be 16 170 km of road in 2011 (adapted from Strategic Plan 2012).

Within this road network, there are about 450 kilometres of roads under the management of Sanral which are equipped with ITS devices and will be expanded over the course of the strategic plan (Strategic Plan 2012). Figure 2.3 indicates the extent to which Sanral plan to extend the ITS network in the Western Cape.

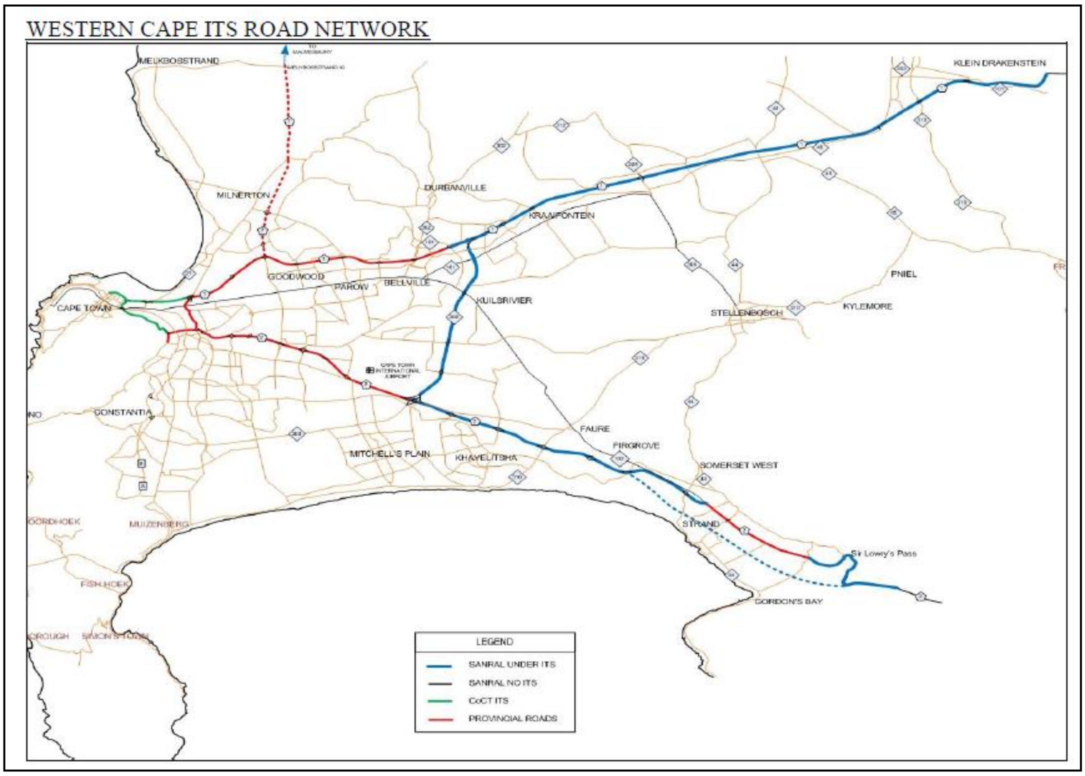


Figure 2.3: Expansion of ITS network (Strategic Plan, 2012)

Sanral plans to extend the FMS network (installing additional CCTV cameras and Variable Message Signs). Based on the discussed improvements in response to incidents, expanding the network would most probably result in a more efficient network as a whole, at the very least it should improve the incidence response and traveller information received in the areas in which the expansion is planned to commence.

2.1.3.2 INCIDENT MANAGEMENT

The FMS has established an elaborate approach to managing and improving incidence response. According to Sanral's website (www.nra.co.za, n.d.), traffic growth statistics for South African roads states that traffic grows by 6% per annum. Additionally, accident rates were determined to contribute to delays, bottlenecks and congestion while additional time taken during detection of accidents, activating responses and gaining access to the scene – these factors have contributed to the necessity for a detailed incident response approach.

The following diagram indicates the procedure followed 'to ensure that the event is responded to in the appropriate manner and that traffic is able to flow normally after the shortest period of time possible.' (www.nra.co.za, n.d.). The reduced delay would also allow for shorter response times which may assist in saving a life in a critical situation.

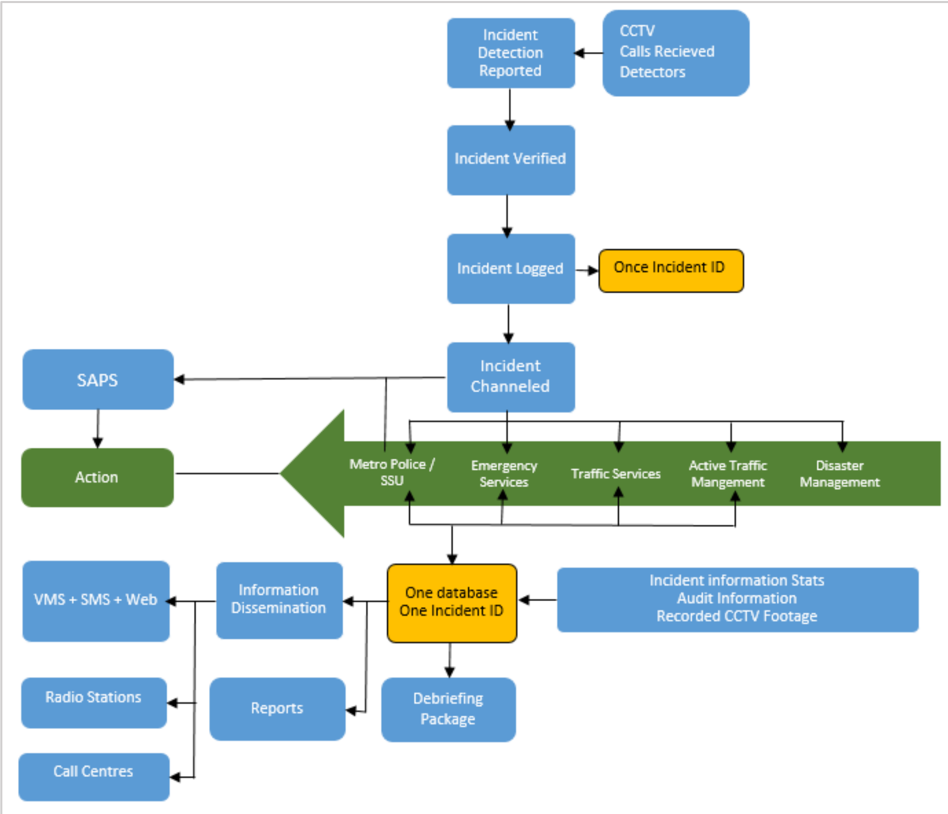


Figure 2.4: Process of addressing incidence response (Adapted from CoCT 2008)

As a result of the procedure in Figure 2.4, responses to incidents by all services has improved along with a reduction in clearance times (Figure 2.2). Vehicles may therefore spend less time in traffic and the network could resume normal functionality in reduced time-periods. Incidence response is seen as a priority according to Sanral (www.nra.co.za, n.d.), however, with a growth rate in traffic of 6% per annum, addressing incidents may become more complex.

2.1.4 TRAFFIC MANAGEMENT CENTRE OPERATIONS

This section will begin with a discussion of the operations of the Freeway Management System, followed by a discussion of the Advanced Traffic Management System and Advanced Traveller Information System within the TMC.

The Freeway Management System incorporates several operational procedures to provide the services necessary for the efficient operation of the traffic network with the assistance of field devices. The FMS attains information with the use of various infrastructure, communication with services and on-site identification of incidents. This information received is the “Input” (Table 2.1), where all of the resources mentioned are used to gain information.

Table 2.1: Resources for information Input to TMC (Adapted from CoCT, 2008)

Input	
Traffic sensors	Commercial radio
Weather sensors	Radio Communication
Telephone and SMS	Traffic Control Systems
E-mail and Internet	Vehicle Location (GPS)

This data is then processed to determine the most relevant and applicable information. The manner in which information is processed, according to CoCT (2008), is illustrated in Figure 2.5. The first step is to capture the information (attained with the above-mentioned resources). Thereafter, the information is validated with the use of a combination of resources or CCTV surveillance footage. During storage, the information is either retained for three months (regular footage) or five years (in the case of an incident), relating to the process of organising the information. The information is then used for calculation purposes (to determine the amount of time of travel on a section of road in the event of an incident). Mining of information refers to determining and extracting the most valuable data and thereafter, enriching that information with additional resources. Thereafter, the information is reported to the relevant parties and distributed to all services to resolve the identified concern.

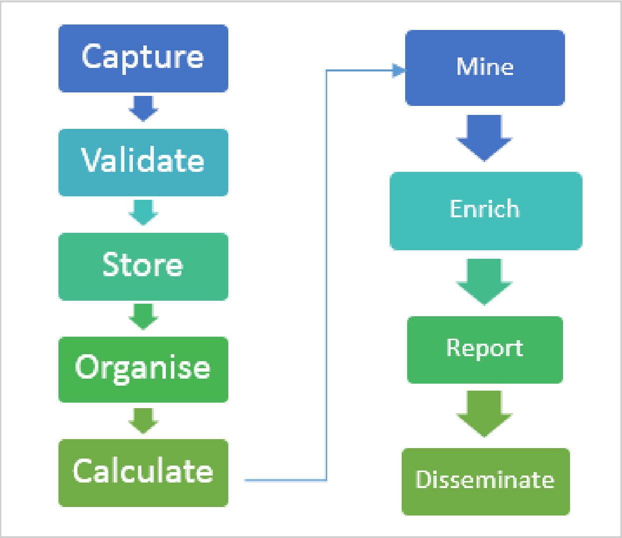


Figure 2.5: Process of utilising information received (Adapted from CoCT 2008)

In relation to the final step in the process (Disseminate), the information is further distributed to the public to allow motorists to make informed decisions; this is referred to as the “Output”, which is distributed via the outlets indicated in Table 2.2.

Table 2.2: Sources of distributing information to the public (Adapted from CoCT 2008)

Output	
Variable Message Signs (VMS)	Social Media (Twitter, Facebook)
SMS and MMS	Applications (i-traffic web application)
Radio and TV Stations	Website (nra.co.za)

Figure 2.6 indicates the current manner in which information is obtained, processed and disseminated for public use and management of the FMS:

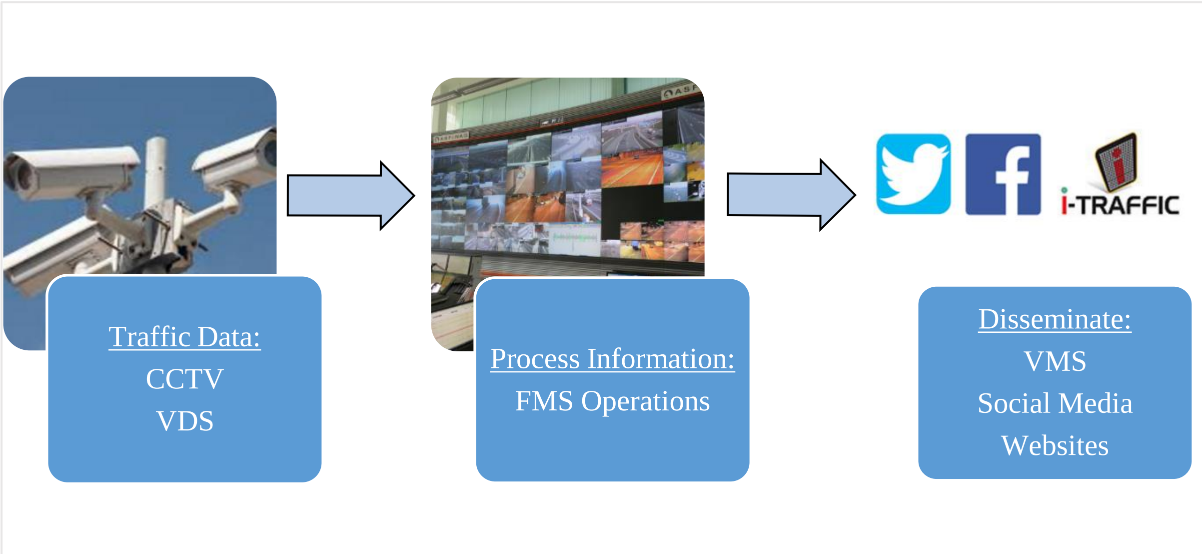


Figure 2.6: Summarised FMS Operations (Adapted from Cable, 2015)

Providing the public with information about road conditions and incidents allows drivers to adjust their route of travel; this allows travellers to save time during travel and allows the traffic network to flow while the congested routes are cleared.

The FMS requires traffic data to produce relevant information (Input and Output), but is also responsible to ensure that the network operates smoothly; this introduces the final operation item "Action". These actions involve identifying the type of incident and requesting assistance of the relevant service provider. Once the type of incident is identified, the applicable services are contacted to address the situation. These services are mentioned in Table 2.3:

Table 2.3: Services required by the TMC for freeway management (Adapted from CoCT, 2008)

Action
Incident Prevention & Response
Traffic Law Enforcement

Transport related Disaster Management Support
Active Traffic Management (FMS, AMS, UTC)
Integrated Rapid Transport (IRT) Management
Special Events: Transport and Traffic

Through effective management and operations, the FMS has produced positive results concerning improved incidence response and clearance times. This is the result of existing infrastructure, granting the TMC real-time surveillance within the Freeway Management System. Furthermore, with the established procedures, management, surveillance, effective operation and investigations in place, the ability to influence the traffic network has produced the positive impact initially envisaged. With surveillance in place and the ability to micro-manage the network, problematic sections may be identified and revised to increase efficiency of traffic.

2.1.5 ADVANCED TRAFFIC MANAGEMENT SYSTEM (ATMS)

The purpose of ATMS is to optimally manage recurring traffic congestion (morning and evening peak-flows) while alleviating the occurrence of non-recurring traffic congestion (incidents, weather conditions) on the freeways in assistance to the FMS. Solutions to congestion are approached by utilising existing infrastructure (such as CCTV footage and VDSs). The problems that are typically considered are congestion caused by normal traffic patterns and traffic problems caused in the event of incidents (Studio, 2013). The ATMS is thus responsible for the "Input" and processing of the information received.

Objectives of ATMS are threefold; to improve safety of all road users, to inform road users of real-time traffic conditions and to improve the efficiency of operation of the traffic network (Maharaj, K. 2012). Maharaj, K. (2012) expands these main objectives to elaborate on the manner in which they are achieved:

- Safety:
  - Monitor road conditions before, during and after
  - Reducing incidents
  - Clearing accidents quickly
  - Monitor daily traffic volume
- Inform
  - Improved efficiency by managing congestion
  - Giving motorists more information
- Efficiency of Operation

- Integration of systems

Operations commence with the identification of an incident. The incident is then confirmed with existing infrastructure to dispense the necessary action and response (Maharaj, K. 2012). Finally, the relevant information is transferred to the Advanced Traveller Information System, which will be discussed in the following section.

2.1.6 ADVANCED TRAVELLER INFORMATION SYSTEM (ATIS)

The aim of ATIS is to provide travellers with real-time and non-real-time information of their journey given the unpredictable behaviour of traffic patterns. This allows users to decide on alternative routes, forms of travel or travelling at different times (Kristof, T., Lowry, M., Rutherford, G., 2005).

ATIS thus assists the FMS with the provision of multiple sources of information to allow travellers sufficient time to adjust their travel route. Information is provided via i-Traffic, VMS information, Twitter, Facebook and SMSs. With these systems in place, travellers may be able to avoid congestion and possibly improve their time of arrival at their destination. Traveller information further assists with the efficient flow of traffic, provided travellers utilise the information provided.

2.1.7 CURRENT OPERATION VERSUS POTENTIAL CAPABILITY

At this stage, apart from management of the roadway, the ITS infrastructure is currently utilised for incident management and the provision of traveller information (as discussed in the previous sections). With the infrastructure available, the extent to which these devices are currently used should be considered.

To accomplish this, consideration of the infrastructure and its use must be established:

Table 2.4: Current use of ITS Infrastructure

Infrastructure	Operation	Current Use
Variable Message Signs (VMS)	Information display	Incident information Traveller Information
Environmental Sensor System (ESS)	Weather information	Traveller information – weather conditions
Vehicle Detection System (VDS)	Detects vehicles	Traveller information – vehicle speeds, travel time, congestion areas, vehicle classification

Closed-circuit television (CCTV)	Surveillance	Incident detection to assist with Incidence response and traveller information of traffic situation. Also used to show users current traffic conditions (i-traffic)
Electronic Toll Collection (E-toll)	Wireless Payment System	User-pay system in place to manage tolled roads
Registration plate Detection System	Speed over distance Traffic Cameras	Used to monitor speed of vehicles travelling along the road network over long distances to ensure conformance to speed limits.

With the current infrastructure in place, as previously mentioned, operators are able to provide information to users, identify incidents and report the information to emergency response units, provide travel time and alternative route suggestion information to users and (with the use of the VDSs) classify the vehicles on the road. However, with the availability of VMSs, the application (in addition to providing travel time information) could be used to adjust or suggest more efficient travelling speeds (Ops.fhwa.dot.gov, 2015) – conversely, a VMS may have to be located above every lane to ensure that all vehicles are aware of the adjusted speed. This is however, a possible extension into managing traffic for efficiency and possibly to save on costs instead of incorporating additional infrastructure.

Additionally, Ramp-Metering (Ops.fhwa.dot.gov, 2015) could possibly be explored. Ramp-metering monitors traffic on freeways and adjusts the access of vehicles from on-ramps to ensure that traffic flow on freeways remain relatively consistent. The infrastructure required (in addition to the existing system) would be minimal (merely requires a traffic light and power source with red and green signals to allow vehicles to access the freeway) and would serve to compliment the current system i.e. ramp metering would work in conjunction with the existing network.

These suggestions indicate that the current means of operation involve the identification of issues on the freeways, management of existing traffic and provision of traveller information. It may be unfair to assume or expect that these methods would alleviate traffic, especially considering that traveller information does not require drivers to utilise the information. While improvements in clearance and response times are indeed confirmed (Figure 2.2), the use of these systems (*Section 2.1.3 to Section*

2.1.6) suggests that there may not specifically be an active attempt to manage and control traffic operations on the freeways with the use of ITS infrastructure.

2.1.8 CURRENT INFRASTRUCTURE DATA COLLECTED

Infrastructure data is dependent on the existing equipment deployed within a region. In South Africa, and particularly the Western Cape, the infrastructure capable of supplying data include Vehicle Detection Systems (VDSs), Closed Circuit Television (CCTV) cameras, Environmental System Sensors (ESSs), traffic signals (although not used in FMS), while information may currently be provided by Variable Message Signs (VMSs). Data that may be transferred as a result of these systems include (MDOT, 2014):

Road Surface Weather Conditions:

- Air temperature
- Wind Speed
- Precipitation
- Visibility

Intersection Status (Potential for data provision, not currently utilised in FMS operations):

- Real-time operation status
- Signal phase and timing
- Intersection geometry
- Approaching vehicle information (position, velocity, acceleration and turning status)

Field equipment status:

- Variable Message Signs
- Dynamic lane signs or control devices

Parking information (not currently in use, potential for future use):

- Location of parking facilities
- Spaces available

Additional information that may be transferred with the deployment of DSRC devices in the network will be discussed in *Section 2.2.5*.

2.1.9 CONCLUDING REMARKS

The presence of the TMC and the operations that it incorporates, specifically the FMS, in the Western Cape has positively impacted the management and operation of traffic on freeways. Multiple infrastructure has been deployed to allow for consistent inspection and monitoring of events and repeated occurrences of events; this has allowed the FMS to deploy the appropriate assistance to relieve the congestion caused by these events.

Consequently, due to the increasing population and the number of vehicles on South African roads since 2010, the improvements achieved by the operations of the FMS may have reached an optimum level. Within the Western Cape, Cape Town has become the most congested city in South Africa (tomtom.com, 2016) and the road accident death rate in South Africa remains high at 25.1% (WHO | Road traffic deaths, 2013) – an informal study determined that the accident death rate in the Western Cape was 8.72 per 10 000 vehicles for the period of 2010/2011 (Africa Check, 2013). Sanral has set systems in place to assist in decreasing congestion on the roads by improving incident management, improving signal phase timing, utilising probe data, proving a website that provides traveller information and VMS signs that provide travellers with the approximate time of arrival at their destination. These systems however, have not produced a reduction in congestion, since the focus with the Freeway Management System is on incidence response and traffic data for traveller information. With the growing live traffic population, increase in crashes and congestion (refer to *Chapter 1 Section 1.4*), a viable solution to managing traffic is required that is more efficient and sustainable.

2.2 THE CONNECTED VEHICLE

Connected Vehicle (CV) technology is currently envisaged to produce a significant change to transportation and presents the possibility of improving the efficiency and safety of transport networks globally. Multiple pilot studies were conducted to investigate the performance of these machines in the real-world. These tests will be used to determine the infrastructure necessary for CV technology to impose the predicted impact on the transportation network, and to determine the amount of technology required in each vehicle for an impact to be achieved. In this section, the development of the connected vehicle will be discussed. Furthermore, a discussion on the possibilities that CV technology may present, the reach that CV technology may provide and the information produced by CVs. Finally, the challenges that will be faced with implementing CV technology and the probable applications available due to connected vehicles will be presented.

2.2.1 DEVELOPMENT OF THE CONNECTED VEHICLE

The idea of having a vehicle communicate with its surroundings began as early as the idea of an intelligent transportation system (NHTSA 2014). The possibility of accomplishing the results that a functional network of connected vehicles would produce may change the entire transportation system. These possibilities include a major reduction in accidents of drivers and pedestrians, a time efficient network operation, and reductions in traffic jams due to more control over the flow of vehicles. The growth of connected vehicles may provide the most significant change to the transportation network with regards to safety; reliance would no longer be placed on the driver – the errors of the driver would be corrected by the technology.

According to the Journal (*Connected Vehicles: Solutions and Challenges*), the connected vehicle refers to wireless connected vehicles that have the ability to communicate with their internal and external environments. There are different forms of communication that describe this internal and external communication, namely vehicle to sensors on-board (V2S), vehicle-to-vehicle (V2V), vehicle-to-roadside infrastructure (V2R) and vehicle-to-Internet (V2I) (IEEE INTERNET OF THINGS JOURNAL 2014: 1:289). Figure 2.7 illustrates the potential use of each system in reality.

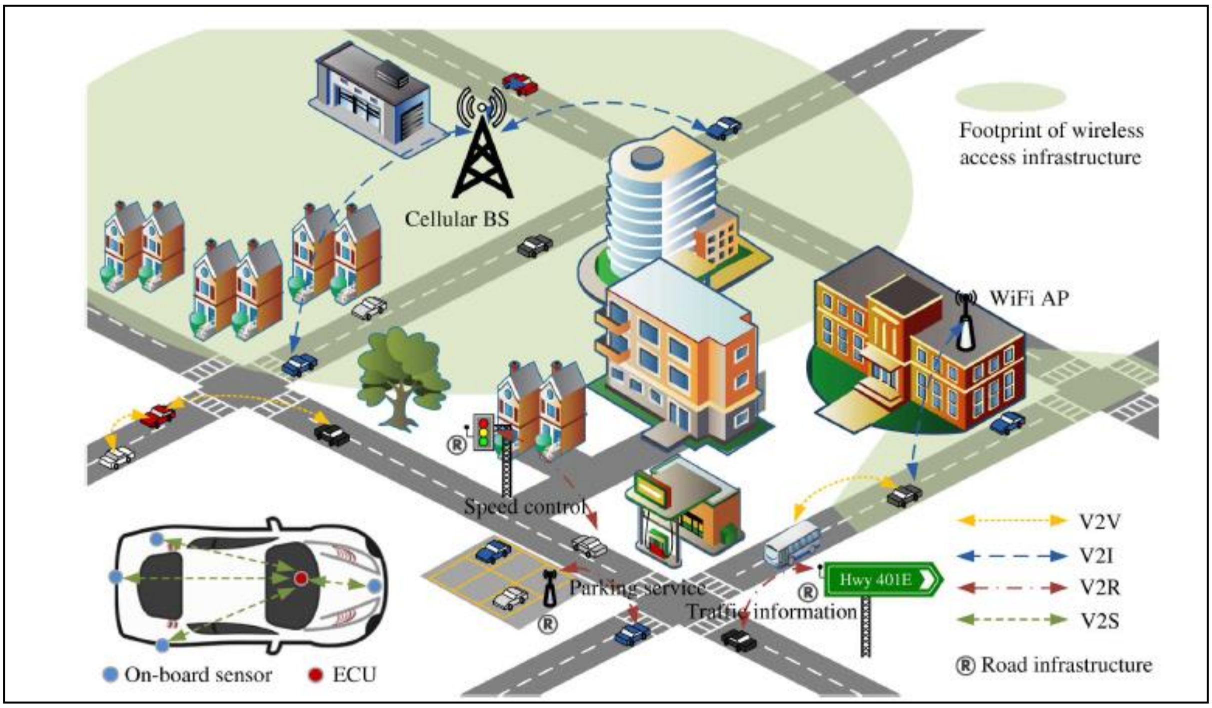


Figure 2.7: Connected Vehicle Communication Channels (Connected Vehicles: Solutions and Challenges (2014))

Collectively, these forms of communication are referred to as Vehicle-to-Everything (V2X) communication (not indicated in Figure 2.7).The internal (on-board) sensors within the vehicle are purely for the safety of the driver and occupants. The sensors have the ability to detect certain patterns in driver behaviour or may be able to predict the behaviour of the driver. Most modern vehicles are equipped with these sensors; the behaviours detected include fatigue or lack of concentration on the road. Furthermore, the sensors assist the driver with areas of the vehicle that are not visible, such as the rear c-pillar (blind spot) and the rear and front bumpers. These sensors will assist in warning the driver if an object is too close to the rear of the vehicle when reversing and if the driver is too close to an object ahead of the vehicle. As many as 200 sensors are forecast per vehicle by 2020 (IEEE INTERNET OF THINGS JOURNAL 2014: 1:290).

Communication between vehicles is arguably the most significant aspect of connected vehicles. Although the sensors within the vehicle will provide the driver with the required assistance to ensure the safety of its occupants, the communication with infrastructure and the internet is additional to the goal of achieving a safer driving experience. If the vehicles can avoid each other via communication, a great percentage of accidents and deaths could be avoided. A factor of concern is the manner in which communication would be established between CVs (V2V communication). The wireless communication required would be affected by line-of-sight (LOS) interference – this could be buildings that are in the path of vehicles approaching an intersection; or a larger vehicle in the path of a light vehicle, whilst the vehicle ahead of the larger vehicle breaks suddenly. Additionally, the communication would be disrupted in a Wi-Fi-dense area. These challenges can be minimised with the consideration that the mobility of the vehicles are restricted to maps, most of which are known – as long as a vehicle can be tracked via the Global Positioning System (GPS) (which is the case for most vehicles) issuing warnings and alerts to drivers can still be achieved (IEEE INTERNET OF THINGS JOURNAL 2014: 1:p. 292).

The communication of vehicles to road side infrastructure is significant to the reduction of accidents (IEEE INTERNET OF THINGS JOURNAL 2014: 1:p. 296). The vehicles would communicate with devices such as traffic signals (the driver will be able to time the green), road signs and roadside sensors (cameras, detectors, speed cameras). The manner in which the infrastructure will communicate with the vehicles is through Dedicated Short-Range Communications (DSRC connectivity), a wireless communication channel which does not operate at the same frequency as Wi-Fi, restricting the communication to vehicles and infrastructure only. Communication between infrastructure and vehicles would provide the most knowledge of the conditions of the traffic network, which would allow for a significant reduction in traffic congestion, would allow vehicles to flow more efficiently and would reduce travel times considerably.

Accessing the internet in vehicles has become a common task based on the globalisation of Smartphones and the necessity of operators to be in contact with the drivers of their vehicles (for the safety of the driver). For example, if a vehicle with access to the internet was involved in a collision, the operator would be able to reach the driver directly to assess the situation and issue the appropriate safety measures. The Journal *Connected Vehicles: Solutions and Challenges* states that a connection may be achieved via a Wi-Fi connection. The associated challenge however, is attaining the connection for long enough to be able to extract data from the vehicle (the Wi-Fi panels are stationary and have high latency). This data will be discussed in the following section (*Section 2.2.5*).

The connected vehicle will incorporate the influence of big data to supply service providers and repair workshops with the necessary information that will allow for prior knowledge to problems that users may experience with their vehicles. As mentioned previously, by 2020, every vehicle will be manufactured with sensors providing data about every detail of the vehicle and the occupants (IEEE INTERNET OF THINGS JOURNAL 2014: 1:290). According to (T-Systems International GmbH, 2013), it was anticipated that 80 percent of road vehicles would be connected to the internet by 2016, implying a growth rate in connection of 36% in vehicles on the road (T-Systems International GmbH, 2013). Additionally, Gartner. Inc. forecasts that one in five vehicles worldwide will have some form of wireless connection by 2020, implying more than 250 million connected vehicles (gartner.com, 2015). While these may be predictions, it does mean that the amount of data received from connected vehicles would grow at an exponential rate. This data for example may constitute the real-time velocity of the vehicle, location, throttle response, vehicle ID etc. (refer to *Section 2.2.5*). According to Glanz et al. (2014), a single Connected Vehicle may transmit between 20 and 100 gigabytes of data per hour. Considering the amount of private vehicles currently on Western Cape roads (1 903 773 as of 31 July 2016 (Enatis.com, 2016)) and the extent of vehicles required to be connected, management of data through cloud computing and Big Data (discussed in *Section 2.2.5.1*) would be a necessity (as an illustration, if only 5 000 vehicles were connected and allowed to transmit all of their data to roadside DSRC devices, between 10 000 and 500 000GB of data may be generated and transmitted per hour). Furthermore, this data will need to be analysed correctly to ensure that customers receive the appropriate attention and information, and that the manufacturers and operators receive the correct data (discussed in *Section 2.2.5*). T-Systems has identified three benefits of implementing big data with connected vehicles:

- Will improve the development of the vehicle
- Will enhance the ability to plan services due to the ability to recognise faults
- Will lead to an increased customer satisfaction

Figure 2.8 provides a description of the information transfer between the relevant parties, namely from the vehicle to the manufacturing workshop, and further the warning and progress alerts to the customer.

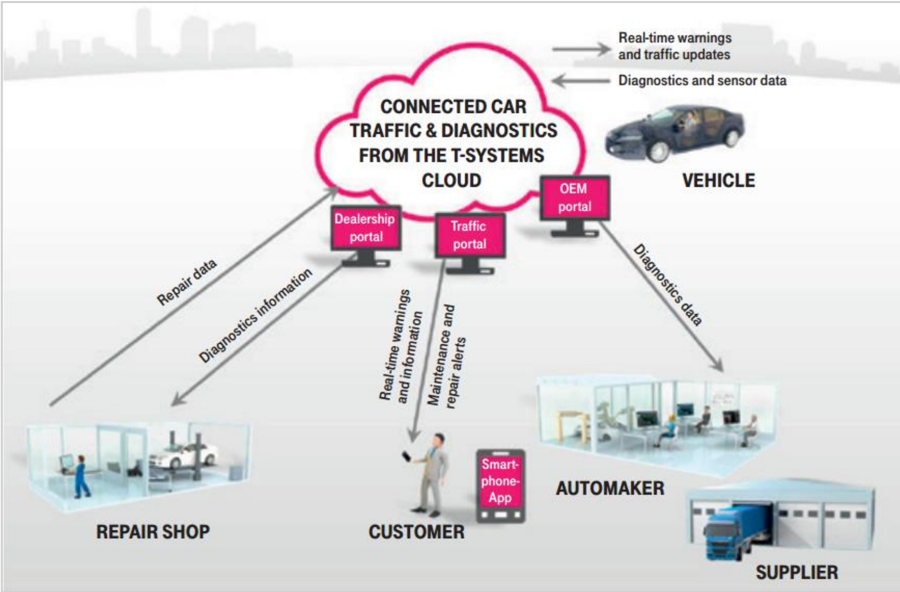


Figure 2.8: Information Transmission between Parties (CONNECTED CAR: TRAFFIC AND DIAGNOSTICS (2013))

Based on the discussion, connected vehicles may significantly impact on the transportation network, given the extent of the network that it would allow transportation operators to access. The connected vehicle will however, only flourish in an environment that supports its capabilities – that is, the road side infrastructure should be able to supplement the potential of connected vehicles to enhance their anticipated performance.

Sections 2.2.5 and *Section 2.2.6* discusses the vehicle data that may be transferred, the vehicle's requirements before installation of any type of connected equipment, and the devices necessary for a connection to be established respectively. For the vehicle requirements to be understood, context of Connected Vehicle Applications must be given – these Applications will be discussed in *Section 2.2.3*.

2.2.2 POSSIBILITIES OF THE CONNECTED VEHICLE

According to a study conducted by the Atkins group (Atkins, 2015), the connected vehicle has the potential to not only improve the safety and efficiency of the traffic network, but could provide previously unexplored opportunities for visually impaired and physically challenged individuals. The following diagram illustrates the (external) opportunities presented by Connected Vehicle technology. It should be noted that CAV refers to Connected and Autonomous Vehicles (refer to *Section 2.3* for Autonomous Vehicles).

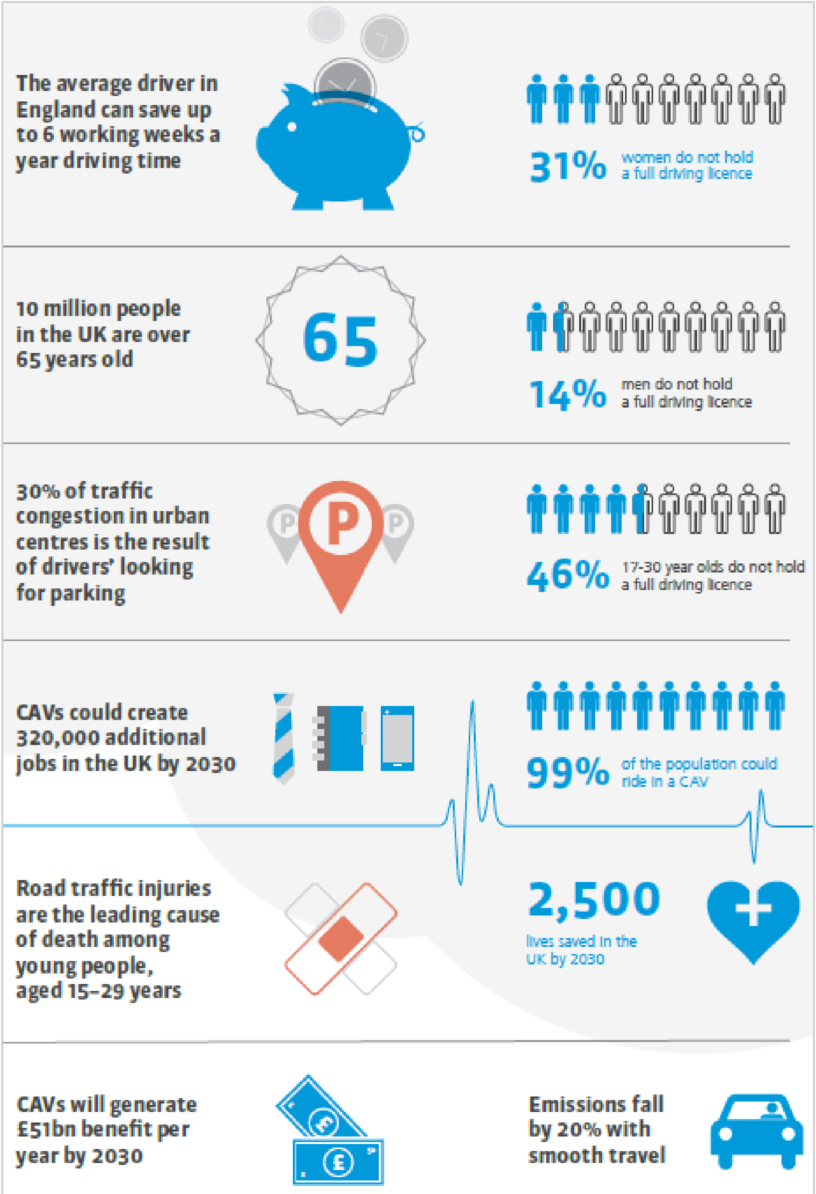


Figure 2.9: Potential effects of Connected Vehicle technology in the United Kingdom (Atkins, 2015, p.8)

Figure 2.9 indicates an influence in mobility, efficiency, safety, environmental health and economic improvement. This is clearly a technological advancement with the potential to improve the productivity of any economy, and should be the direction pursued in management of the traffic network.

Additionally, a study conducted by KPGM (Leech et al., 2015) confirms the forecasted impact presented in Figure 2.9 and suggests an improvement in the GDP of the economy. The study proceeds further into the opportunities that exist because of CV technology:

- **Decision-making software**: Connected Vehicles will present an immense amount of data may be utilised for software development. These software packages will be required to analyse complex information to be optimise the options available for decision-making purposes. For example, in the event of an accident, the vehicle may be presented with a situation in which a collision is certain and unavoidable and the best option should be executed. The best decision however, may be for the safety of the driver or for the safety of all road users. The risks associated with this software may negatively affect the reputation of vehicle manufacturers depending on the decision made by the vehicle.

- **Vehicle cyber security**: CV technology will be connected to the internet, presenting the possibility of hacking (cyber-attacks) into vehicles and either manipulating the system protocols or gaining personal information from vehicle owners. The opportunity in this case is the development of software and security to ensure the prevention of cyber-attacks.
- **Data Opportunities**: As was previously stated, connected vehicles will generate great amounts of data about consumers. As a result, different vendors may be able to seize the opportunity for developing software that will assist consumers in terms of vehicle requirements and consumer needs. Based on the traveller's routine, the vehicle may be able to suggest locations for the driver to consider – for example, if the driver exhibits unnatural driving behaviour, the vehicle may suggest pulling off at the nearest fuel station. Additionally, vehicle manufactures and aftermarket developers may be able to monitor vehicles and the operation of their products to assist in maintaining or replacing these items.

Although there are areas where connected vehicles may fall short, these are purely software related and may be addressed with the implementation of stricter systems and exploring the possibility of creating software accessible only to vehicle manufacturers, that is, creating software that is exclusive to manufacturers. This may further present compatibility and market penetration concerns, but is an area that requires great attention.

Connected Vehicle technology presents excellent opportunities for future developments, while the barriers need to be addressed appropriately. It is however clear that the positive possibilities far outweigh the drawbacks. Improving the efficiency and safety of the transportation network is crucial, especially in South Africa where limited expansion opportunities are available. CV technology therefore, may present the gap that currently exists in achieving optimal travel times and reducing the number of lives unnecessarily lost in the event of road accidents.

2.2.3 CONNECTED VEHICLE APPLICATIONS

This section provides a description of the possible Connected Vehicle applications that may be employed (Iteris.com, 2016) and discusses the relevance that these applications may have to the South African environment. Thereafter, the applications were marked in terms of applicability to South Africa and the possible implementation period. The implementation period was divided into Near-Future (5 – 10 Years) and Deployed Later (10+ Years) to indicate the potential time period in which applications of this nature may be deployed in South Africa. The basis for selection of possible near-term or later deployment was the anticipated complexity of the systems necessary and the environment that would be required to support the applications described. For example, an application such as Advanced Traveller Information may currently be in place and further developed since the technology exists in South Africa, in the Western Cape, for its use. Alternatively, an application such as CV-enabled Origin-Destination Studies would require a substantial market penetration of Connected Vehicles to be a useful system. The following table analyses the current possible Connected Vehicles as stated by the USDOT (Its.dot.gov, 2016).

Table 2.5: Description and Evaluation of Connected Vehicle Applications

	Application	Description	Applicability	Near-Future (5 – 10 Years)	Deployed Later (10+ Years)
Mobility	Border Management System	May provide international border registration border inspection capabilities.	Not applicable to South Africa	N/A	
	Advanced Traveller Information System	Collects, categorises and distributes traffic information such as road weather and traffic conditions to all possible information channels (Applications, Road signs, etc.)	Highly applicable. Would be able to assist with better traffic management and operation.	√	
	Intelligent Traffic Signal System (I-SIG)	Optimises the traffic signal phasing and timing operations based on real time evaluation of intersection behaviour by obtaining movement data from equipped and non-equipped vehicles.	Very useful. Could reduce delays significantly and increase throughput at intersections, especially due to changing demand.	√	
	Signal Priority (Transit, Freight)	Utilises V2I communication to determine the presence of heavy vehicles to increase traffic signal times, allowing heavy vehicles to pass through signalised intersections. The heavy vehicle uses V2I communication to “request permission” to pass through an intersection.	Also useful. Heavy vehicles decrease the maximum throughput of vehicles due to increased start-up times. Allowing heavy vehicles to pass through intersections may increase flow of network. Applicable to South Africa given the distribution of heavy vehicles (enatis.com, 2016)	√	

	Mobile Accessible Pedestrian Signal System (PED-SIG)	Will be used to gain access to pedestrian mobile devices for integration with traffic operation to detect the presence of pedestrians on crossings at signalised intersections. Provides the pedestrian with a time to cross an intersection by considering the movement of traffic.	Would prevent pedestrian accidents at intersections and warn drivers when vehicles pedestrians are not in sight. Smartphones mean that this could be applied in South Africa.	√	
	Emergency Vehicle Pre-emption (EVP)	Provides priority to emergency response units regardless of opposing traffic demand.	Highly applicable. EMSs obtaining priority at intersections may prevent other vehicles stopping suddenly in signalised intersections to give EVs priority. Furthermore, it could improve the response time if EVs do not have to slow down at intersections and slowly move past stationary traffic at these intersections	√	
	Dynamic Speed Harmonisation (SPD-HARM)	Provides a suggested travelling speed along the roadway to reduce delays and improve efficiency	May improve efficiency within the network, reducing emissions and fuel consumption, increasing driver response awareness and may reduce congestion.	√	
	Queue Warning (Q-WARN)	Provides users along a roadway with information of potential queues and existing queues downstream of travel, and suggests the use of alternative routes with the predicted time of arrival for the suggested alternative.	May improve efficiency by allowing vehicles to be aware of queue formations, vehicles may then be able to consider alternative routes, or may adjust their speeds to reduce delays if in the queue.	√	

	Cooperative Adaptive Cruise Control (CACC)	Allows vehicles to communicate with one another to promote the formation of platoons when travelling along the freeway. The vehicles following a leading vehicle are warned immediately of changes in speed and lane changing information.	May improve the throughput of vehicles as it would optimise road capacity, decrease occurrence of shockwaves and thereby reduce emissions and fuel consumption.		√
	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)	Intended to provide emergency response units with the severity, location and status of incidents before arrival on the scene.	Would reduce the amount of time that vehicles are at a standstill due to incidents as Emergency Responders would be able to coordinate actions before arriving at the scene of an incident – this would increase clearance times.	√	
	Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)	Will provide road users of information concerning incidents along a particular route. This information may be used to motivate the use of an alternative route and, if the road users remains on the route, allows the user to initiate safer driving behaviour.	Warns drivers ahead of time to be cautious and aware of an accident ahead. This allows the workers to be more focussed on addressing the scene and ensures that drivers behave accordingly. With information provided to road users, may reduce ‘rubber-necking” and reduce congested traffic flow in the event of an incident.	√	
	Emergency Communications and Evacuation (EVAC)	Supports evacuation incidents (from hospitals or similar buildings) by optimising communication between transfer facilities, reducing waiting and travel time between the relevant facilities.	Only applicable in special cases and occurrences; will however increase efficiency of evacuation situations.	√	

	Transit Connection Protection (T-CONNECT)	Provides public transport users with real-time information concerning public transport operations, arrival and departure times as well as availability of space (seating). Users would have an opportunity to request the desired form of public transportation to delay the departure time, allowing public transport users to enhance travel time using public transportation.	Increases efficiency of public transport travelling and reliability of destination arrival times. Better planning of public transport may serve as motivation for more commuters to make use of public transportation services.	√	
	Dynamic Transit Operations (T-DISP)	Provides public transport users to request travel information from multiple public transport services, allowing users to optimise their travel times.	Increases efficiency of public transport travelling and allows for improved trip planning.	√	
	Dynamic Ridesharing (D-RIDE)	Promotes the use of carpooling, provided via a cell phone application and matching the route of a user to that of a driver.	May improve network efficiency by reducing the number of private vehicles on the road. May also serve as motivation for introduction of HOV lanes.	√	
	Freight-Specific Dynamic Travel Planning and Performance	Supports planning of trips before and during travel to optimise efficiency of travel and allow freight operators to improve travelling in real-time.	Reduces stops and delays for freight vehicles – may improve traffic efficiency as other vehicles would be less affected with the presence of heavy vehicles (slower moving vehicles, occupying large space).	√	
	Refuse Optimization	Intended for freight operation. Establishes communication between docking stations or railroad terminals and available vehicles for transportation. Aims to optimise scheduling of operations to reduce travel time and distance on the road.	May improve operation of freight movement and reduce heavy vehicle time on the road network.	√	

V2I Safety	Red Light Violation Warning	Warns a driver heading to a signalised intersections that, at their current travel speed, the traffic signal will indicate red at the time of their arrival.	Would reduce unnecessary and inefficient braking, may motivate vehicles to drive according to the posted speed limits and would reduce occurrence of vehicles increasing speeds to pass through an intersection if drivers are aware that they may not be able to pass through at their current speed.	√	
	Curve Speed Warning	Uses V2I communication to determine, based on a vehicle's acceleration, road conditions and geometry, whether a vehicle is expected to navigate through a bend efficiently, and issues a warning message to the driver.	Reduces speed along curved edges (if applicable) and may eliminate occurrences of vehicles losing contact with the road and potentially causing a crash.	√	
	Stop Sign Gap Assist	Provides road users entering an intersection with two stop signs, with an indication of a time-gap between vehicles passing along the main route to assist drivers with entering the main routes more safely.	Would reduce accidents from occurring if vehicles at the stop sign are aware of an appropriate gap to enter the traffic stream. Would also prevent vehicles in the traffic stream from sudden braking if the vehicle in the stop zone misidentified a suitable gap.	√	
	Spot Weather Impact Warning	Drivers would be provided with warnings about serious road conditions downstream of travel to allow drivers to choose an alternative route.	Would assist with warning drivers of real-time weather conditions and allow drivers to adjust driving behaviour to be more suitable for the changing conditions, reducing the chances of	√	

			spinning a vehicle or causing a bumper-bash due to inappropriate travelling speed.		
	Reduce Speed/Work Zone Warning / Lane Closure	Drivers would be provided with information concerning work zones downstream of travel. This information concerns the location of the work zone (left or right-hand side along route), the speed applicable to approaching traffic and whether or not a lane has been closed, requiring the merge of traffic lanes etc.	Increases driver safety by allowing drivers to adjust driving behaviour before-hand. Would increase reliability on protection of labour force completing roadworks as vehicles would be aware of their presence ahead of time.	√	
	Pedestrian in Signalized Crosswalk Warning (Transit)	Public transportation services are provided with the location of pedestrians in the road, along the crosswalk. Vehicles will therefore be aware of the conditions of a downstream intersection, especially if the vehicle is turning into a road and may not identify the presence of a pedestrian in some cases.	Multiple benefits may be achieved from this application. Pedestrians would be able to cross more safely with assurance of driver awareness. Vehicles would not have to brake suddenly or erratically evade the pedestrian if unaware of the pedestrian, improving safety of the passengers and reducing fuel consumption and emissions.	√	
	Road Departure Warning	Uses V2I communication to determine, based on a vehicle's acceleration, road conditions and geometry, whether a vehicle is expected to depart from the road surface, and issues a warning message to the driver.	This application would reduce excessive speeding where not necessary for vehicles (curved sections), reducing road departure accidents.	√	

V2V Safety	Emergency Electronic Brake Lights (EEBL)	Warns CVs immediately surrounding a CV (through V2V communication) of a sudden braking event (i.e. the host CV warns CVs that it will be braking suddenly).	Warning surrounding vehicles of the intention of the vehicle would reduce the occurrence of rear-end collisions.	√	
	Forward Collision Warning (FCW)	Issues a warning to a driver that, based on the speed currently travelled and the braking status of the vehicle ahead, that a forward collision may occur, allowing the driver to reduce their speed or execute a lane change.	May reduce rear-end collisions.	√	
	Intersection Movement Assist (IMA)	Provides drivers with time gap and safety suggestions before entering a route at a stop-sign or uncontrolled intersection.	Would prevent T-bone accidents and prevent vehicles in the main route from sudden braking.	√	
	Right Turn Assist (RTA)	Assists the driver with a message, when it is safe to execute a right turn at an intersection based on on-coming traffic.	Right turns present difficulties with approaching traffic as it may not always be clear to see approaching vehicles. This application therefore reduces the chance of a vehicle executing a right turn when approaching traffic may be imminent.	√	
	Blind Spot/Lane Change Warning (BSW/LCW)	Assists the driver with lane changing by warning a driver about the presence of a vehicle or anticipated presence of an approaching vehicle in its blind-spot.	Vehicles would be able to execute safe lane changes by making drivers aware of approaching vehicles.	√	
	Do Not Pass Warning (DNPW)	Warns the driver if a pass cannot be executed due to oncoming traffic.	Would allow vehicles to only execute passing vehicles safely and not endangering oncoming traffic.	√	

	Vehicle Turning Right in Front of Bus Warning (Transit)	Determines the movement of vehicles near to a transit vehicle stopped at a transit stop and provides an indication to the transit vehicle operator that a nearby vehicle in front of it is to make a left turn – this will assist by allowing the driver to know if the space will be occupied as the bus pulls away.	Allows public transport service to increase throughput of their vehicles and stick to schedule requirements. May also allow for improved efficiency of operations by allowing these vehicles to optimise travel time.	√	
Environment	Eco-Approach and Departure at Signalised Intersections	Provides CVs along a route with speed suggestions to allow the vehicle to pass through signalised intersections on a green phase downstream, along the entire route.	Would reduce the travel speed and offer an opportunity for overall reduction in vehicle emissions.		√
	Eco-Traffic Signal Timing	Optimises traffic signals for the environment. Processes real-time and historical CV data at signalised intersections to reduce fuel consumption and emissions.	Assists in throughput of vehicles and would reduce fuel consumption as vehicles would be less-likely to brake inefficiently due to mistiming a traffic signal.		√
	Eco-Traffic Signal Priority	Allows transit vehicle approaching a signalised intersection to request signal priority to reduce the occurrence of stops for heavy vehicles.	See Signal Priority		√
	Connected Eco-Driving	Provides customised real-time driving advice to drivers for behaviour adjustments to save fuel and reduce emissions. Information provided includes recommended driving speeds, optimal acceleration/deceleration. Provides driver feedback to encourage environmentally friendly driving	Optimising driving and may thereby enhance the efficiency, improve safety by increasing driver responses, collectively reducing emissions.		√

	Electric Charging Stations Management	Provides an exchange of information between vehicle and charging station to manage the charging operation – possibly to estimate time to complete charging.	Would improve movement of electric vehicles and reduce ability to exceed charging time. Area would require a significant number of electric vehicles to establish overall improvement in operation.		√
	Eco-Lanes Management	Supports the operations of eco-lanes but optimized for the environment. Determines the necessity of an eco-lane based on surrounding traffic operation and road conditions.	Not currently applicable as South Africa does not make use of High Occupancy Vehicle (HOV) or High-Occupancy Toll (HOT) lanes (excluding BRT lanes). Should be considered in future to reduce emissions.		√
	Eco-Cooperative Adaptive Cruise Control	See Cooperative Adaptive Cruise Control. Includes automated control while considering eco-driving strategies.	Aims to enhance movement of multiple vehicles in the traffic network – this may produce a collective reduction in fuel consumption and lead to a higher throughput of vehicles.		√
	Eco-Traveller Information	See Advanced Traveller Information	Provides travellers with an opportunity to enhance the operation of their vehicle during travel. The benefits include efficiency when travelling, improved fuel consumption and emission reduction, as well as improved safety as the driver would increase their response time to imminent events.	√	
	Eco-Ramp Metering	Determines the most environmentally efficient way to operate traffic signals at freeway on-ramps to manage the rate	Not currently applicable.	N/A	

		of entering vehicles whilst considering vehicles travelling along the freeway.			
	Low Emissions Zone Management	This application aims to restrict the use of high-polluting vehicles in a certain location, providing information about available parking zones and alternative transportation modes etc.	Not applicable while viable alternative does not exist.	N/A	
	AFV Charging/Fuelling Information	See Electric Charging Stations Management	See Electric Charging Stations Management		√
	Eco-Smart Parking	Provides real-time information on where best to park and make use of alternative transportation.	Reduces the time vehicles spend searching for parking – reduces fuel consumption and emissions.	√	
	Dynamic Eco-Routing (Light Vehicle, Transit, Freight)	Determines most eco-friendly route specific to driver (minimum fuel consumption or emissions) – similar to existing navigation applications.	Allows for optimised travelling and reduction in overall time spent travelling.	√	
	Eco-Integrated Corridor Management Decision Support System	Determines the most efficient operation decisions that are environmentally beneficial to the corridor based on existing data concerning management and operation of the corridor.	Provides an opportunity for freeways to be managed in a more environmentally conscious manner – may produce significant reductions in fuel emissions and carbon emissions collectively.		√

	Eco-Speed Harmonisation	Determines eco-speed limits based on traffic conditions, weather information and GHG emissions. See Dynamic Speed Harmonisation	Emissions and fuel consumption may be reduced as a result of recommended speed limits.	√	
	Roadside Lighting	Roadside infrastructure detects the presence of vehicles along the road and adjusts the lighting to save power. A street light switches on when a vehicle is heading towards it and switches off automatically after the vehicle passes through.	Would reduce the power used on the traffic network, reducing costs of power usage and conserving energy for alternative use.		√
Agency Data	Probe-based Pavement Maintenance	Vehicles detect potholes and similar road imperfections and issue reports to traffic agencies via V2I communication of the location and severity of the detected irregularity.	Would allow agencies to obtain road information remotely and more frequently. This may create a data-map of points at which potholes are frequently reported, allowing agencies to focus on road sections requiring urgent maintenance/repair.		√
	Probe-enabled Traffic Monitoring	Uses V2I communication to determine traffic conditions and traffic flow.	Traffic agencies would be able to manage security capabilities through monitoring vehicle information transmission and collect traffic data for improved network management.	√	
	Vehicle Classification-based Traffic Studies	Application that would allow sorting of vehicle behaviour data by vehicle type.	Provision of detailed vehicle type information would improve road design and lifecycle calculations and predictions.	√	

	CV-enabled Turning Movement & Intersection Analysis	Analyses the operation of road networks based on reports obtained from CVs to determine demand, phasing, rehabilitation or upgrading of roadways.	This information may be utilised to improve road geometric design where consistent reporting of flawed road section designs exist.		√
	CV-enabled Origin-Destination Studies	Obtains information from CVs relating to origin and destinations of travelling. The route would thereafter be extracted and used in traffic demand and flow studies.	This would improve traffic prediction studies since detailed information would be accessible, and would reduce the cost of field infrastructure for conducting O-D counts of vehicles (such as Number Plate detectors, etc.).		√
	Work Zone Traveller Information	Monitors, collects and broadcasts work zone data to road users.	Determining the effect of work zones on traffic flow may allow for improved designs of road-work zones to reduce the effect on traffic flow.	√	
Road Weather	Motorist Advisories and Warnings (MAW)	Collects road weather and road condition data from CVs to develop short term warnings that may be provided to specific motorists (for example, travelling along a route with low quality surface while a more appealing alternative route may be used).	Warning motorists of road conditions beforehand would allow drivers an opportunity to adjust their driving behaviour for safety.		√
	Enhanced Maintenance	Incorporates the additional information that may be obtained from collection of road weather data from CVs to inform an existing maintenance support system. This information may be issued directly to employees to improve maintenance	May reduce maintenance costs by focussing on areas requiring immediate attention, and may thereby reduce the effect of weather on traffic flow (for example, if a traffic signal becomes faulty due to bad	√	

	Decision Support System (MDSS)	response and reduce the time elapsed before a road-related issue is addressed (for example, traffic lights not operating correctly)	weather and is located at a site with high volume intersection flows, this information would be provided to maintenance personnel and would allow for prioritising of sections that require immediate service).		
	Vehicle Data Transfer (VDT)	Provides probe data information obtained from vehicles in the network to support traffic operations, such as incident detection.	Would allow transport agencies to determine the location of potential incidents for quicker response.	√	
	Weather Response Traffic Information (WxTINFO)	Utilises road weather information from CVs and current and historical data from multiple sources (Weather Stations, ESSs) to determine the appropriate real-time safe travelling speed.	Would improve safety in challenging weather conditions and reduce emissions and fuel consumption.		√
Smart Roadside	Wireless Inspection	Would be used to reduce the time freight vehicles are inspected to reduce costs of inspection and reduce delay of freight vehicle operations.	Would improve operations of freight companies since they would not be required to accommodate for time lost for vehicle inspections.	√	
	Smart Truck Parking	Provides freight vehicles with parking information along or near route of travel to optimise freight operations and fleet management.	Would reduce heavy vehicles from stopping in locations meant for vehicles and allow freight companies to design their route to allow for stops throughout the trip, ensuring that the drivers are	√	

			always fit for commute and that the vehicle fleet is managed optimally.		
Support	Core Authorization	CV support used to prioritise applications that may be applicable to specific CVs travelling along a route.	Reduces labour necessary to complete tasks and eliminates "trial and error" method of assigning tasks by optimising performance through utilising only the necessary resources.		√
	Data Distribution	Manages the distribution of data from data providers to data consumers and vice versa. This is used to protect the data from unauthorised access.	Improves management of data and improves security measures.		√
	Infrastructure Management	Maintains and monitors the performance and configuration of the connected roadside infrastructure in the CV environment.	Provides an opportunity to optimise use of exiting ITS infrastructure. May allow for design of a more effective system by in-explicitly highlighting gaps in locations of effective information distribution.	√	
	Map Management	Defines interfaces that can be used to download or update all types of map data used to support CV applications.	Ensures that travellers are always aware of the latest information and are not presented with unexpected road conditions when travelling.		√
	Object Registration and Discovery	Provides the services necessary to allow CV objects (e.g. DSRC RSUs) to locate other CV objects (e.g. DSRC In-Vehicle Radios) within the connected environment.	More applicable for management of network equipment.	√	

	Privacy Protection	Application that may be used to ensure that personal information obtained from CV owners is protected and confidential.	Security measures increase attractiveness of system usage as travellers will not be concerned security concerns over private information.	√	
	System Monitoring	Monitors and controls the operation and function of the entire CV system for operation and management of the traffic environment as a whole, with focus on the function of the CVs operating in the environment.	Ensures that the managing agency is always aware of the current users – reduces the possibility of security breaches by allowing the agency to spot inconsistencies with users (suspicious increase in number of users, inconsistent data provided, etc.)	√	

Based on the above information, it is can be seen that Connected Vehicle technology presents great opportunities for improvement in traffic conditions and management of existing operations. These applications may serve as a criteria for traffic agencies to identify target areas of improvement (Safety or Efficiency for instance), and to design an environment that supports the improvement of these target areas.

2.2.4 EXTENT OF CONNECTED VEHICLE TECHNOLOGY

Connected Vehicle technology will allow for all internet or wirelessly accessible systems to be connected. Vehicles will be able to access the internet, allowing for communication between vehicles, infrastructure and other internet devices (Internet of Things). The exact time in which all new vehicles manufactured will be connected is unknown at this stage (although certain articles predict 2019 or 2020).

At this stage, it is clear that CVs will not only be able to communicate with other vehicles - the possibility of connecting with road side infrastructure and Smartphones is an opportunity for hardware and software development companies to extend their expertise to the transportation environment. A few examples are currently in use and, in some cases, on the verge of deployment.

In the case of Smartphones, Apple™ have developed integration software that allows the Smartphone (an iPhone in this case) to be plugged into the vehicle (for vehicles containing centre consoles with video display), granting the display the capability of the phone (alternatively, the Smartphone may be mounted on the dashboard). Furthermore, Apple's iPhone makes use of a voice command/recognition system called Siri which allows the occupants to communicate with the device via voice activation (the driver is thus free of operating the systems physically and may instruct the system audibly). In this case, the connectivity is established via the Smartphone (Integrated connectivity). Since Smartphones may connect to related devices, this provides an opportunity for these devices to assist the driver in identifying pedestrians on the road (if they are in possession of a smartphone).

Connected Vehicles may potentially have the ability to communicate with each other, then to communicate with road side infrastructure and hand-held devices. This level of communication would create a safer, more efficient environment, especially in consideration of the above discussion.

2.2.5 INFORMATION PRODUCED BY CONNECTED VEHICLES

Connected Vehicles may produce large amounts of information that may be structured or unstructured. Additionally, millions of vehicles will eventually be connected, providing immense quantities of information. The effective utilisation of this information will be crucial for improving the efficiency and safety of transport networks. This section therefore discusses the data that may be obtained from gaining access to vehicle systems and the by-products of the large quantities of data produced as a result of CV technology.

2.2.5.1 TRANSPORTATION MANAGEMENT DATA RETAINED

Incorporating Connected Vehicle support through provision of DSRC roadside devices would allow the traffic agency to gain access to detailed vehicle information which may be used to assist with improving traffic management strategies and network operations. The following data may be obtained from vehicles allowing for wireless communication (MDOT, 2014):

- Traffic speed of individual vehicles
- Travel times
- Volumes
- Occupancy
- Density
- Origin and destination for vehicles that opt to provide this information
- Incident status
- Video images
- Vehicle data *(Section 2.2.5.3)*

This information is currently accessible through VDS data and may be enhanced with deployment of DSRC roadside equipment.

2.2.5.2 TRAVELLER DATA RETAINED

With a connected environment, travellers would interact with the environment, requesting traffic information, providing location data, travelling within the network and gaining access to multiple connection point. As a result of this mobility and provision/requirement of real-time information, the following data transfer would be possible (MDOT, 2014):

- Trip origin, destination, and timing
- Traveller's personal data such as trip records and profile data
- Service information (e-tolls, parking etc.)
- Vehicle occupancy
- Vehicle Kilometres Travelled (VKT) data by vehicle characteristics, time and location

2.2.5.3 CONNECTED VEHICLE DATA

Connected vehicles would make use of installed sensors, processors and other on-board equipment (User Interface On-Board Unit, Cameras, etc.) to accumulate and transfer useful traffic data to surrounding vehicles and infrastructure. This data includes the vehicle geometry, behaviour during travel, weather data, vehicle equipment behaviour and related information. According to the Michigan Department of Transport, in the report *Connected V. Automated Vehicles as Generators of Useful Data* (2014), the following data may be generated from vehicles:

- Vehicle type and Characteristics (length, width, bumper height)
- Time stamp
- Speed and heading
- Vehicle acceleration and yaw rate
- Turn signal status
- Stability control status
- Driving wheel angle
- Vehicle steering
- Tire pressure
- Traction control state
- Wiper status and run rate
- Exterior lights
- GPS status and vehicle position (longitude, latitude, elevation)
- Obstacle direction
- Obstacle distance
- Road friction
- Current and average fuel consumption
- Vehicle emissions data – measured emissions of specific vehicles comprised of exhaust pollutants including hydrocarbons, carbon monoxide, and nitrogen oxides
- Air temperature and pressure
- Weather information such as rainfall rate and solar radiation data
- Electronic stability control

Further information may be provided by the vehicle depending on the extent of the equipment installed in the vehicle upon purchase. Conversely, some information may not be available from vehicles without certain on-board equipment (such as Electronic Stability Control for example). A list of sensors currently used in vehicles is provided in Appendix B.

The information that may be sent by Connected Vehicles is compiled specifically for DSRC devices to comply with standards set out by the Society of Automotive Engineers (SAE) (Standards.sae.org, 2016). The compilation of this data is referred to as a Basic Safety Message (BSM). The following section describes the BSM in more detail.

2.2.5.4 UNDERSTANDING THE BASIC SAFETY MESSAGE (BSM)

According to the U.S.DOT, the messages sent by a vehicle will be a BSM, a subset of SAE J2735 Standard (*Section 2.4.1.2*) consisting of two parts, namely BSM Part 1 and BSM Part 2, conveyed in the 5.9GHz DSRC (Table 2.6 below) medium. BSM Part 1 contains the core data elements in reference to a specific vehicle, such as the size of the vehicle, its speed, position, heading etc., and would be transmitted at a rate of 10 times per second to ensure that traffic management agencies are constantly aware of the environment conditions and driver behaviour (Cronin, 2012).

BSM Part 2 contains information added to BSM Part 1, such as the activation of Traction Control for example (Cronin, 2012). BSM Part 2 is more flexible with regards to the availability of data. The extent of equipment preinstalled in a vehicle is dependent on the vehicle model purchased by the owner – BSM Part 2 accommodates for this variation by providing information that may be accessed from a vehicle depending on the installed equipment. Since the messages transmitted in BSM Part 2 would not be necessary, BSM Part 1 would be the focus for initial deployment with Connected Vehicles.

For applications relating to mobility (*Section 2.2.3*), certain data that may be transmitted by vehicles would be beneficial to assist with the suggestion of alternative routes and suggested information. This information includes Weather Data (Ambient Temperature, Traction Control Status, Wiper Status) and Vehicle Data (Exterior Lights Status, ABS Status) (Cronin, 2012).

The following table provides the specific data transmitted in the BSM Part 1 and BSM Part 2 data elements that may be transmitted:

Table 2.6: Messages Sent as Part of BSM-I and BSM-II (Adapted from Cronin, 2012)

BSM Part 1	**BSM Part 2**	
Timestamp	Recent Braking	Differential GPS
Position (Longitude, Latitude, Elevation)	Path Prediction	Lights Status
Speed	Throttle Position	Wiper Status
Heading	Vehicle Mass	Brake Level
Acceleration	Trailer Weight	Coefficient of Friction
Brake System Status	Vehicle Type	Rain Type
Vehicle Size	Vehicle Description	Air Temperature
Steering Wheel Angle	ABS, Traction Status	Air Pressure
Positional Accuracy	Stability Control	Vehicle Identification
	Cargo Weight	GPS Status

Based on the information that may be obtained through BSM Part 1 and BSM Part 2, the potential improvement that CV applications may be able to achieve is extensive, and may further enhance the operation and management of the road network through access to multiple vehicle's real-time information.

2.2.6 CONNECTED VEHICLE SYSTEMS: HARDWARE AND SOFTWARE

Multiple studies have been conducted to determine the equipment necessary for establishing communication between vehicles and infrastructure. A study with a more detailed layout to the requirements of this investigation however, was the study conducted by Sheaf et al. (2014), *System Design Document for the INFLO Prototype*. The components that constitute a connected vehicle are largely dependent on the extent of the connected applications implemented or the desired capability of a user's vehicle. This presents the options and variations associated with connected vehicles and related capabilities in Table 2.7:

Table 2.7: Associated Improvement Based on Vehicle Capability

Option	Focus Area	Equipment	Description
1	Mobility	Tablet/Cellular Device	Applications that present the user with notifications of real-time network associated information and updates. In this case, the user is only required to receive the information and communicate its position. A device with a display, location storing capability (GPS) and internet connection would be sufficient. In this case, the communication established is V2I.
2	Safety	Tablet/Cellular Device and DSRC	With safety applications, it is crucial that the information provided to the user is immediate – DSRC assists in this regard, providing information for the user to initiate immediate action. Furthermore, the capabilities of the vehicle (to initiate a throttle, braking, swerving response) is dependent on the model purchased by the user – the vehicle's internal system should be capable of assuming control over the vehicle under pressing circumstances (braking suddenly if the driver is unable to)

			and in traffic (such as cruise control/adaptive cruise control). For this instance, the vehicle will be able to communicate with other connected vehicles (V2V) as well as infrastructure (V2I)
3	Environment	Tablet/Cellular Device and DSRC	This is similar to the description for safety in that the vehicle should be contain the relevant equipment upon purchase from the manufacturer. For environmental aspects however, the CV applications are designed allow the user to operate the vehicle in a more efficient and environmentally-friendly manner. Once again, communication may be established with vehicles (V2V) and infrastructure (V2I),

The applications referred to were discussed in *Section 2.2.3* and the connected vehicle equipment was briefly discussed in above (further discussion follows below). Based on the requirements and proposed investigation in this report, the relevant equipment to achieve the desired output of application include the following devices:

- **In-Vehicle Network Access System (IVNAS)**: Connects to vehicle OBD port to retrieve vehicle data to populate BSM-I and BSM-II message library (refer to *Section 2.2.5.4*).
- **DSRC Radio**: Transmits information to vehicles and roadside equipment.
- **Weather Sensor**: Detects real-time weather conditions on the road.
- **Nomadic Device (Smartphone)**: Provides display for user information.

A vehicle that is considered connected may simply contain a portable device with a display and internet connection, or may be extensively packaged with advanced equipment – this is dependent on the user and the vehicle model purchased. However, these additional components are extensions of CV capabilities and allow for more advanced application usage. A basic connected vehicle is one that can establish Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication. For this to be achieved, it has been determined that the vehicle would require the following equipment (Battelle/TTI, 2015):

- In-Vehicle System User Interface Module (Android User Interface and Cellular Radio)

- In-Vehicle System DSRC Radio Module (Processor and DSRC Radio)
- In-Vehicle Network Access System (Vehicle Controller Area Network (CAN) Network)

Figure 2.10 below indicates the basic requirements for a vehicle to be connected to the surrounding environment. The Nomadic Device, which may be a Smartphone or Tablet, displays the information to the user. The Weather Sensor obtains information from the road for weather condition data, and the DSRC Radio is responsible for transmitting the relevant data to other vehicles or the DSRC roadside units. The In-Vehicle Network Access System is responsible for obtaining data conforming to the OBD-II requirements (refer to Appendix B for OBD-II data) and populates the Basic Safety Message Part II (BSM2) to a DSRC Radio device via a Bluetooth connection.

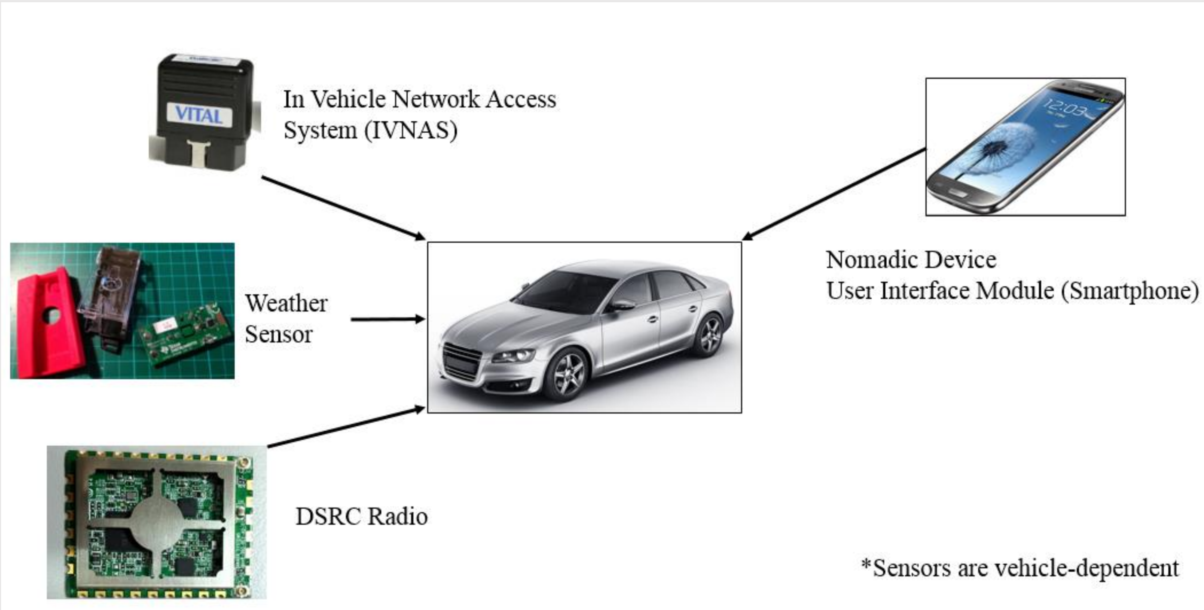


Figure 2.10: Basic Requirements for a Connected Vehicle

The DSRC Radio in the vehicle would be responsible for transmitting data to the surrounding environment, and receiving a response (if necessary) within a short period of time (refer to *Section 2.4.1*). This is applicable for addressing safety, since road users need to respond instantly to serious conditions that may lead to a potential accident. Alternatively, the focus may not particularly revolve around safety, but is more inclined to enhancing the efficiency of a traffic network. In this instance, it may be suitable to focus on the Nomadic Device, since it is anticipated that users may only require notifications with regards to improving efficiency. From Figure 2.10, the In-Vehicle Network Access System, Weather Sensor and DSRC Radio would not be necessary and may reduce costs substantially. This concept will be explored in this study, and will be discussed further in the chapters hereafter.

2.2.6.1 BIG DATA

Big data is a term describing data that is so vast, it is challenging to store on a single storage device. According to IBM, 2.5 quintillion bites are created every day and 90% of the data in the world was created in the past two years (IBM 2015). It describes the exponential growth of data that is both structured and unstructured (SAS 2014). Previously, the ability to make use of this data was extremely complex. Many companies had investigated this phenomenon because the possibility of making use of the data that could be obtained was seen to present multiple possibilities for companies in their ability to sell products and provide information to the public.

Big data is often described under three terms, namely Volume, Variety and Velocity (known as the 3Vs of big data) (SAS 2014). Volume refers to the amount of data. These forms of data could be received from transactional information, unstructured data obtained from social media streaming as well as the collection of data from sensors and machine-to-machine communication. While the storage of this information has been resolved through cloud computing and parallel processing, the current concern is the ability to analyse the information and predict trends for marketing purposes. Velocity implies the speed at which all of this information is received. People all over the world make banking transactions, send tweets and messages on other forms of social media, as well as making purchases with their credit cards via online shopping. According to a report compiled by McKinsey Global Institute, 5 billion mobile phones were in use by 2010, 30 billion pieces of content was shared on Facebook every month and that it would cost on average R6000 to store all of the world's music (McKinsey & Company 2011: vi - vii). These statistics provide an indication of the vast amount of data that is available and continues to be supplied and updated. Additionally, they embody the three Vs description that has been ascribed to big data. A fourth V is also used to aid the description of big data, namely Veracity. Veracity refers to the uncertainty of data. According to an infographic sheet from IBM, data may not conform to an expectation of the information obtained (known as outliers), implying a certain distrust of the information received. Veracity should also be understood as data of poor quality, as well as information that may be inaccurate. Based on the research conducted, companies have chosen to incorporate either the description of 3 Vs (BIG DATA EUROPE | Empowering Communities with Data Technologies, June 2015) or 4 Vs (IBM 2013). Figure 2.11 provides a graphical description of the 3 Vs of big data.

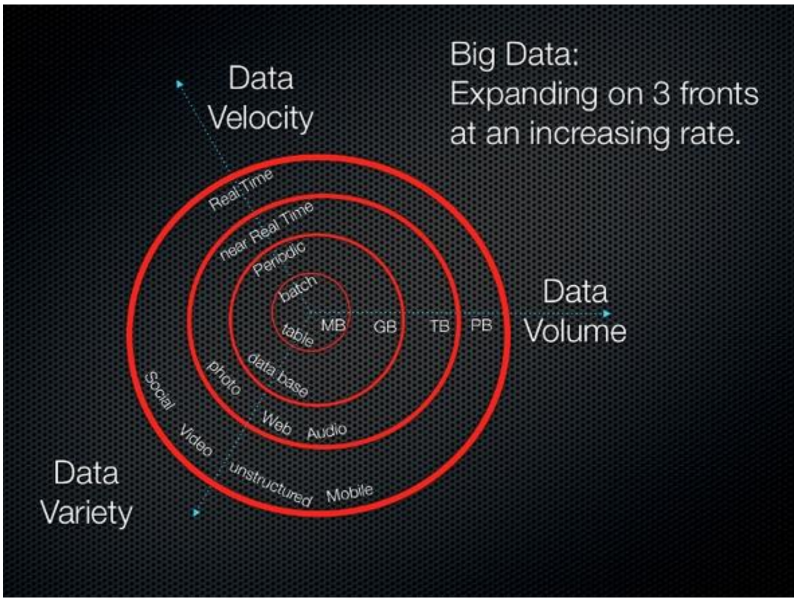


Figure 2.11: Description of the 3Vs of Big Data (WhatIs.com, 2013)

In the past, solutions were obtained from a sample of data as well as intuition which, by the present standards, is an inefficient means of analysis. The entire set of data (as opposed to a sample) is currently able to be analysed with the correct tools and expertise. Data scientists and data analysts are able to unlock incredible forms of information from large amounts of data, whether structured or unstructured. An excellent example of this would be Amazon®. Amazon® keeps track of their customers' trends such as the subjects on which they tweet, the subjects they like on Facebook and previous purchases. Using all of this information they are able to provide suggestions as to products that the purchaser may be interested in. This has led to Amazon® becoming the largest and most successful online book sales store (BIG DATA 2013). The ability to understand and implement the possibilities of big data allows for tremendous improvements in the environment and allows users to save time.

With the ability to make use of the information provided by users, such as the scope of their travelling, their purchases and social media status, big data has great significance in transportation. Additionally, transportation and urban planning has seen major changes due to the increase of information available through the implementation of sensors (ISTC 2015). These changes have risen with response to two factors; an increased volume of sensors have been deployed and a need to measure the performance and make decisions based on the results of the sensors. According to the article (Big Data in Transportation and Urban Planning 2015), this increase in transportation data can be described with regards to three factors. These factors are the Type, Volume and Coverage of information. The Type of information is increasing due to new technological developments for monitoring traffic patterns and behaviours. An example hereof would be the high-definition radar sensors, used to detect vehicles speeds and compile traffic counts (ISTC 2015). The data Coverage and Volume are a direct result of the amount of traffic sensors that have been implemented. At this stage – based on the amount of vehicles using the network

– it is clear that a great amount of data is generated as a result of the increased sensors. This therefore constitutes the necessity for the accommodation of big data analytics in transportation.

An example of the use of big data in transportation would be the use of the Oyster card in London. This is a system that allows the users to pay for public transport with a card (pre-loaded with credit) instead of physically using money, which reduces the possibility of theft on trains for example – this is known as the Automatic Fare Collection (AFC) system. The manner in which these cards are used by the operators is that the locations of the users are recorded. The identity of the individuals remain anonymous, their entry and exit points are the only requirements. With knowledge of the entry and exit points, the transport service is able to predict the times at which the capacity of the mode of transport will become a concern. This allows the service to manage the amount of a particular mode of transport that is necessary to be deployed and the frequency at which they are required to operate to accommodate the increased capacity requirement (Bernard Marr 2015).

In South Africa, the Gautrain (Johannesburg) and the MyCiti (Cape Town) services are local examples of this type of data collection. These services make use of the AFC method of payment which, among other benefits to the system, would allow for the collection of large amounts of data for capacity analyses. Therefore, the ability to provide optimised solutions in terms of travel times and vehicle occupancy with big data analytics is possible on a local scale.

The use of big data and the anticipated possibility that it presents is progressing at a phenomenal rate. Predicting trends and providing more relevant information has shown a vast improvement, particularly since less weight is placed on intuition and more on real-time information. Big data and the correct use thereof can create the necessary optimisation in any and every transportation sector (in terms of capacity utilisation and reductions in travel times) – it is thus a crucial factor for the improvement of transportation.

2.2.6.2 DATA CAPTURE AND MANAGEMENT (DCM)

Data capture refers to the acquisition, quality-checking and integration of data in an automatic manner, in this case, the acquisition of data from vehicles (Thompson, n.d.). The data that is acquired is in real-time and is required to be of high-quality and from multiple forms of vehicular transportation as well as non-vehicular sources (Hong et al., 2015). These sources include, according to Hong et al. (2015), connected vehicles, mobile devices and infrastructure. The data that is obtained includes the vehicle status and location, transit data, weather data and infrastructure data (Thompson, n.d.).

The purpose of data capture from vehicles is to improve the provision of real-time traveller information. The information provided from this data comprise enhanced weather applications, real-time transit signal priority (such as the Bus Rapid Transit system in Cape Town), traveller information, fleet management applications (Third party usage) and possibly safety advisory systems (Thompson, n.d.).

According to Hong et al. (2014) in the report *Connected v. Autonomous Vehicles and Generators of Useful Data*, the USDOT has been involved with a program in which data was collected from multiple source of transportation as well as sources of data provision. These items include private vehicles, transit vehicles and heavy vehicles for example (in the case of transportation) and traveller information, infrastructure, weather and parking data (with regards to sources of data provision) (Hong et al., 2014). The aim hereof, was to attain a singular data warehouse where the users of such a system would obtain a view of the transportation system as a whole. This is clearly a step toward the creation of a connected environment.

Additionally, the data that is attained needs to be mined to ensure that the most relevant information is retained and used to provide information to the public – this refers to the management of captured data. This is achieved through the incorporation of Big Data Analytics, a concept and practice discussed in *Section 2.2.6.1*.

The effective use of DCM technology has the potential to increase the efficient operation of the transport network as well as improve the safety on roads. With travellers aware of their environment (since the decision for the most effective route is to their discretion) and constantly informed about the route on which they travel, the entire traffic network may be optimised in terms of operation.

2.2.6.3 PROBE DATA

This section provides an elaborate discussion of probe data, the sources, benefits and associated challenges associated with the collection and analyses thereof. The section closes off with a discussion of the perceived leaders in probe vehicle analytics to provide an explanation of the manner in which data is obtained, and how these institutions utilise the data within traffic management operations with the provision of traveller information.

SOURCES OF FLOATING CAR DATA

The major sources of floating car data include Global Positioning System (GPS) devices, mobile phones and Bluetooth. Currently, there are three viable types of probe vehicle data collection systems that are available. These systems have produced decreasing cost of equipment over time due to the high reliability identified by the consumer market (Young, 2007). Probes allow for continuous, real-time data collection and minimal human interaction. The probe vehicle systems described are as follows (Young, 2007):

- **Cell Phone Probes**: Cell phone probes cover any method used to determine the location of vehicles using the on-board cell phones and their associated tower infrastructure. The data collection falls between two broad categories – Tower hand-off timing and embedded cell phone GPS location data.

- **Automated Vehicle Location (AVL) Services**: Generally incorporated by established commercial businesses. These systems utilise GPS receivers to track individual vehicles in a fleet. The locations are reported continually through satellites, radios or cellular data services.
- **Toll-Tag Technology**: Shares similar attributes to that of cell phones and AVL probes, but requires additional toll-tag readers. These systems are owned and maintained by road traffic authorities and related transport management organisations.

Probe data (also known as floating car data) is the use of localization data obtained from the GPS coordinates of mobile phones to be able to identify the location of vehicles in the traffic network and is a method used for the calculation of traffic speeds. The information collected includes speed, direction of travel, location data and time information from the mobile phones inside the vehicles. Every vehicle with an active mobile phone essentially acts as a sensor on the road network. With all of the data obtained, traffic congestion can be identified, travel times can be calculated and traffic reports can be generated more rapidly than with the use of conventional infrastructure (Floating car data (Wikipedia) 2015).

OPERATION OF PROBE DATA

CELLULAR:

Floating cellular data is a method used to determine traffic information for vehicles with on-board cellular devices. The data concerning the location of the vehicles may be obtained with the use of cell-phone towers or satellites that are able to determine the GPS coordinates of the device. Cell-phone towers locate the devices using a method called triangulation. Cell towers are used to identify the location of cellular devices. These cell towers cover three sectors, referred to as alpha (**α**), beta (**β**) and gamma (**γ**) (Locke, 2012), indicated in Figure 2.12:

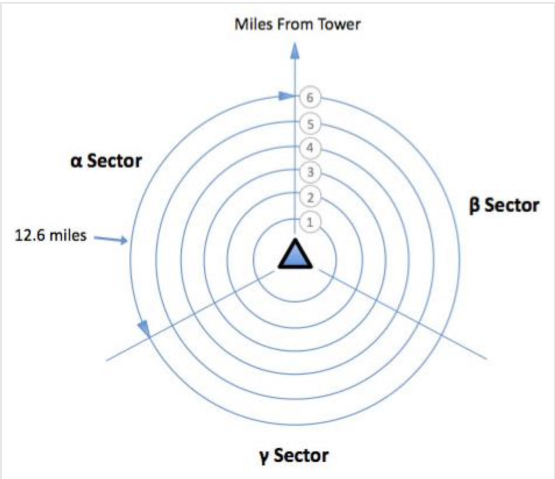


Figure 2.12: Cell Tower Sections and Radial Distance (Locke, 2012)

Figure 2.13 indicates the sectors and the manner in which the tower determines the location of a cellular device. A single tower is able to determine the location of the device, however, in densely populated areas (urban areas), more cell towers are expected to be present – with an increase in the number of cell towers in an area, the accuracy of the identifying the location increases:

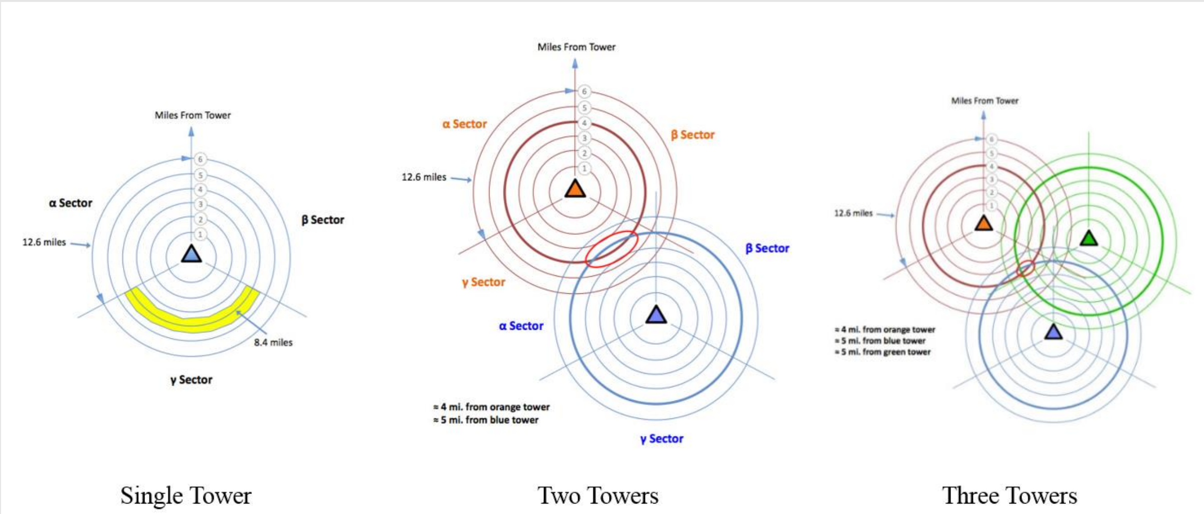


Figure 2.13: Increasing Accuracy with Increasing Number of Cell Towers (Locke, 2012)

TOWER HAND-OFF:

The location of the mobile phones may also be obtained as hand-over data from the network operators. It is the responsibility of the parties making use of probe data to eliminate cell phone data that bears no contribution to the traffic network. For example, pedestrians on the side of the roads will have no influence on the traffic stream and any calculation concerning traffic reports. For this reason, complex algorithms have to be used to eliminate any data that will compromise the quality of the information required.

GPS LOCATION:

For both cell phones and toll-tags, these devices contain built-in receivers that determine the location of the device with three GPS satellites (Gordon, n.d.). The GPS satellites locate the GPS receivers using a method called triangulation. Triangulation is the communication established between the three nearest satellites that the receivers communicate with. This allows the GPS satellites to provide an approximate location of the device, ranging between 2 – 8 meters in accuracy (Gordon, n.d.). Figure 2.14 shows a graphical description of this method:

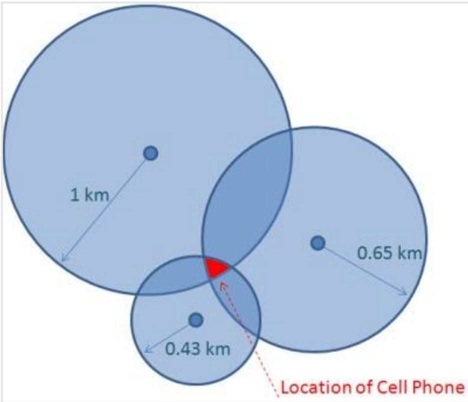


Figure 2.14: Emergency9 Mobile Alert Cell Phone Triangulation (2015)

As shown in Figure 2.14, the overlap of the radii (highlighted as red) indicates the approximate location of the GPS device.

The location of the mobile phones may also be obtained as hand-over data from the network operators. For traffic use, it is the responsibility of the parties making use of probe data to eliminate cell phone data that bears no contribution to the traffic network. For example, pedestrians on the side of the roads will have no influence on the traffic stream and any calculation concerning traffic reports. For this reason, complex algorithms have to be used to eliminate any data that will compromise the quality of the information required.

BENEFITS OF PROBE DATA

The benefits of making use of probe data include the fact that it is a very detailed information source; it is capable of covering a vast amount of applications and has a large time-period of data. Additionally, the entire network is covered and is one of the few solutions that can deliver a detailed origin (of the probe), destination and route choice information (TomTom 2014). The advantages that floating car data has over conventional methods – such as the use of loop detectors and CCTV cameras – are that it is less expensive to implement and does not require hardware to be installed inside the vehicles or within close proximity to the road network. Finally, it does not enable maintenance concerns and it is relatively easier to set up (will not provide any form of hindrance to the traffic network).

The advantages are as follows (Uno, N., Kurauchi, F., Tamura, H. and Iida, Y., 2009):

- **Low cost of obtaining data**: Once the infrastructure has been set up, the data may readily be collected at a low cost. There is no need to set up and disassemble the system
- **Continuous data collection**: The data may be collected 24 hours with ITS probe systems, as long as the infrastructure is in place.
- **Automated data collection**: Data can be collected electronically (from the probe vehicle to the ITS control facility).

- **Uninterrupted traffic**: The traffic is not influenced by the manner in which the data has to be collected.
- **Direct observation of travel time**
- **Real-time observation possible**

Additionally, Ludec, G. (2008) highlights further advantages that probe data collection presents to traffic management:

- Possible reduction in congestion
- Improved Origin-Destination estimations
- Traffic queue detection
- Improved incident management
- Optimised use of existing infrastructure
- Improved information services (traffic information, dynamic route guidance)
- Possible improvement in information quality
- Improved vehicle fleet management
- Cost reductions due to possible decreased travel times

CHALLENGES OF PROBE DATA

ITS probe vehicle systems for travel time data collection has the following disadvantages (Uno et al., 2009):

- **Great amount of data to be processed:** GPS technology reports the current location (spatial coordinates), heading direction and speed information (Lui, K., Yamamoto, T., Morikawa, T., 2008). This information is collected periodically to for real-time information processing – this means that a single vehicle-probe continuously sends data to a receiver; this information becomes immense with increased probes on the traffic network, especially since a large network of probe data collection is necessary for accurate information provision.
- **Transaction costs if real-time observation is required**
- **Data bias:** Information obtained only from vehicles with probes (GPS devices, brought-in navigation device)

WHY IS PROBE DATA A CONSIDERABLE MEANS OF ANALYSIS?

There is a necessity to make use of new methods of providing control over the traffic network. Based on the information obtained on the use of probe data in comparison to implementing infrastructure, it may be inferred that the costs associated with the provision of infrastructure out-weigh the costs of probe data. Even though the cost of utilising probe data is not negligible, the future costs regarding maintenance and updates presents a bad reflection on implementing infrastructure. Another factor to consider is that South Africa may not have the financial capability to be able to maintain the infrastructure.

INSTITUTIONS SPECIALISING IN THE USE OF PROBE DATA

INRIX and TomTom are two of the leading firms providing traffic information on a global scale. The input data the firms require are obtained via communication to probes located over the traffic network. A description of the information required and the output that each company provides is presented in the following subsections

PROBE DATA SPECIALISTS: TOMTOM

TomTom is claimed to be the global leader in navigation, traffic and map products whilst also dealing with products such as GPS Sports Watches and the provision of fleet management solutions (TomTom 2015). TomTom was the first institution to implement digital mapping in 1988, as well as the first to use active (monthly map edit reports) and passive (data points) community input to ensure that their maps remained updated (TomTom 2015). As a result, TomTom can be credited with being the founders of mapping technology that is known throughout the world.

TomTom provides an array of information to assist drivers with the route in which they commute to their desired destination, essentially optimising their travel time. The information provided consists of:

- Real-time traffic information
- Navigation
- Speed camera alerts
- Weather information

The purpose of the real-time traffic information is to allow the user to make immediate adjustments to their route of travel (specifically to and from work) based on the changing conditions of the road. This provides the optimisation in that the user is constantly informed and will save on travel time (provided the route suggestions are considered). According to TomTom, independent tests compiled showed that the users of TomTom Traffic (an accurate, real-time information system based on changing map information as well as historical data) may save up to 18.5 percent on journey time (Tesco Tech Support 2015). Furthermore, they believe that if 10 percent of drivers used TomTom Traffic, there would be a reduction in the travel time for all road users. TomTom also provides alerts of all traffic congestion within the vicinity of the user. In this case the user would be able to receive the best alternative route to avoid a traffic jam in a nearby location. Figure 2.15 provides an indication of the manner in which the possible routes are analysed to provide a suggestion of the best alternative route.

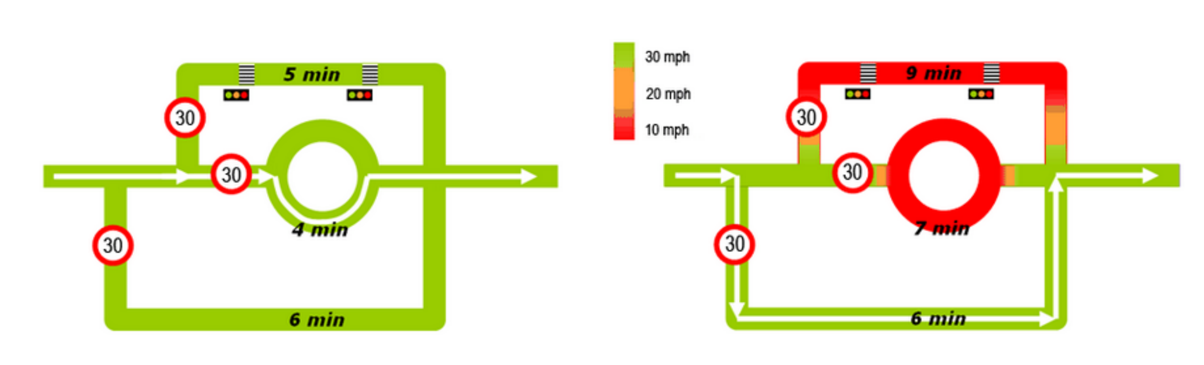


Figure 2.15: TomTom route calculator (www.tomtom.com)

Accurate and up-to-date information is of incredible value, especially with the manner in which the conditions of the road change according to accidents and construction. With this in mind, TomTom has to be aware of the constant changes in order to make the required adjustments. This is done with the following procedure:

- Detection of the change
- Validation of the change
- Updating the Central Database
- Publishing the change

This procedure allows TomTom to be on the forefront of map-making technology as well as creating innovative ways to obtain their data. The data itself is obtained from the input of the community; with the community being the 100 million map users from around the world who provide the information via map feedback tools. The data is also obtained from GPS probe data; the information is received through connected TomTom devices, as well as the connected devices of companies with which they are partners.

Although all of the above mentioned factors imply that TomTom would provide an excellent means of monitoring traffic networks in addition to infrastructure such as CCTV cameras, the following criticism should be considered.

- **Evaluations are done in 15 minute intervals**: If an accident occurs there will be a traffic jam and TomTom will only be able to provide a warning of the incident at a later stage.
- **The speeds presented by TomTom are averaged and smoothed** for a particular section, so the user is not able to gain an exact prediction of an incident (i.e. the vehicles may slow down for a truck that is ahead of the stream for example).
- **TomTom is volume dependent**: If there is a low volume of probe penetration, the system will not work effectively.

In conclusion, TomTom is recognised as providing the best routing due to its IQ Routes ™ and TomTom Traffic calculators. The IQ Routes ™ bases the information on speed humps, roundabouts as well as bumps in the road. Additionally, the route is based on the actual speed travelled by the road users and not the posted speed limit. TomTom traffic observes the congestion of traffic on all of the routes possible. Even though the criticism towards the system is crucial to the efficiency of the road network, the combination of these applications would provide the most efficient route possible and would allow users to arrive at their destinations both safely and punctually.

PROBE DATA SPECIALISTS: INRIX

INRIX is a traffic information company that provides public information and services with the implementation of probe data analytics and crowd-sourcing. The company was founded in July 2004. INRIX believes that the ability to analyse the vehicles in the traffic network is directly proportional to the understanding of traffic conditions (Why INRIX, 2014). With this idea borne in mind, INRIX has access to multiple sources of information, namely vehicles, cell-phones, cameras and sensors. The extent of its reach was stated to be in the proximity of 6 and a half million kilometres of road (including ramps and interchanges) in a total of 40 countries (Why INRIX 2014). INRIX not only supplies traveller information to the public; multiple companies require their services. These companies include vehicle manufacturers (Audi, Ford, and BMW for example) as well as news media and government organisations (Why INRIX, 2014).

HOW DOES INRIX OBTAIN ITS INFORMATION?

INRIX has incorporated a combination of multiple sources of information to be able to supply the traffic solutions to travellers. These sources include traffic alerts (received from helicopters and commuters), historical data, real-time information (sensors and cameras) and crowd-sourcing (obtained from but not limited to GPS data received from in-vehicle electronics and cell-phones) (Inside INRIX – how traffic data is collected and what it means to you 2010).

HOW HAS INRIX BECOME RECOGNIZED AS A WORLD LEADER IN TRAVELLER INFORMATION?

INRIX claims to be the best provider of traffic information (inrix.com/press, 2010). They are able to obtain and incorporate information from different sources – these sources include historical data, probe data, GPS data from vehicles making use of the INRIX app as well as information obtained from the network of service providers. Incorporating this information into their systems leads them to the use of Big Data Analytics; it has to be understood that all of the information that they obtain may not necessarily be structured information. Additionally, their information is updated every minute (*A closer look at INRIX, the world's largest traffic intelligence network* 2013), although the information may not physically be obtained in real time by the users, the ability to spot an incident with the use of infrastructure would probably take a comparable amount of time, meaning that this information would be provided at a relevant time to that of the traffic incident. Figure 2.16 provides a description of the events incorporated to provide accurate travel time information.

Figure 2.16: Incorporation of Events Influencing Travel Time and Routes (www.inrix.com)

The information that INRIX obtains is provided by different vendors. The information is of course received from the users of the service, that is, the users of personal vehicles, as well as taxi and bus services. INRIX provide the following types of information:

- Weather data
- Real time traffic incidents, traffic routes, congestion information
- Alternative routes
- Parking information
- Fuel station locations
- Cloud connection
- Connection to other vehicles

Figure 2.17 provides a graphical description of the information provided and how it can assist the driver along their route:

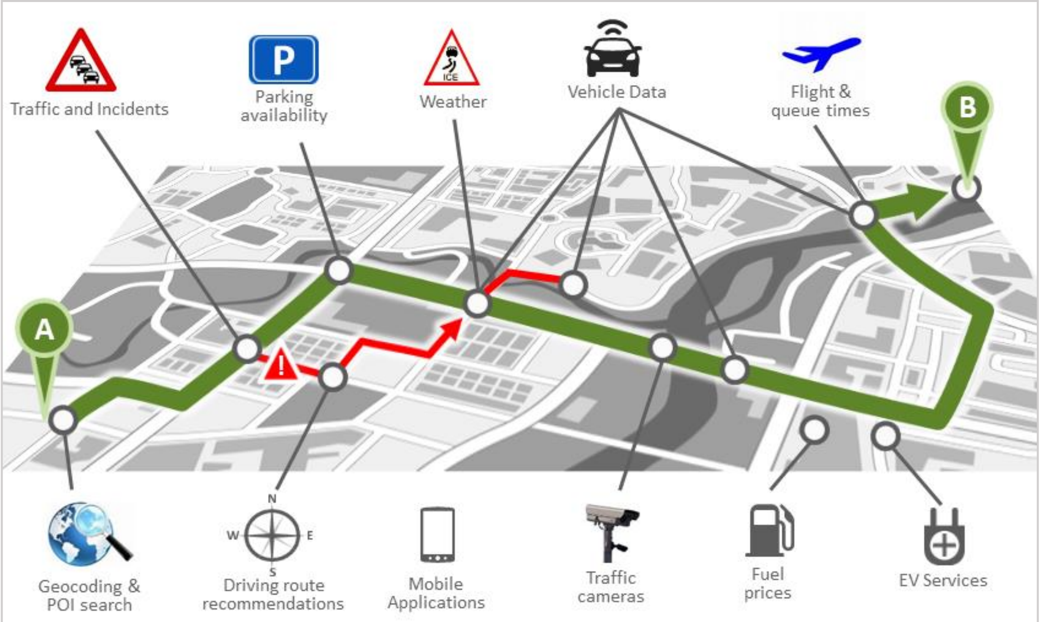


Figure 2.17: Information Services provided by INRIX (www.inrix.com)

2.2.7 INTERNATIONAL PRACTICES AND PROJECTS

A report compiled by MDOT & CAR (2013) highlights the projects and testing conducted internationally. The continents included in the report comprised of North America, Europe, Asia, Oceania and the Middle East. A brief description of the projects of specific countries in each continent will be provided. Appendix B provides an indication of the number of countries considered and the number of projects related to each country.

NORTH AMERICA

MICHIGAN

According to an article in *The Verge* (2012), the U.S.DOT and the University of Michigan Transport Research Institute (UMTRI) commenced on a pilot study of connected vehicle technology in 2012. The objective was to determine the behaviour of connected vehicle technology in an open environment. The investigation included 2 836 private vehicles with Dedicated Short Range Communication (DSRC) connectivity – this later expanded to 9000 vehicles (Campbell-Dollaghan, K., 2015). This would allow vehicles to communicate with each other (Vehicle-to-Vehicle communication) and the surrounding environment (Vehicle-to-Infrastructure and Vehicle-to-everything communication). Barbaresso, J.C. and Johnson, P. (2014:23) state that the deployment of connected vehicle infrastructure will be guided by federal policy, and the movement in this direction will enhance development in connected vehicle technology and market penetration.

CALIFORNIA

California is involved with connected vehicle research; the investigations are conducted by automotive companies operated by BMW, Daimler and Volkswagen North America. BMW has interest in "using wireless pipelines to connect BMW drivers for safety, mobility and commercial applications" (MDOT & CAR, 2013).

ARIZONA

This state deployed the *Arizona E-VII Program* in 2008, where connected vehicle technology was tested to assist with incident management and traffic control. Prototype applications tested include traffic signal priority and pre-emption, ramp metering pre-emption and mobile incident warning (MDOT & CAR, 2013).

COLORADO

Colorado conducted a connected vehicle study (*Denver E-470 test),* where multilane free flow (MFF) and open road tolling (ORT) applications were tested. The test involved the use of DSRC connectivity to establish the communication between vehicles and infrastructure (MDOT & CAR, 2013). According to Hill, M (2008, cited by MDOT & CAR, 2013), 27 vehicles were tested and included the use of toll tags and detectors, vehicle detection and classification, and automatic license plate recognition solutions. Kapsch (2008, MDOT & CAR, 2013) stated that a study comparing the performance of DSRC toll tags against a GPS data logger, concluded that 100 percent of the samples tested identified by the GPS data logger, were also identified by the DSRC toll tags.

NEW YORK

According to an article in GIZMODO (2015), 10 000 vehicles would be used to test connected vehicle technology, making it the largest test pilot for connected vehicles to date. The testing conducted in this state is similar in nature to the test pilot in Michigan, and may be thought of as an extension to the Ann Arbor (Michigan) test pilot. In this pilot however, pedestrians will be included by providing tech for smartphones; this will allow the connected vehicles to 'sense' pedestrians and predict imminent collisions (GIZMODO, 2015).

ASIA AND OCEANIA

JAPAN

In 2010, Japan was involved with three testing systems, all under the banner of *ITS-Safety 2010 Industry-Wide Tests.* The three tests were Driving Safety Support Systems (DSSS), Advanced Safety Vehicle (ASV) and Smartway (MDOT & CAR, 2013). DSSS tested vehicle-to-infrastructure communications and featured tests such as alerts for traffic signals, stop signs, turning and lane changing. ASV involved testing of vehicle-to-vehicle communication, achieved with 5.8 GHz DSRC and 700 MHz connectivity. The tests included warnings for rear-end, crossing and turning collision warnings (MDOT & CAR, 2013). Smartway incorporated a collaboration of communications. Vehicles communicated with infrastructure concerning information about road obstacles and congestion. This information would thereafter be relayed to other vehicles through vehicle-to-vehicle communication (MDOT & CAR, 2013).

TAIWAN

The Industrial Technology Research Institute (ITRI) of Taiwan developed a WAVE/DSRC Communication Unit (IWCU) which allowed communication between vehicles and infrastructure, vehicle-to-vehicle and vehicle-to-infrastructure communication (MDOT & CAR, 2013).

AUSTRALIA

A technology company based in Australia (Cohda Wireless n.d., cited by MDOT & CAR, 2013), "developed a signal processing technology that enhanced transmission quality of 802.11p radios used in connected vehicles" (Stone 2009, cited by MDOT & CAR, 2013). The technology was later approved for testing in 2011 for connected vehicle testing purposes. The test studied vehicle-to-vehicle and vehicle-to-infrastructure, consisting of 10 vehicles collecting data from road-side infrastructure.

EUROPE

GERMANY

Germany initiated a project called *Safe and Intelligent Mobility Test Germany* (sim^{TD}) to test vehicle-to-vehicle and vehicle-to-infrastructure communications (MDOT & CAR, 2013). The project stated in 2008 and included multiple connectivity options such as wireless local area network (WLAN), 802.11p and 802.11 b/g, Universal Mobile Telecommunications System (UMTS) and GPRS. According to TN (2012), "the vision for sim^{TD} was to create a system could enhance road safety, improve traffic efficiency, and integrate value-added services." The study found that a connected vehicle penetration rate of 20% would produce significantly positive effects on the conditions of traffic. The study concluded in 2013, where an exhibition allowed attendees to use a connected vehicle from the test fleet (sim^{TD} 2013, cited by MDOT & CAR, 2013).

FRANCE

France conducted three projects including components of vehicle-to-vehicle and vehicle-to-infrastructure communication, these projects were *CyberCars-2*, *CyberCars* and *CyberMove*. CyberCars-2 involved testing vehicle-to-vehicle communication with vehicles following at close and regular distances (platooning) and vehicle-to-infrastructure communication at intersections (MDOT & CAR, 2013). Cybercars began in 2006, making use of existing vehicles with upgraded software and communications technology. The project concluded in 2009 and, according to CyberCars-2 (2009, cited by MDOT & CAR, 2013), the final result of the project was as follows:

- Dual-mode vehicle prototype capable of autonomous and co-operative driving
- A communications architecture
- Algorithms for various manoeuvres
- A management centre to support communications
- A simulation for evaluating the impact of larger deployments

ITALY

To address road safety concerns, *Co-Operative System in Cars for Road Safety* (I-WAY) was initiated in Italy (2006 - 2009). The objective was to improve driver perception and included vehicle-to-vehicle and vehicle-to-infrastructure communications. Information was obtained from the vehicle sensing system, road infrastructure and neighbouring vehicles. This data was used to monitor and recognize “the road environment and the driver’s state in real time” (MDOT & CAR, 2013).

UNITED KINGDOM

According to the report issued by the Department of Transport (*The Pathway to Driverless Cars*, 2015*)*, the UK will develop Codes of Practice for the use of Connected and Autonomous vehicles and plans to initiate allowing access to autonomous vehicles on UK roads (Appendix B provides a proposed timeline for the development of these automated vehicles). Additionally, multiple studies have been conducted in support of connected and autonomous technology. Consequently, four cities in the UK have received approval for testing autonomous vehicles, namely Greenwich, Milton Keynes, Coventry an Bristol (Driverless cars: 4 cities get green light for everyday trials - News stories - GOV.UK, 2014). Although the outcome and results of these test are unknown at this stage, it is clear that connected and autonomous technology is thoroughly tested in the UK, and approval of their use will be sought by government and leading automotive institutions.

ISRAEL

Israel began testing vehicle-to-vehicle and vehicle-to-infrastructure communication in 2007 and 2008 with the project *Cooperative Communication System to Realize Enhanced Safety and Efficiency in Europeans Road Transport* (COM2REACT). The test procedure included a virtual traffic control sub centre (VSC) and was stated to “control a moving group of vehicles in close proximity” (MDOT & CAR, 2013). Through vehicle-to-vehicle communication (using 2.4 GHz Wi-Fi), VSC creates a network with vehicles in close proximity and captures data concerning the status of traffic and safety concerns. Thereafter, vehicle-to-infrastructure communication (2.4 GHz Wi-Fi) allows VSC to "transmit this information to a regional control centre" and distributes commands to the nearby vehicles (MDOT & CAR, 2013).

CONCLUDING REMARKS

A clear trend can be identified for implementing technology as a means of either managing and operating traffic flow or enhancing efficiency and safety of vehicles through direct communication with the vehicle fleet. While focus areas may differ (traffic data, driver safety, travel efficiency), it can be seen that the centre of consideration is the vehicle (although various forms of communication have been described such as DSRC/WAVE or UMTS).

For South Africa, the consideration must be given to the available resources and the application areas (safety, efficiency, etc.) that may be specific to the South African economy. In Chapter 1, it was shown that the vehicle fleet is trending toward an increase, along with increases in congestion and crashes on the freeway. Multiple ITS infrastructure has been installed (*Section 2.1.7*) in the Western Cape and other parts of South Africa and is significant to the management of traffic; however, there is an absence in the Active Management of traffic (such as Ramp-Metering, Variable Speed Limits, etc.). The reason for this may be a cost factor associated with implementing these systems (increasing the infrastructure network by adding more VMSs for example).

The studies conducted in these countries therefore offers an opportunity of leverage to South Africa. The tests conducted and the information exchanged, as well as the results obtained may offer an opportunity for exploring an alternative means of traffic management, where costs may be reduced on behalf of the managing agencies by making use of existing technology and equipment – in this case, leveraging the capabilities of Smartphones for use in vehicles as connected devices.

2.2.8 CHALLENGES OF CONNECTED VEHICLES

Connected Vehicles will incorporate internet connectivity and will provide vast amounts of information including the status of the vehicles, operation of vehicle components, geometric information of the particular vehicle etc. The understanding of big data components and the mining thereof has led to the creation of a new environment not previously explored. CV applications and vehicle-behaviour prediction has the potential to produce an extensive impact on efficiency and safety, as well mobility of handicapped members of society. This revolution of the automotive industry and transportation faces challenges that may hinder the level of penetration into the market expected by vehicle manufacturers and transport institutions.

The challenges that exist as a result of connected vehicles include security of the systems, privacy, data ownership and ethics related decisions that computers may not be capable of making. An article written by Raza, A. (2015) on the motorburn™ highlighted the following challenges that connected vehicles (and later, autonomous vehicles) will face upon implementation:

- **Faith in Vehicle Capabilities**: According to Raza, A. (2015), vehicles with technology that does not require their full assistance is a commitment that will have to be learnt. Trusting a vehicle to control parts of the journey (such as negotiating turns and speeding up) may not be a convenient habit to adapt.
- **Ethical Choices**: CVs will be mostly under the control of the computer in the vehicle; in the case of an incident however, vehicles will be faced with the decision of choosing the most appropriate course of action to reduce the level of damage. The decision in this case would be to save the passenger or save a pedestrian and, according to Raza, A. (2015), a human would be able to make the decision instantaneously and can be held responsible for the actions taken; the responsible party in terms of connected vehicle technology remains to be determined.
- **In-vehicle Space**: although this is more applicable to autonomous technology, the option of incorporating this technology into existing vehicles makes this point relevant to the study. The technology used is stated to include extensive hardware, decreasing the availability of space within the vehicle – this may be impractical for most vehicle owners
- **Legal Pitfalls**: since vehicle manufacturers will be collaborating with different vendors (such as OEM and multiple software companies), there is the concern about which party will take responsibility for the causes of incidents.
- **Driving Laws**: At present, driving laws will have to be adjusted or altered to allow the operation of connected vehicles on public roads amongst other vehicles and road users. With regards to South Africa, there are no existing pilot studies of CV technology and the concept is in the developmental stages; it will therefore be (some time) before legislation is changed to allow the presence of CVs (and later, AVs) on public roads.
- **Software Security**: Since CVs rely extensively on software and applications, the data these vehicles produce and the protocols in place to ensure the safe operation of the vehicle, bear the risk of being hacked. With this risk in place, consumers may not trust the technology and ease of travel that CVs may provide. Software developers and vehicle manufacturers will therefore be required to investigate and propose solutions to eliminate the possibility of the vehicle software being tainted.

The challenges mentioned appear to be extensive, however, if each is addressed in the correct manner and protocols are put in place to approach the above mentioned concerns, the opportunities that CV technology presents is likely to outweigh these issues based on the claimed benefits of connected technology (*Section 2.2.2*). Issues pertaining to legislation will eventually be addressed with the proposal of an acceptable solution, and security issues may be addressed with the creation of exclusive software (software only available and accessible by vehicle manufacturers and the collaborating software developers). Although many challenges can be presented, the benefits that may be achieved in saving lives of drivers and pedestrians, improving efficiency through detailed traveller information and environmental awareness may exceed these drawbacks, especially since the challenges are individual based while the benefits extend to the improvement of the economy as a whole (refer to Chapter 1, *Section 1.1*).

2.2.9 MOBILITY FOCUSSED CONNECTED VEHICLE APPLICATIONS

CVs will contain multiple applications that may assist occupants in mobility, safety and efficiency. Additionally, these applications may assist in the efficiency of the traffic network as a whole (depending on the rate of penetration of connected vehicles) and create a safer environment in which to travel.

The following CV applications were identified by U.S. Department of Transport (2016) (refer to *Section 2.2.3* for description and local applicability of applications):

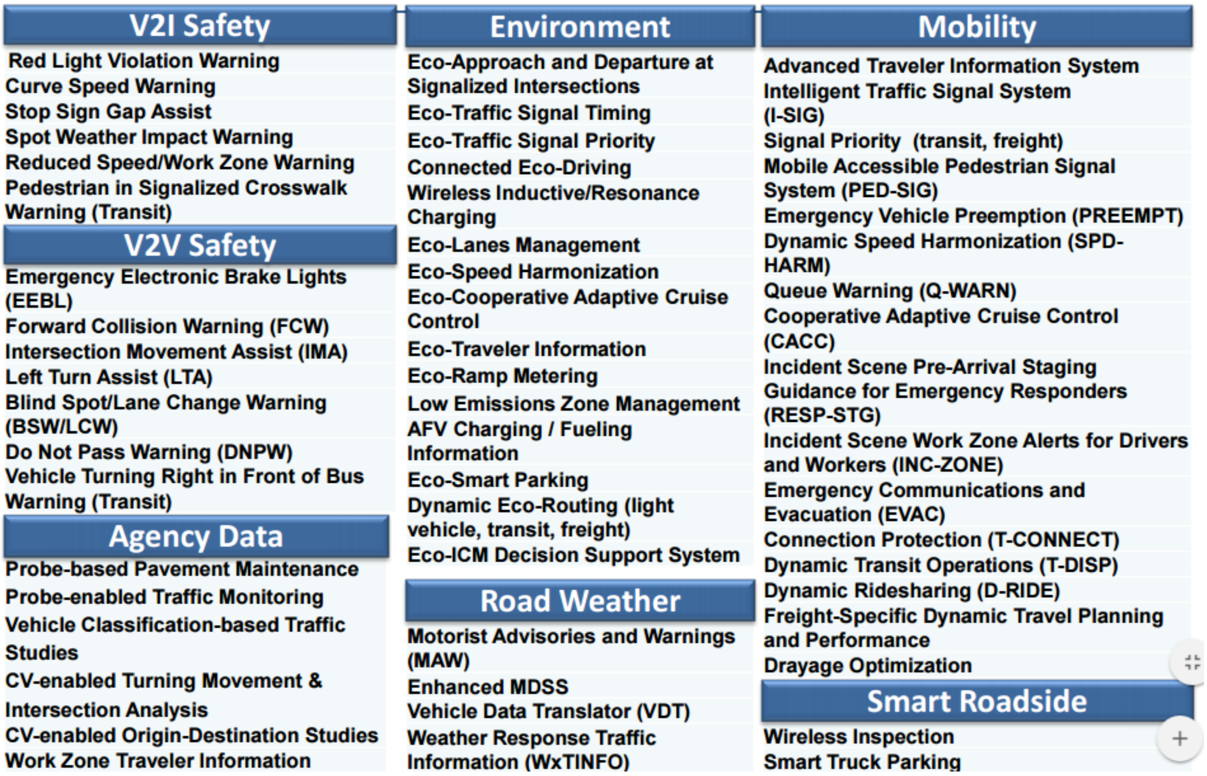


Figure 2.18: Connected Vehicle Applications (Source: USDOT, 2016)

As the figure indicates, there is an extensive amount of applications available as a result of connected vehicles, and the applications will improve and increase as a result of improved technology and software development. Based on the applications stated, there are certain applications that take priority over others in short-term development of a connected environment. The following applications were identified as being the most appropriate for short-term implementation purposes:

APPLICATIONS AFFECTING MOBILITY

With the focus of this study directed toward considering efficiency of traffic in the Western Cape, the applications focussed on improving mobility are therefore described below:

- **Signal Priority (transit, freight)**: Allowing freight and transit vehicles signal priority on roads will improve the flow of light vehicles as these vehicle increase delay due mainly to their size. Furthermore, even if these vehicles were programmed to produce reaction times in-sync with the time taken for traffic signals to allow throughput, a great amount of time is taken for heavy vehicles to attain speed and clear the stopping-line of a signalised intersection. This decreases the amount of time for a sufficient throughput of light vehicles, essentially increasing congestion (in areas with large quantities of freight and transit vehicles). Additionally, areas in which freight and transit vehicles travel regularly are prone to feel the effects hereof more extensively. These areas should therefore be identified to optimise the use of infrastructure used for this purpose.
- **Dynamic Speed Harmonization (SPD-HARM)**: According to Iteris.com (2015), the Speed Harmonization application determines the most appropriate travel speed according to traffic and weather conditions. Establishing speed harmonisation will improve efficiency by preventing additional congestion and allowing traffic to flow continuously. This application may be used in cases of incidents causing congestion (accidents), bottlenecks and special events. As a V2I application, road users may be informed via on-board equipment (OBE) or with the use of VMS equipment.
- **Queue Warning (Q-WARN)**: Q-WARN provides information to nearby vehicles that may be approaching a queue (Iteris.com, 2015). The information may be provided by infrastructure systems that detect a queue based on the status of a vehicle in the queue, or by the vehicle itself. This will allow other vehicles to consider an alternative route to avoid congestion or possible rear-end collisions.
- **Cooperative Adaptive Cruise Control (CACC)**: This will allow vehicles to follow one another with a pre-set following distance and the speed of the vehicle leading in the queue. At traffic signals, this would allow vehicles to move in a pack instead of depending on the driver reaction time. Figure 2.19 illustrates the manner in which vehicles proceed at traffic signalised intersections:

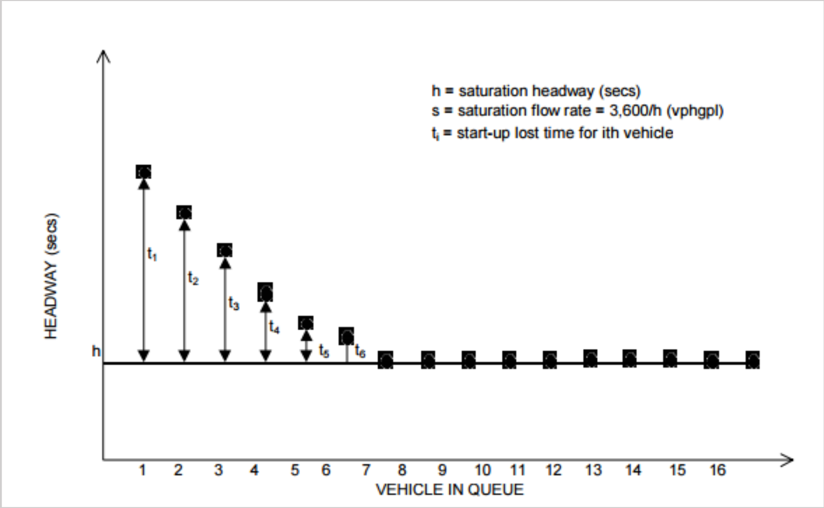


Figure 2.19: Headways at a traffic interruption (Bester and Varndell, 2002)

Based on the reaction time of the first vehicle, a ripple effect is produced as the vehicles begin to proceed beyond stop-line. Adding all of the times indicated in the figure ($\sum_1^6 t$) is the total amount of time lost as a result of vehicles being operated independently. If these vehicles proceed at every signalised intersection at the time h, more vehicles would be able to proceed through intersections. Cumulatively, this would increase efficiency within the traffic network by reducing stopping and starting events.

- **Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)**: Providing real-time information of the occurrence and magnitude of incidents would allow travellers to adjust their travel routes to reduce the possibility of congestion. Additionally, this would allow incidence response services more convenient access to the incident zones. With easier access and the possible elimination of traffic disrupting the crash scene, services would be able to address the incident more efficiently and allow the facility to function normally in a shorter period of time.
- **Dynamic Ridesharing (D-RIDE)**: Although this application is more appropriate to the North American market (highways in the United States distinguish between high occupancy vehicles (HOV) and single occupancy vehicles (SOV)), the impact that it may present is applicable to all transportation systems. D-RIDE, according to the Washington Transportation Research Board (Levofsky, A. and Greenberg, A., 2001), central database or ridesharing agency. Once a request is made, a potential driver is searched for that relates to the time and direction of the travel intended until a match is found. Currently, the company Uber (a transportation request service) has established itself in 384 cities globally (uber.com). Users may utilise the application to request transportation. Additionally, any person owning a vehicle may register to be part of the service, essentially making the personal vehicle a taxi – this means that no additional vehicles are added to the traffic network. Integrating this service with connected

vehicle technology will allow public members to attain transport within shorter periods of time, and may receive communication from registered Uber vehicles in emergency situations.

Although not specifically mentioned, collection of data for payments from vehicles is an additional application that may be immediately applicable since vehicles would be able to communicate with the environment. For example, an application may be developed that allows users to pay for tolls without stopping or purchasing additional hardware. Once a CV passes a toll collection point, the vehicle's coordinates may be used to determine if a payment is required. Allowing vehicles to pay remotely whilst in the vehicle would reduce costs to users for hardware and would alleviate payments from traffic agencies to issue the necessary technology, update software and maintain toll infrastructure.

PROVISION OF AGENCY DATA

- **Probe-enabled Traffic Monitoring**: This would allow traffic management agencies to monitor traffic based on probe information and reduce the necessity for CCTV cameras, loops and related static infrastructure. Additionally, probes allow for consistent monitoring of traffic and provide information on segments, as opposed to singular locations (only at an intersection for example).
- **CV-enabled Turning Movement and Intersection Analysis**: Monitoring the turning movement of traffic and the behaviour of the intersection as a whole would allow traffic management agencies to determine the placement of priority to allow for a greater throughput of traffic and increase the efficiency of the network, especially in areas with multiple signalised intersections.

2.2.10 CONCLUDING REMARKS

The implementation and deployment of Connected Vehicle technology is still in development (its.dot.gov, 2016) and may further be delayed for local deployment before the technology is present in South Africa and CV technology penetrates the South African market to the extent that positive effects may be observed. It is forecast that approximately 21 million vehicles sold world-wide in 2018 will allow for Smartphone integration (SBD, n.d.).

These effects may present a beneficial impact on the environment in which they are located as discussed in *Section 2.2.1*. The effects, at first, may not be felt by the traffic network as a whole, but may eventually influence the lives of the individuals exposed to the technology. The automotive industry appears to be conducting significant research on this technology, while certain levels of connectivity already exist on some vehicle models (GSMA, 2013). It is forecast that over 380 million connected vehicles will be on the road by 2021 (world-wide, not necessarily including South African market (Greenough, 2016)) and that local penetration of connected vehicles is expected to reach 3.26% by 2020

(Statista, 2016). This level of connectivity may increase in consideration of the availability of Smartphones as a possible means of establishing connectivity between vehicles and infrastructure.

The creation of connected vehicles, regardless of the drawbacks stated, seems to be inevitable since research continues to be presented on the progress of these vehicles. It is thus clear that Connected Vehicles will eventually penetrate the market on a global scale.

2.3 AUTONOMOUS VEHICLES

Autonomous Vehicles (AVs) may be defined as vehicles possessing the intelligence to operate the vehicle in a real-world environment without the assistance of human input (Lloyds', 2014). AVs present the potential for an accident free environment, where the vehicles determine the optimal speeds, routes, parking facilities and innumerable decisions that the driver will no longer be faced with. This will allow for a more productive environment, where drivers may be able to use travel time to complete work, utilise infotainment available in the vehicle, or any related tasks eliminated during the task of travelling (Bertoncello and Wee, 2015). According to the article *Ten ways autonomous driving could redefine the automotive world,* AVs could save users 50 minutes a day, an amount of time in which more pressing matters could be addressed. An environment consisting almost entirely of autonomous vehicles has the potential to recreate efficiency and completely eliminate road accidents, saving thousands of lives locally, and millions globally. Figure 2.20 indicates the levels of autonomy as defined by the Atkins group (Leech et al., 2015)

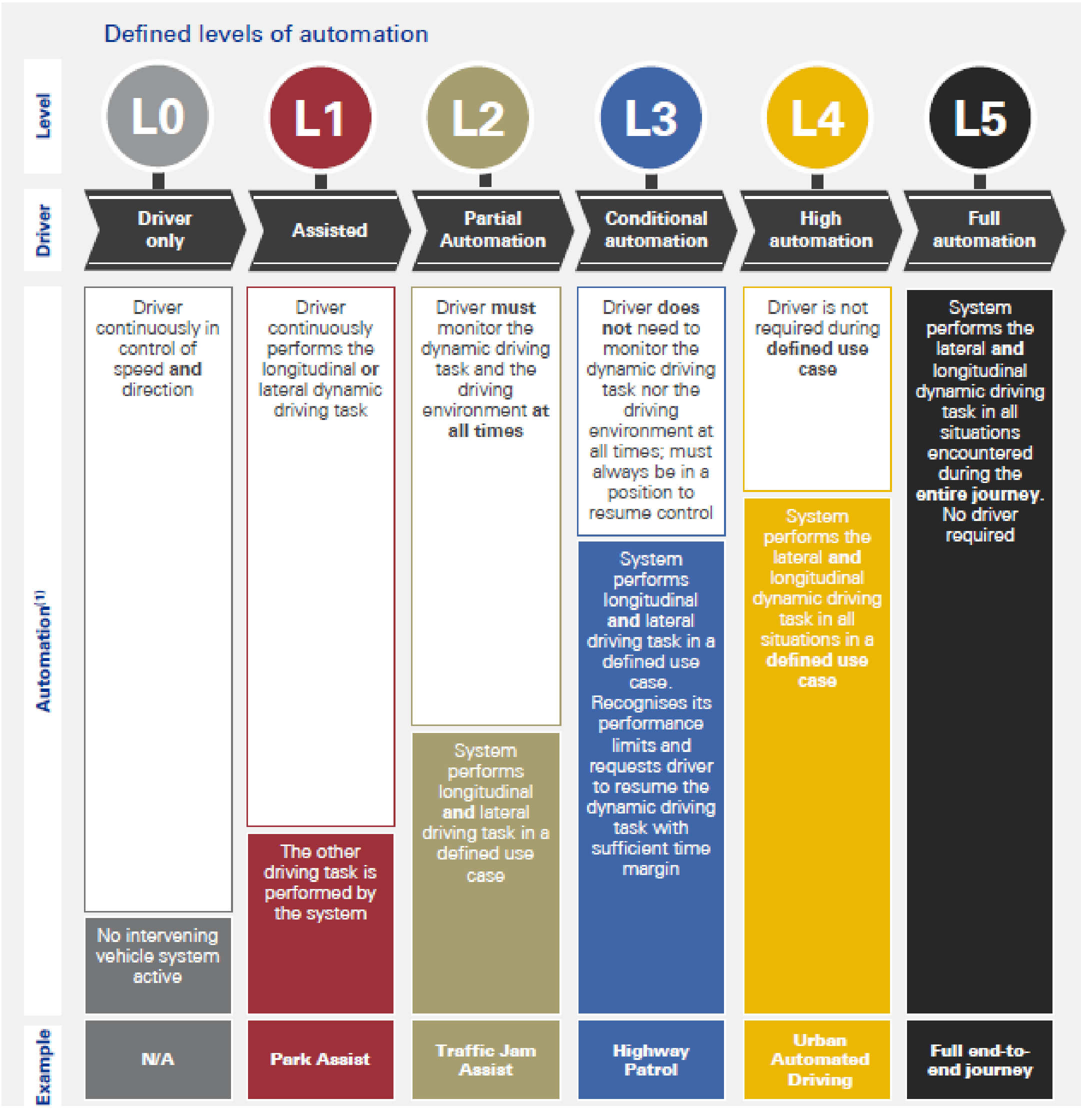


Figure 2.20: Progression of automation technology of future vehicles (Atkins, 2015)

2.3.1 CURRENT LEVEL OF AUTOMATION

Presently, fully autonomous vehicles have not impacted the market and are still in developmental stages. Different levels of autonomy have however, been identified as well as the stages in which they are predicted to enter the real driving environment. Figure 2.21 indicates that adoption of automated vehicles may only be realised between 2025 and 2035.

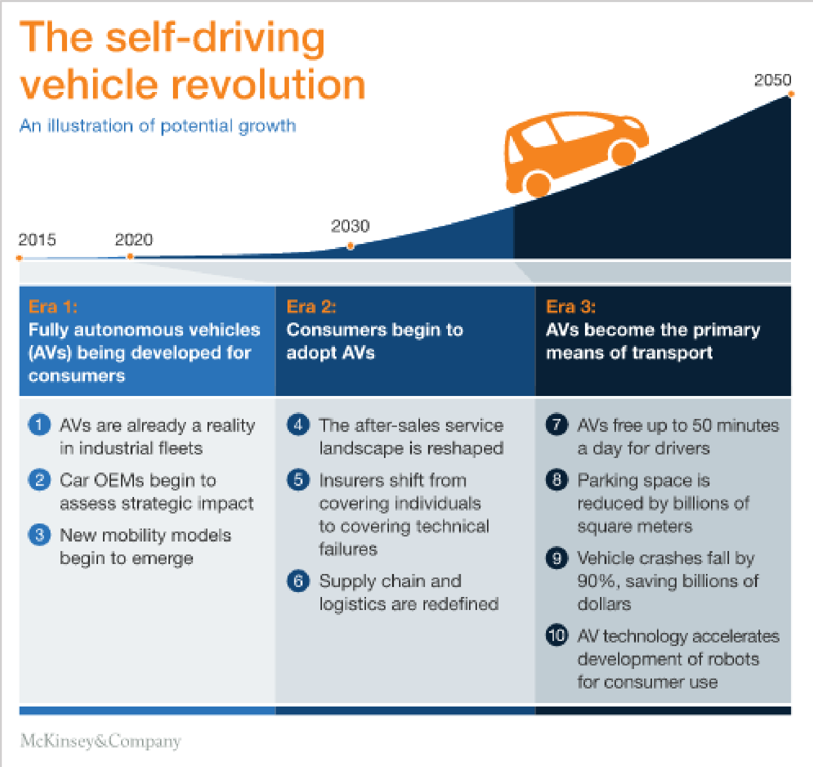


Figure 2.21: Projection of penetration of Automated Vehicles in the UK (McKinsey&Company, n.d.)

Multiple pilot studies with autonomous vehicles have been conducted. The most popular autonomous vehicle at the moment is Google's Autonomous car. According to Birdsall (2014), the Google vehicle uses LIDAR (Laser Imaging Detection and Ranging) to localize its location and completed 805 000 kilometres by 2014, and has achieved significant progress in a short period of time. Figure 2.22 illustrates the technology used by automated vehicles to navigate in open environments.

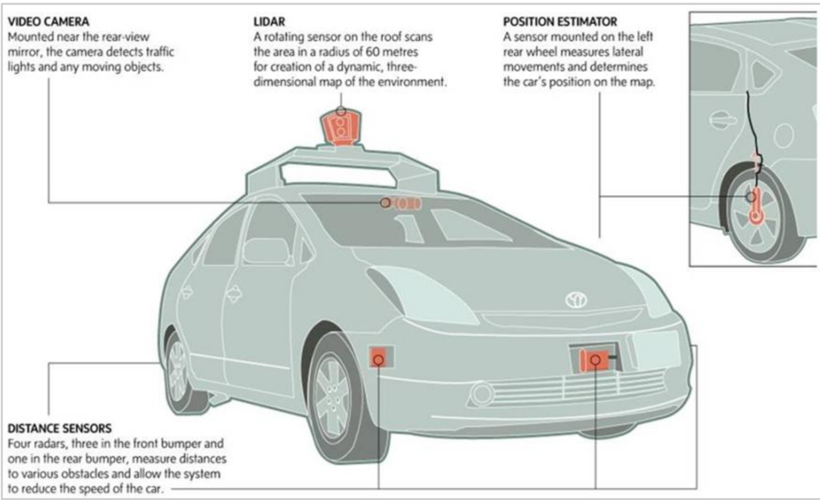


Figure 2.22: Technology Incorporated into Vehicles to achieve Autonomous Functionality (Driverless Transportation, 2014)

The technology is however constantly developing and has several drawbacks. Plumer (2016) states that the Google car can only drive on detailed map routes. Furthermore, the route has to be mapped multiple times before the vehicle attempts to traverse the route. Additionally, the use of Lidar has limited the vehicle's ability to distinguish between temporary and permanent objects. Finally, the vehicle struggles to function in changing environments as the data cannot be processed fast enough – the vehicle will thus struggle in bad weather conditions, such as snow (Plumer, 2016).

Additional drawbacks include navigation at 4-way stops and roundabouts (Plumer, 2016). Navigation through 4-way stops relies on human interaction and depends on driver's level of urgency (some drivers may choose to proceed through a 4-way stop in pressured circumstances). Secondly, the Google car was alleged to have failed to exit a roundabout (Barnard, n.d.) – this indicates that progress of the system is still in development as the vehicle should be able to perceive the presence of vehicles and acceptable gaps to initiate overtaking manoeuvres.

Ford released a vehicle called the Fusion Hybrid in 2013. The vehicle makes use of high-resolution 3D Mapping and Lidar for localisation in the absence of road markings (Motoring: Wheels in Action, n.d.). Ford's research in automation has allowed for the following developments (Ford Research Centre, 2015):

- **Autonomous vehicle virtual test drive**: allows virtual interaction between autonomous car and pedestrians, replicating real-world situations to better understand and develop responses to unexpected events.
- **Sensor fusion**: Sensors on autonomous vehicles detect and track objects in the vehicles view, fusing information together to provide a 360-degree view of the car's surroundings.
- **Camera-based pedestrian detection**: Camera sensors allow the vehicle to identify and sense pedestrians.

Ford is currently involved in testing the behaviour of its Fusion Hybrid model in snow under autonomous operation (Ford Research Centre, 2015). Testing the capabilities of autonomy in snow is a progressive achievement as previous models of automated vehicles travelled according to meticulously rendered maps. Achieving fully autonomous functionality in snow means that the system can adapt changing environments.

Mercedes-Benz has been involved with autonomous technology since 1994 with the assistance of Professor Ernst Dickmanns (Mercedes-benz.com). During 1994, autonomous vehicles may not have been affordable for the general public, but due to the mass-production of hardware and improvement in software development, Mercedes have been able to create variations of autonomous vehicles that may be used by the public. Mercedes has titled this functionality Drive Pilot, featured in the 2017 Mercedes-Benz E-Class (R&T, 2016). Drive Pilot will allow the 2017 E-Class to drive autonomously for 60 seconds (previously 10 or 15 seconds) before requiring the driver's hands on the steering wheel. Drive Pilot will be able to follow traffic in front, controlling the accelerator and braking input and assisting in steering at speeds up to 200 km/h. Finally, the 2017 E-Class will park remotely (Remote Parking Pilot) in narrow parking spaces (R&T, 2016).

The technology has been developed to the extent that it is highly possible to own an autonomous vehicle in the near future, if by the means to do so. Autonomous vehicles may not be immediately affordable to the general public, but the long-term development of technology will allow AVs to be affordably priced. Although drawbacks in the technology were identified, the level of progression in AV technology has increased drastically and in shorter time-spans; the presence of fully autonomous vehicles functioning in the real-world is imminent.

2.3.2 IMPACT OF AUTONOMOUS VEHICLES

The influence of AV technology extends beyond the scope of this study, however, the impact that this technology will have on transportation, the environment and society is discussed to provide an idea of the future of transportation. Additionally, based on the impact studies conducted by McKinsey&Company (2015) and KPGM (2015), fully autonomous vehicles will be pursued as the leading form of travel with eventual penetration to, possibly, the global market.

The existence of AV technology will revolutionize travelling by affecting efficiency, safety and economy. AVs may present the following advantages applicable in the real-world. These were summarised according to the website *Advantages and Disadvantages – autonomous systems*, the webpage *Self-driving Vehicles Offer Potential Benefits, Policy Challenges for Lawmakers* (2014), the article *The pros and cons of a driverless future* (Borroz, 2015) and the article *The Driverless Car Debate: How safe are Autonomous Vehicles?* (Keating, 2015) respectively:

- May reduce the rate of accidents by eliminating human-error
- May reduce the rate of automobile-related deaths
- May reduce the rate of traffic and congestion
- May reduce the amount of time spent travelling
- May reduce capital usage (spent on accidents, fuel savings, time savings, labour costs spent whilst travelling)
- Disabilities will not hinder the ability to own a vehicle or engage in the operation thereof
- Parking would be optimised since machines are better at judging distance than humans
- Drivers test would not be necessary (Acquiring a driving license)

A study conducted by Eco Centre for Transport (Keating, 2015) indicates the monetary effect based on the level of penetration within the United States (Figure 2.23):

Assumed adoption rate	10%	50%	90%
Crash cost savings from AVs			
Lives saved (per year)	1,100	9,600	21,700
Fewer crashes	211,000	1,880,000	4,220,000
Economic cost savings	$5.5 B	$48.8 B	$109.7 B
Comprehensive cost savings	$17.7 B	$158.1 B	$355.4 B
Economic cost savings per AV	$430	$770	$960
Comprehensive cost savings per AV	$1,390	$2,480	$3,100
Congestion benefits			
Travel time savings (millions of hours)	756	1680	2772
Fuel savings (millions of gallons)	102	224	724
Total savings	$16.8 B	$37.4 B	$63.0 B
Savings per AV	$1,320	$590	$550
Other AV impacts			
Parking savings	$3.20	$15.90	$28.70
Savings per AV	$250	$250	$250
Vehicle miles traveled increase	2.0%	7.5%	9.0%
Change in total # of vehicles	-4.7%	-23.7%	-42.6%
Annual savings: economic costs only	$25.5 B	$102.2 B	$201.4 B
Annual savings: comprehensive costs	$37.7 B	$211.5 B	$447.1B

Source: Eno Center for Transportation.

Figure 2.23: Estimates of Annual Economic Benefits from Autonomous Vehicles (AVs) in the United States (Eno Centre for Transportation, cited by Keating 2015.)

The benefits of AV technology will clearly affect the future in terms of travelling more efficiently and safely, as well as improving productivity and utilising time more effectively. Unfortunately, the presence of this level of technology presents disadvantages that are inherent to placing complete reliance on technology. These disadvantages include:

- Ethical concerns
- Hacking into the mainframe of the vehicle and manipulating the standard protocol
- Poor response to bad weather conditions
- Concern about computer malfunctions, leading to a collision
- May eliminate jobs requiring driving skills (Freight, Taxi and Bus drivers)
- May not be affordable initially due to advanced technology

The ethical issues in this case may be illustrated with an example. Keating (2015) suggested the scenario of a child suddenly entering the road area to chase a ball and questioning the response of the vehicle, "would the vehicle swerve into oncoming traffic, and potentially destroy the vehicle itself, threatening the life of the passenger and the other occupants, or would it know to immediately stop?" Scenarios producing consequences of related situations would result in responsibility being placed on vehicle manufacturers, or the laws adhered to in the execution of the vehicle's logic procedure (legislation).

AV technology is however still in the stages of development and, according to Ryan Hagemann (a specialist in auto robotics and automation, cited by Keating 2015), is most likely to be available for the public by 2025. Although this technology will take time to penetrate the market, the release thereof is relatively imminent.

2.3.3 EXCLUSION FROM THIS STUDY

Autonomous Vehicles are expected to be introduced to the market by 2025 (Leech et al., 2015). Thereafter, it will take time for the technology to grow within the market as consumers may not purchase autonomous vehicles immediately. Consequently, consumers may not be inclined to purchase AVs at all. The exclusion of the autonomous vehicle from this study however is twofold:

- **Independent production**: Autonomous Vehicles and the related technology is at the discretion of vehicle manufacturers, of which most appear to be involved with investigations – 33 corporations, of which 20 are vehicle manufacturers (CB Insights - Blog, 2016) and 8 of these vehicle manufacturers currently reside in the top 10 for highest market share (Edmunds.com, 2016). Therefore, AVs will be developed and manufactured without dependence on a connected environment.
- **Possibly independent of Infrastructure**: Although AVs will incorporate multiple elements of CV technology, AVs may not require the assistance of infrastructure to function completely and effectively in an environment. Mercedes-Benz has developed the concept fully autonomous vehicle that navigates driving, locates parking and determines the best route according to GPS maps (Mercedes-Benz F 015 – Mercedes-benz.com, 2016).

Autonomous Vehicle technology will be able to exceed the achievements of Connected Vehicles and will provide opportunities for individuals incapable of driving since AVs would eliminate the influence of human error. At present however, AV technology is in development and practical automated vehicles are not expected to affect the market until 2040 according to the rates of penetration of AVs predicted by McKinsey & Company (2015), and later in the South African market due to adaptation rates since the vehicle fleet age in South Africa exceeds that of the study area considered (United Kingdom).

2.4 CONNECTIVITY

For vehicles, infrastructure and Smartphones to communicate with each other, a reliable and efficient form of connectivity needs to be established between all of the systems involved. Since vehicles will be mobile in most cases, a consistent connection needs to be established. Additionally, the connection must be established with a low latency to ensure that the vehicle remains connected to the network and may communicate with other vehicles throughout the journey. This section will discuss the current option of connectivity desired to be implemented, the types of connectivity that may be considered as an alternative to purchasing a new vehicle and the connection between vehicles and the external environment.

2.4.1 DSRC AS THE MAIN TECHNOLOGY FOR ESTABLISHING CONNECTIVITY

There are a few options concerning connectivity that is available for connected vehicles, mainly DSRC connectivity, Wi-Fi and GPS. According to Gandhi et al. (2014) DSRC is currently the only technology available that provides the appropriate "latency, precision and consistency" that is required for active application – latency is the amount of time it takes for a single packet of data to move from one node to the next. Furthermore, Atkins (2015) states that CVs in the future will comprise of multiple connectivity alternatives including LTE, Wi-Fi, WiGig and IEEE 802.15.4. At present however, it appears that more focus is placed on DSRC connectivity – the U.S.DOT Safety Pilot consisted only of DSRC communication between vehicles and infrastructure (U.S.DOT, 2016). As a result, the Federal Highway Administration (FHWA) presented specific expectations from the American Association of State Highway and Transport Officials (AASHTO) regarding field infrastructure after a meeting was held in Washington, D.C. in 2014; the first expectation being that all new vehicles will contain DSRC connectivity by 2020 (Barbaresso, J. 2014).

According to the U.S.DOT (*Dedicated Short Range Communications*) (Its.dot.gov, 2015), DSRC is currently the most appropriate form of communication for V2V and V2I technology as:

- It operates in an unlicensed frequency band (Wireless Access in Vehicular Environments (WAVE) intended for vehicular communication systems – According to www.icasa.org.za (*Spectrum Usage and Availability Q3 2015*, 2016), this frequency (5.9 GHz 802.11p) is available in South Africa) (Table 2.9, page 2.70)
- It is primarily allocated for vehicle safety applications
- It provides a secure wireless interface required by active safety applications
- It supports high speed, low latency, short-range wireless communications
- Performance is immune to weather conditions (e.g. rain, fog, snow, etc.)
- It is designed to be tolerant to multi-path transmissions typical with roadway environments

In support of the low latency mentioned above, the following figure was obtained from the USDOT (*Vehicle Safety Communications Project – Final Report*, cited by Head, L. 2016). In Figure 2.24, it is clear that DSRC far exceeds the latency capabilities of the alternative connection options (particularly cellular and Wi-Fi). With this speed in information transfer, the CV applications (discussed in *Section 2.2.3*) requiring immediate response may be addressed (Table 2.8).

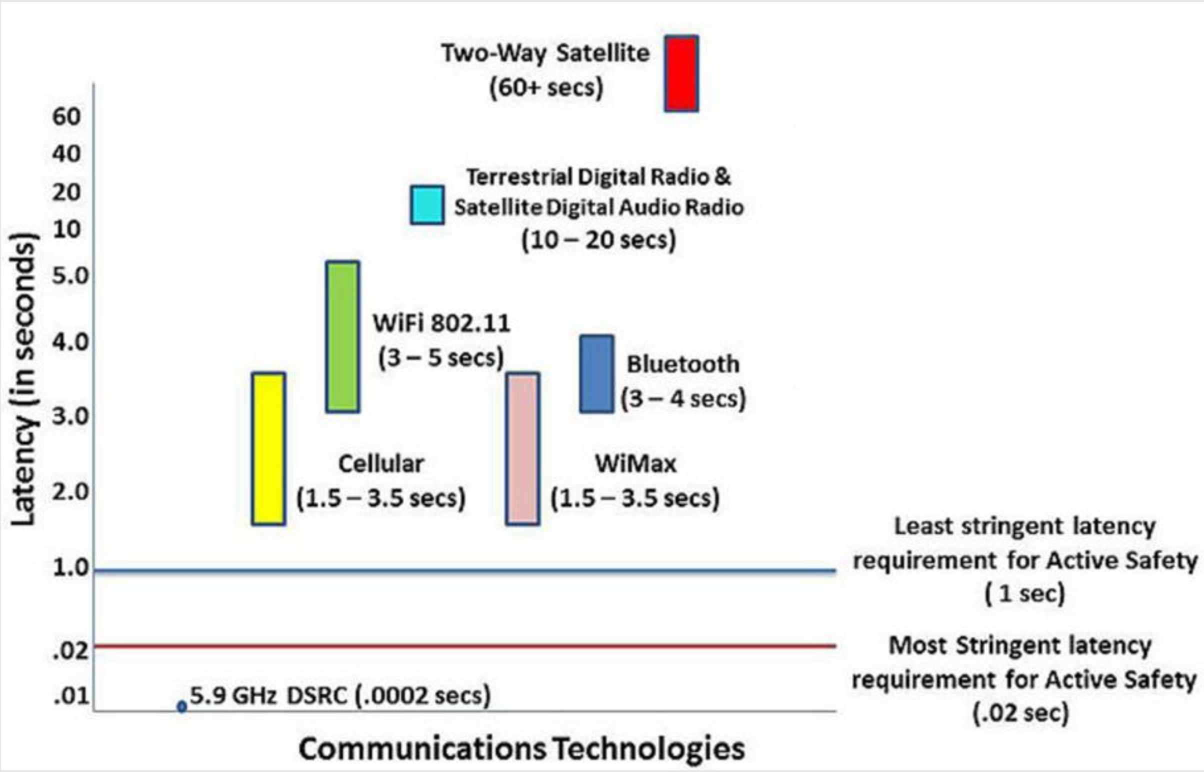


Figure 2.24: Latency of Communications Technology (USDOT: Vehicle Safety Communications Project – Final Report)

Table 2.8 indicates the limiting time that is required for active safety applications to be successful – for example, for a vehicle to be able to respond to a Traffic Signal Violation Warning, the on-board equipment of a vehicle should be in communication with the traffic signal infrastructure (roadside equipment), determine that the speed currently travelled by the vehicle is not sufficient to successfully pass through the intersection and therefore issue a warning under 1 second. DSRC currently has the capability of achieving this communication within the required time.

Table 2.8: Latency Requirements for Active Safety (USDOT: Vehicle Safety Communications Project – Final Report)

Active Safety Latency Requirements	**Time (sec)**
Traffic Signal Violation Warning	0.1
Curve Speed Warning	1
Emergency Electronic Brake Lights	0.1
Pre-Crash Sensing	0.02
Cooperative Forward Collision Warning	0.1
Left Turn Assistant	0.1
Lane Change Warning	0.1
Stop Sign Movement Assistance	0.1

At present, the most promising wireless connection appears to be DSRC. South African transport agencies should therefore pursue planning of infrastructure with this technology as the basis of connectivity. Studies and investigations into connectivity are however, currently in progress and a connected environment is in the early stages of development. More efficient and affordable options may present themselves after future studies are completed; at present however, the connected environment should be established with DSRC.

A perceivable benefit of DSRC radios is that these devices operate on the 5.9 GHz unlicensed spectrum – this means that it is not necessary to apply for a license for the use of these devices (Wi-Fi operates in a similar fashion) (Moyo, A., 2014).

Table 2.9: Spectrum Usage Availability (Source: Icasa.org.za, 2015)

Frequency Band	Availability	Frequency Band Size	User	Application	Channel Bandwidth applicable (duplex)
5.85-6.725 GHz Fixed	Yes. Spectrum available pending radio co-ordination possible with existing terrestrial and satellite services.	5.85-6.725 GHz	WBS	Fixed TDD	5-20 MHz TDD channels

Table 2.9 presents the information obtained from the ICASA website. While it can be seen that the frequency band is available in South Africa, the frequency bandwidths would need to be directly specified for use by DSRC communications devices. This is discussed further in *Section 2.4.1.1*.

COMMUNICATION AND STANDARDS: GENERAL REQUIREMENTS FOR INTEROPERABILITY

This section discusses the allocation of frequency bands to safeguard operation of DSRC communication. A brief discussion of a recommended protocol for DSRC communication follows the frequency band allocation. The intention of the protocol would be to validate vehicle and traveller information that may be sent and received in terms of confidentiality, safety and compliance to standard message requirements for convenient information handling by traffic agencies.

2.4.1.1 DSRC PROPOSED FREQUENCY BAND ALLOCATION

DSRC equipment, as with any other electronic device, may be manufactured by different vendors with the possible intention of producing a product that is more robust and appealing than a competitor's product. These DSRC devices however, will be designed to meet the same requirements to ensure that, regardless of the vendor, the same basic messages can be transmitted and received seamlessly (Shulman, 2015). The requirements are that the communication be established on the same frequency, using the same language, with the necessary security measures in place and with the communication load on the channel managed for effective use (Shulman, 2015). The frequency refers to the 5.9 GHz DSRC frequency band. This frequency band is recommended as it may reduce the level of interference that may be experienced during communication with other surrounding DSRC devices. Recognition of the presence of other existing wireless communication devices is crucial to the development of an operationally efficient Connected Vehicle environment. The frequency band should also be specifically allocated for V2X usage to prevent interruption in communications by other wireless devices (such as Wi-Fi panels etc.). An example of the potential allocation for the frequency band is indicated below.

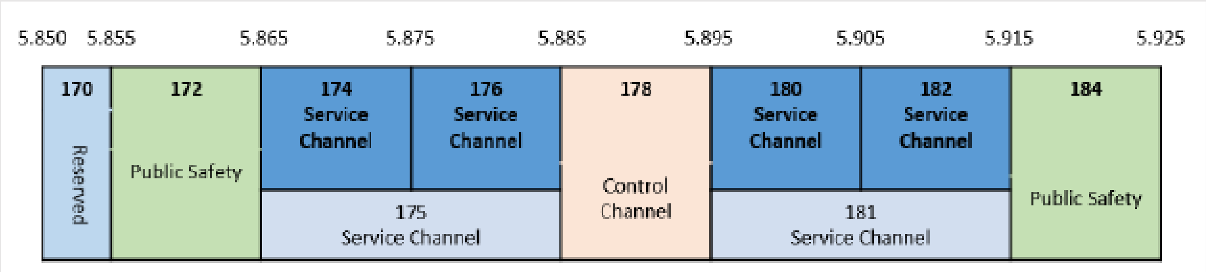


Figure 2.25: DSRC Band Plan (Adapted from FCC 16-68 Public Notice, 2016)

This frequency allocation plan for the DSRC devices, completed by the Federal Communications Commission in Washington (FCC 16-68, 2016), indicates that two channels (172 and 184) have been allocated for public safety and one channel (178) has been allocated as a control channel. The remaining five channels were allocated for future development (FCC 16-68, 2016). For local consideration, ICASA (Independent Commissions Authority of South Africa) would be the responsible institution for developing a similar plan in the event of national deployment of CV technology. Once again, frequency band allocation is necessary to ensure that other wireless devices (such as Wi-Fi, which operates on a similar unlicensed frequency) are not able to communicate within this environment, potentially harming message delivery between DSRC devices.

2.4.1.2 DSRC PROTOCOL STACK

The following standards development was as a result of aiming to establish the correct communication architecture, standardised messages, protocols and communication standards for DSRC equipment. This is referred to as the DSRC-protocol stack

SAE J2735 Standard Message Set Dictionary: Supports interoperability among DSRC applications through the use of standardised message sets, data frames and data elements. This standard specifies basic message sets, data frames and data elements for use by applications utilising the DSRC devices for connected vehicle environment communications (Standards.its.dot.gov, 2009).

IEEE 1609.2 Security Services: This service is responsible for ensuring that the information transferred remains anonymous, that the information is authentic and that it remains confidential through-out interaction with network systems (other vehicles and infrastructure) (Weil, 2009).

IEEE 1609.3 Networking Services: The networking service is responsible for multiple tasks for granting wireless access. This service provides the description and management of the DSRC protocol stack, handles the application interfaces and the transmission and reception of the application messages (Weil, 2009)

IEEE 1609.4 DSRC/WAVE Medium Access Control Layer (MAC): According to (Guo and Balon, 2006), the MAC layer is required to attribute the access to the wireless channel – the lack of a MAC layer would result in no coordination of the data transmitted; as a result, data collisions would occur and this data would therefore be lost during transmission. The MAC layer is thus incorporated tor prevents nodes within transmission range from transmitting at the same time - this prevents the occurrence of collisions (Guo and Balon, 2006). Additionally, the media access control should be designed to prioritize traffic fairly and efficiently.

IEEE 802.11p Physical Layer (PHY): The Physical layer serves as the link between the MAC layer and the medium that allows sending and receiving block data (in this case, the DSRC device). This layer generally handles hardware specification, coding and formatting the data according to certain requirements (*IEEE 802.11P: Physical Layer*, 2015) such as the requirements of the SAE J2735 standard.

2.4.2 TYPES OF CONNECTIVITY

According to GSMA (2012), there are three types of in-vehicle connectivity options which will play an important role in the CV environment. These types are Embedded, Tethered and Integrated:

- **Embedded**: Devices are built into the vehicle, ensuring constant connectivity.
- **Tethered**: Connectivity is achieved through external devices dedicated to providing vehicle connectivity "via wired, Bluetooth or Wi-Fi connections and/or UICC" (GSMA, 2012).
- **Integrated**: Vehicle connectivity is achieved with the assistance of the vehicle owner's handset (Smartphone) (GSMA, 2012).

2.4.3 THIRD PARTY TECHNOLOGY

There are some applications that, although are still in development, prove that integrated connectivity may be achieved. A brief discussion of these platforms will be addressed in this section.

2.4.3.1 APPLE'S CARPLAY VS GOOGLE'S ANDROID AUTO

Technology companies Apple and Google have developed new in-car platforms that allows users to access their smartphone applications via the centre console of the vehicle. The interface of either platform (Figure 2.26) is similar to the interface on hand-held devices to allow users to be familiar with the system and applications immediately.

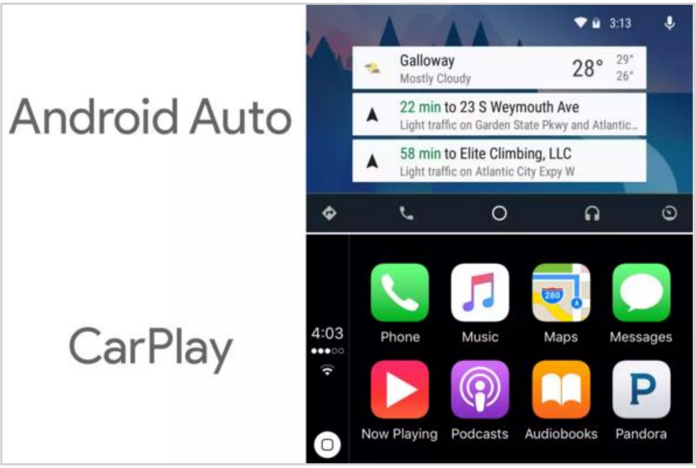


Figure 2.26: Interface of Google's Android Auto and Apple's CarPlay respectively (Amadeo, 2016)

The intention of these in-car platforms is to extend the user experience within the vehicle and enhance infotainment applications. This technology however, is a step toward implementing connected vehicle technology with integrated connectivity. Users may now receive alerts on the dashboard. These systems are constantly connected to the internet; with the appropriate connection in place, drivers may be alerted of events leading to congestion and may have easier access to traffic information. Additional applications to assist drivers will eventually be presented to the new platform once the technology is allowed to mature and a wider audience is affected. According to Korosec (2015), a combined 68 million vehicles will be deployed with these platforms by 2020; identifiable CV applications may thus be available by this time.

2.4.3.2 TOMTOM BRIDGE

Vehicles may not be equipped with touch-screen centre consoles. In this case, TomTom has addressed this issue with the creation of the TomTom Bridge. This device allows vehicles to connect to the internet, use applications related to business requirements and provides navigation services. Figure 2.27 indicates the design of TomTom's Bridge device.

Figure 2.27: TomTom Bridge (Tomtom.com, 2016)

This device is targeted at business including freight, taxi-dispatch and fleet transportation services. The device however, consists of an interface that may be customised. According to an article on the website Mobile-Knowledge.com (2015), the TomTom Bridge is a navigation device "built for vehicle fleets that seamlessly connects business applications with TomTom maps, traffic and navigation software". Additionally, the article states that applications specific to companies using the device may be integrated into the device. This makes it possible to attain connectivity between vehicles and the dispatching party (Mobile-Knowledge.com, 2015).

This device may therefore be used in vehicles without touch screen centre consoles. Although the target market is business associated, the device may be refined to accommodate other travellers and may be used as a form of integrated connectivity. Alternatively, TomTom may be able to develop a version of the Bridge that accommodates Smartphone connectivity or supplies independent applications usable to all travellers (such as radio, messaging and phone-call apps). The existence of this device however, proves that CV technology, and specifically V2X communication can be achieved on a broader scale and in a shorter period of time.

2.4.3.3 SMARTPHONE PENETRATION RATES IN SOUTHERN AFRICA

The penetration of mobile devices in Southern Africa, according to GSMA (2015), reached 160 million individual devices in 2015 and is expected to reach 540 million Smartphones by 2020 (GSMA, 2015). Additionally, the level of connectivity to mobile broadband was over 20% and is anticipated to reach a rate of 60% by 2020. Not only will Smartphones make up a large percentage of internet users in Sub-Saharan Africa (GSMA, 2015), but will produce larger volumes of users accessing the internet. This level of penetration would increase the possibility of vehicle owners possessing cell phones during travel, and may present an opportunity to leverage the application development for transportation purposes (i.e. provision of traveller information), and gaining immediate access directly to users.

Smartphones would allow traffic agencies to communicate directly to users, providing useful traveller information and suggestions for improving mobility during travel. Furthermore, it presents an opportunity for traffic agencies to reduce the ITS Infrastructure utilised for the Freeway Management System. As indicated in Figure 2.24, the latency that cell phone communication experiences would be sufficient for providing information to road users and may be considered a viable alternative to providing traveller information with Variable Message Signs.

2.4.4 V2V AND V2I CONNECTION

Based on the research conducted, DSRC appears to be the most appropriate option for the development of a conceptual CV environment. DSRC has proven to be effective according to the pilot study conducted by U.S.DOT (Harding et al., 2014:8). An elaborate description of DSRC as the choice of connectivity can be found on the USDOT (2015) (*Dedicated Short Range Communications*) webpage, where the following reasons for the selection of DSRC was provided:

- Operates in an unlicensed frequency band.
- Primarily allocated for vehicle safety applications by FCC Report & Order – Feb. 2004 (75 MHz of spectrum).
- Provides a secure wireless interface required by active safety applications
- Supports high speed, low-latency, short-range wireless communication
- Works in high vehicle speed mobility conditions
- Performance is immune to extreme weather conditions (e.g. rain, fog, snow, etc.)
- Designed to be tolerant to multi-path transmission typical with road environments
- Supports both vehicle-to-vehicle and vehicle-to-infrastructure communications

These points highlighted by the U.S.DOT (2015) prove that DSRC would be the most effective tool for achieving connectivity between vehicles and roadside infrastructure. The alternative options (at present) do not present the same level of potential (for example, Wi-Fi is currently expanding in global use and has established a 25% worldwide rate of penetration according to STRATEGY ANALYTICS (2012) – this may lead to extensive levels of interference in communication in parts of the world with extensive Wi-Fi hot-spots)

The types of connectivity for the conceptual CV environment may include embedded/integrated and tethered options as either of these may be feasible within a connected environment. Vehicles in South Africa may not have access to connected technology at present, based on the rate at which vehicles are replaced in South Africa (vehicles have an average age of 11.9 years (Letshwiti et al., 2003)). This rate of vehicle replacement appears to indicate that the rate of penetration of Connected Vehicles in the South African market may be extensively delayed. For this reason, the focus of this study will remain confined to tethered and integrated forms of technology with connected vehicles.

2.4.5 CONCLUDING REMARKS

Connectivity between vehicles and infrastructure is presently in stages of development and will be more focussed and centralised as the technology is allowed to mature and road users are given the opportunity to become familiar with the operation thereof. DSRC provides promising levels of certainty and, according to the research conducted, appears to be the most effective option available. It will be necessary for stakeholders and third party institutions in South Africa to collaborate on the approach to achieving a connected environment concerning the manufacture and distribution of DSRC devices and mandating their use or inclusion in road worthy vehicles. With the appropriate responsibility confirmed, the foundation necessary for creating a more efficient road network will be in place.

2.5 COMMUNICATION

This section discusses the various areas of communication within the CV environment. This includes a brief discussion of the backhaul communications that should be deployed to allow for V2I communication, the various interfaces granting users access to the incorporated systems and the interaction of the equipment utilised with this technology.

2.5.1 BACKHAUL COMMUNICATIONS – A BASIC DESCRIPTION

With the development of an entirely new communications environment, it is relevant to provide context of the systems architecture and the facets necessary for the network to operate as required. Backhaul makes use of communication systems to retrieve data from an end user (cell phone user) to a node (cell phone communications tower) in a large network (Rouse, 2006). According to McGee and Fritsky (2016), using cellular communication as an example, cell phone towers connect to local phones to create a large, local communication network. These cell phone towers then communicate with a central routing system. The local network created is known as the edge system while the central routing system is known as the backbone. The method in which these systems communicate is the backhaul (McGee and Fritsky, 2016). The following figure illustrates the backhaul network and the communications between systems for a conceptual Connected Vehicle environment:

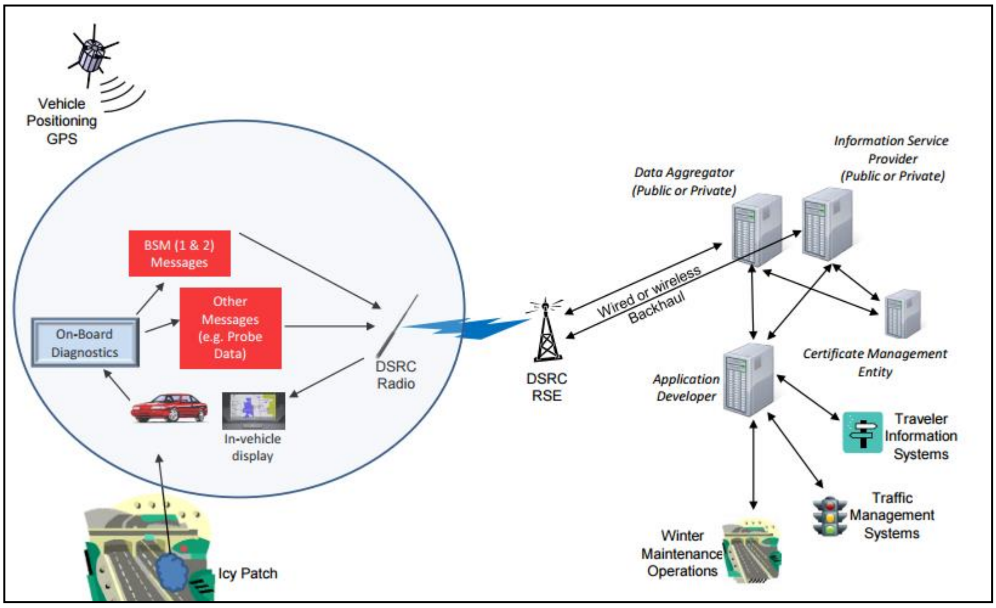


Figure 2.28: DSRC Basic Communications Backhaul Network Layout - Weather Information Scenario (Cronin, 2012)

Figure 2.28 indicates a potential CV scenario, where the vehicle would receive and transmit weather information (via BSM) to the roadside equipment (DSRC RSE) regarding challenging weather conditions to obtain a suitable response. From the figure, the following items may be identified:

- **Icy Patch**: Information obtained by vehicle during real-time travel, to be transmitted to the relevant traffic management agencies for suitable response.
- **On-Board Diagnostics (OBD)**: On-board device connected to a vehicle's OBD port, responsible for providing BSM-I and BSM-II data packages with the relevant vehicle information.
- **BSM (1 & 2) Messages**: Refer to *Section 2.2.5.4*
- **In-Vehicle Display**: Traffic information display for driver (User Interface). Refer to *Section 2.5.2.*
- **Other Messages (e.g. Probe data)**: Information that may be obtained from vehicles, not necessarily via BSM Messages
- **DSRC Radio**: On-board Device capable of transmitting and receiving information. Refer to *Section 2.2.6.*
- **Vehicle Positioning GPS**: Satellite communicating with on-board device (In-vehicle display device or vehicle GPS system) to determine vehicle location.
- **DSRC RSE**: Roadside equipment communicating with On-board DSRC Radio.
- **Data Aggregator**: Used to gather and aggregate data efficiently to improve network lifetime (Patil and Patil, 2010).
- **Information Service Provider**: Provides services for accessing network information, transporting information electronically (Wikipedia, 2016).

- **Application Developer**: Responsible party for the potential application developed to receive and disseminate the information to the relevant parties (Traffic Management Systems or Winter Maintenance Operations for example).
- **Certificate Management Entity**: Manages digital security certificates. Processes include the creation, storage, provision and withdrawal of security certificates (Techopedia.com, n.d.).
- **Traffic Information Systems**: Refer to *Section 2.1.7*.
- **Traffic Management Systems**: Refer to *Section 2.1.4* to *Section 2.1.6*.
- **Winter Maintenance Operations**: Indicates the entity relevant to the information obtained by the vehicle. Since the Scenario involves weather information obtained from the road (Icy Patch), the Winter Maintenance Operations would receive the information to possibly respond within a shorter period of time.

These items indicate the basic requirements of a communications network that would require development for a DSRC enabled Connected Vehicle environment for receiving, transmitting, distributing and storing relevant traffic information.

2.5.2 DIRECT SYSTEM TO USER INTERACTION

The following components specify the basic requirements for the applications tested in this investigation – this information may be found in the USDOT report *System Design Document for the INFLO Prototype – Final (2014)*, where the component requirements and system interfaces are elaborately discussed. Each component however must be designed with a user interface to allow for maintenance, monitoring and debugging (USDOT, 2014):

- **Connected Vehicle (Nomadic Device) Driver Interface System**: This device is responsible for displaying the Queue Warning and Speed Harmonisation information to the driver.
- **Roadside Equipment**: According to USDOT (2014), the roadside equipment would be designed with an interface according to the requirements of the device specification (Fehr, W., 2013). These specifications can be found in *5.9GHz DSRC Roadside Equipment: Device Specification, Version 3.0 (March 1, 2013)* report (Fehr, W., 2013).
- **Nomadic Device DSRC Radio Module**: The interface for access to this device was designed for the software development and deployment team (not the end user/driver). The purpose of the interface was to allow for installation and operation of software components on the device, setup configuration parameters, status monitoring, and for performing self-tests (testing the operation of the device) (USDOT, 2014)
- **Cloud Service**: This interface is once again intended for use by the development team. The user interface will allow for monitoring of the vehicle-data database, the web-service used to facilitate the exchange of data from/to vehicles, monitoring the state of the connected vehicle

network, and to allow for configuration of parameters associated with the interface design for future dissemination (USDOT, 2014).

- **Traffic Management Entity (TME)**: The TME (or TMC) would provide an interface to configure settings associated with the functioning of the Speed Harmonisation and Queue Warning algorithms, and to monitor status and performance of the application usage (USDOT, 2014).

2.5.3 DEVELOPMENT FOR FUTURE INTEGRATION

Consideration should be given to broader development of a connected vehicle environment, not only in an area specific implementation (for example, focussing on deployment in Cape Town) but to national deployment and integration. Although the operation and management will differ depending on the traffic behaviour in a specific area, the development of connected vehicle applications should be designed with the intention of eventual integration of the systems involved. To elaborate in a South African context, if potential CV applications in Cape Town were designed to be integrated with applications in Johannesburg and Kwa-Zulu Natal for a national integration of systems, it would be beneficial to establish national standards and a platform to which these cities must conform for seamless integration at a later stage. The USDOT (2014) report therefore recommends that the applications be developed with an open architecture, making use of standardized message formats and interfaces. The following facets are part of the overall Connected Vehicle architecture currently established by the USDOT (2014) that the DSRC devices are required to support:

- Society of Automotive Engineers (SAE) J2735:2009 – Message Set for DSRC Communications (discussed in *Section 2.4.1.2*)
- Communication Standards: NTCIP family of standards
- TCP/IP (v6) and RESTful web services: Standards used in the broader global internet

With these standards in place, seamless integration of applications may be possible in support of a national deployment.

2.6 SECURITY

A major concern with wireless communication and dependence is security of the information transferred and received within the CV environment. Since communication between various sources is possible, multiple foreign sources could potentially gain access to the database. This presents a concern that this access may provide an opportunity for hacking, harming the transfer of information and possibly corrupting user details.

The focus of security measures, according to the USDOT report (2014) would be placed on DSRC based over-the-air security between vehicles and infrastructure and between infrastructure and vehicles (since cellular networks already address network security measures). The measures in place at the moment may be leveraged off the existing *USDOT Safety Pilot Model Deployment*, where the security measures were addressed using a Security Credential Management System (SCMS) and a secure DSRC Protocol Stack (refer to *Section 2.4.1.2*) (USDOT, 2014, p.30).

Security for cellular-based communications would be leveraged from existing practices, as these communications currently implement security measures against breaches. An example of an industry-practice implemented to protect users is called Secure Socket Layers (SSL). According to (info.ssl.com, 2005), SSL is a standard security technology for establishing an encrypted link between a web server and a browser, ensuring that the data passed remains private.

Backhaul connections (from roadside devices, TMC or cellular provider) as well as the previously mentioned cloud-based data repository and computing platform (refer to *Section 2.5.2*) should also implement industry best-practices for security (Its.dot.gov, 2014).

SAFETY AND SECURITY OF CONNECTED VEHICLE ENVIRONMENT: A SECURITY CREDENTIAL MANAGEMENT SYSTEM

The Security Credential Management System (SCMS) is an elaborate support application in place to ensure that the information transferred from vehicles, infrastructure devices and mobile devices is protected from foreign access by unauthorised parties. According to Iteris.com (2016), the application of an SCMS provides "trust credentials" to mobile and infrastructure devices that meet the required standards with regards to security, in the CV environment – this is necessary to allow other devices to be aware of the security status of the surrounding connected environment. These credentials may be requested and may be withdrawn if a potential security risk is identified or detected (Its.dot.gov, 2014). Additionally, integrity of the system is further enhanced through the secure exchange of trust credentials between devices (Its.dot.gov, 2014); this assists in preventing interception of the data transferred. The system ensures privacy protection of user data and prevents access to the origin of transmission to reduce access to private user information (Its.dot.gov, 2014).

2.7 CONNECTED INTERACTIONS

With the multiple devices in place to establish the necessary communication, the possible communication that would be established between these devices is briefly discussed below. This information may be found in the report *System Design Document for the INFLO Prototype – Final Report* completed by Sheaf et al. (2014, pp. 13-20):

- **Nomadic Device[1] to Nomadic Device**: Transmit/Receive BSM-I and BSM-II between vehicles through DSRC radios.
- **Nomadic Device to Roadside Equipment**: Nomadic device will receive and process BSM messages from roadside equipment.
- **RSE to Cloud API**: The Cloud service would be required to host a secure web server to service requests (such as requesting location data of vehicles for example) form RSEs.
- **Cloud Services to TMC**: Would grant the TMC access to client data.
- **Cloud Service to Database**: This communication would provide the back-end functionality required to process inbound BSM data.
- **TMC to Database**: This communication describes the distribution of traffic information along with the suggested connected vehicle application information. This information would be obtained from systems that would provide information to the TMC (VDS data, Traffic Signal data, etc.) and would be processed (to provide speed suggestions and queue alerts) for provision to users.
- **Nomadic Device to Cloud API**: Users would gain access to relevant traffic information via this communication.

COMPONENT REQUIREMENTS

As discussed in the basic requirements for connected vehicles, the following components would be required to establish communication between the vehicle and the surrounding infrastructure (Sheaf et al., 2014):

- **In-Vehicle Network Access System**: Would implement the OBD-II interface (plugs into the vehicles OBD-II port to obtain vehicle data). This allows the DSRC radio to receive vehicle data to be able to transmit the Basic Safety Message Part II (Sheaf et al., 2014). Refer to *Section 2.2.5.4* for discussion about BSM-II.
- **Nomadic Device (Smartphone)**: Provides the user interface for traveller information and communication to the user. Additionally, the device communicates with the DSRC radio via Bluetooth connection to send data to the DSRC radio and receive messages from the TMC (Sheaf et al., 2014)
- **Nomadic Device DSRC Radio Module**: Receives messaging from the DSRC radio and the cellular network and will process the messages and supply information needed for driver notifications. (Sheaf et al., 2014). Additionally, the radio can receive information from V2V and I2V communications, and will transmit BSM-I and BSM-II to DSRC radios that are within range.

[1] A Nomadic Device is a handheld wireless device such as a Smartphone

- **Road Side Equipment**: This would be used to establish communication from a TMC to the vehicles and nomadic devices (DSRC radio and Smartphone) and communications from vehicles to a TMC.
- **Cloud Service**: The cloud service (recommended) would comprise of the following components (Sheaf et al., 2014):
  - **SQL Database**: This is used to store the user information (registration, device name, login credentials, etc.).
  - **Web Role**: This would be the Traffic Management Centres web server.
  - **Web Role**: Administration Portal
  - **Worker Role**: Database Worker
  - **Virtual Machine Role**: Traffic Management Centre application
- **INFLO Database**: This database is used to hold the information received from nomadic devices (BSM data) and road side alerts.
- **Virtual Traffic Management Agency**: Would host the Speed Harmonisation and Queue Warning applications and support software. Would also make use of an SQL database to log input data, recommendations of these applications and the system configuration information (Sheaf et al., 2014). This configuration information would be the roadway network configuration, user settings, and threshold used by the CV applications in making decisions and providing recommendations (Sheaf et al., 2014) – for example, setting a specific amount of vehicles as a base value for maximum flow; a vehicle count above this base (or threshold) would result in the recommendation of a lower travelling speed by the Speed Harmonisation application to optimise traffic flow

With an understanding of the information transmitted or received, devices in place, interfaces required for communication and the multiple communication routes in mind (refer to *Section 2.2.6, Section 2.5.2, and Section 2.5.3*), the interaction between these systems can be illustrated graphically. The following diagram indicates the probable interaction that would take place if the above mentioned systems and interfaces were deployed (Sheaf et al., 2014):

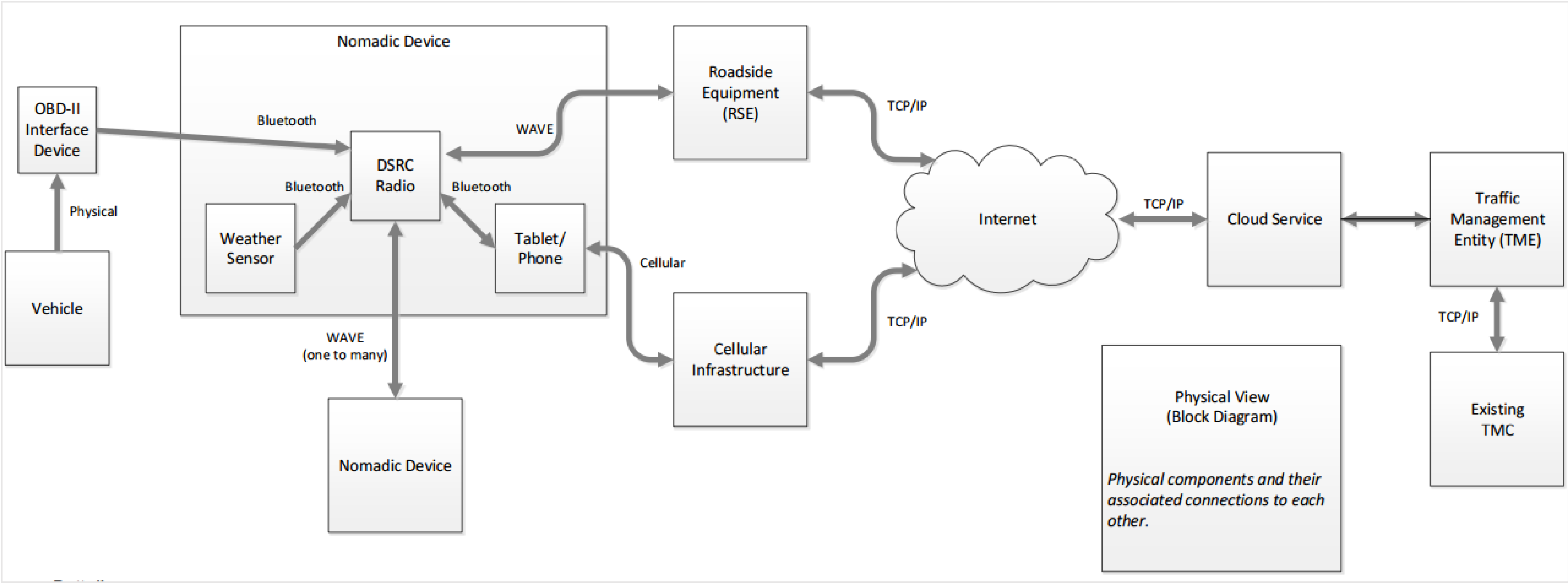


Figure 2.29: Communication between Connected Network Components (Sheaf et al., 2014)

The following description was provided to describe the information illustrated in Figure 2.29. To reduce any redundancy, where a description is not provided, the item was identified as self-explanatory.

VEHICLE COMPONENTS

- Vehicle Block: Representation of host vehicle
- OBD-II Interface Device:
- Nomadic Device:
  - Weather Sensor: Responsible for obtaining weather information on the road
  - DSRC Radio: Transmits and receives information from roadside equipment
  - Tablet/Phone: In-vehicle mobile device
- Nomadic Device: Other DSRC-enabled connected vehicles in the network

ROAD NETWORK COMPONENTS

- Roadside Equipment (RSE): DSRC devices installed on the road network.
- Cellular Infrastructure: Cellular towers, Backhaul Communications

NETWORK SERVICES

- Internet (Cloud): provides the communication between roadside equipment and the traffic management entity.
- Cloud Service: Facilitates exchange of data to/from vehicles (see p. 2.81)
- Traffic Management Entity: Receive information for analysis, processing and dissemination.
- Existing TMC: Physical location of the building

CONNECTIONS IN FIGURE

- Physical: Attached to the device (in this case, the OBD-II device would be plugged into the vehicle).
- Bluetooth: Wireless communication between in-vehicle devices
- WAVE: Wireless communication to DSRC devices
- WAVE (to-many): Wireless communication to Connected Vehicles
- TCP/IP (Transmission Control Protocol/Internet Protocol): Basic communication language/protocol of the internet.
- Cellular: Connected to Cellular towers

Figure 2.29 therefore describes the basic architecture for a Connected Vehicle environment.

2.8 CONCLUSION

Based on the research conducted, the Freeway Management System (FMS) in the Western Cape is being managed appropriately. With all of the systems in place within the TMC (including ATMS and ATIS), the progress achieved thus far is an improvement over past management, coordination and protocols followed. The progression of management of the traffic network has however reached a somewhat optimum position, and efforts to alleviate traffic congestion and improve incidence response has become steady while the costs of maintenance, licensing and software updates continue to accrue.

Additionally, these systems may not have directly affected the accident death rate on South African roads (even though this was not the intent of deploying the infrastructure) and congestion occurs regularly, to the extent that travellers may have adjusted their schedules to arrive at their destinations on time, accounting for congestion.

A possible solution to this dilemma could be Connected Vehicle technology, or an adaptation thereof. Connected Vehicles reduce the dependence on driver behaviour and human-error. The capability of the technology allows drivers to be extensively aware of the environment and will provide real-time alerts, giving drivers more time for an appropriate response. With more CVs in the traffic network, an improvement in efficiency is certain.

Vehicle manufacturers such as Mercedes-Benz, BMW, Audi, Volvo, Volkswagen, Jeep, Land Rover and Ford are on the forefront of creating connected vehicle technology that will improve the efficiency of travel and increase the safety of the occupants (CB Insights – Blog, 2016). Moreover, third party software companies are in developmental stages of creating interfaces that may allow for integrated connectivity with the use of smartphones. This provides an opportunity for all vehicle owners to experience a certain level of connectivity as the technology matures and users grow accustomed to a connected environment.

With the automotive industry pursuing CV technology, and software development companies expanding their market to include CV technology, the only outstanding factor is the provision of an environment in which connectivity is established. That is, the inclusion of road side equipment and infrastructure that assists and optimises Connected Vehicles during travel.

In South Africa, Sanral has planned to deploy infrastructure to assist with traffic management (based on the success of the systems thus far). The adjustment that should take place however, is the incorporation of connectivity to communicate with vehicles in the traffic network. CV technology is present in a limited number of vehicles, but continues to develop and is anticipated to eventually impact the South African market significantly. Traffic management agencies should therefore pursue the opportunity to attain information from this technology, and utilise the data to improve the efficiency and safety of the traffic network. This may, in addition, allow for deployment and requirement of less field infrastructure.

CHAPTER 3 : RESEARCH DESIGN AND METHODOLOGY

This chapter describes the design of the research investigation and the manner in which these tasks were intended to be executed. The layout of the following sections addresses the research design, followed by a flow diagram of the aspects considered in this study, and thereafter, the methodology.

3.1 RESEARCH DESIGN

With the restricted amount of information available, the current development of CV technology and multiple restrictions involved with sufficient (real-world) testing locally, it was necessary to conduct an elaborate study on incorporating CV technology into the South African transportation system, with specific focus on the Western Cape. This section therefore discusses the testing methods to be incorporated with the aim of highlighting the impact of CV technology and the components immediately available in terms of infrastructure, software and connectivity.

The procedure followed in the research design discusses the approach to the study systematically, covering the Conceptual Design of the environment, the Applications that will be investigated for this study, a simulation of the road network operations, followed by the Cost-Benefit analysis and thereafter, a basic Execution Strategy for possible implementation of the most suitable choice (the selected Alternative approach) for local deployment, that is, within the Western Cape. The Execution Strategy will be produced with the aim of assisting traffic agencies with initiating development of a functional connected environment.

This procedure was designed to present a perspective of the areas concerned with connected technology and to possibly highlight areas of further development. The Literature Review (Chapter 2) and Introduction (Chapter 1) provided information on the current situation of traffic management and operations, progress and plans intended to be executed. Thereafter, a suggestion of the consideration of CV technology as an alternative solution to increase the optimisation of traffic operations was presented. This section is thus intended to elaborate on the manner in which connectivity may be achieved locally, and further presents the areas used to obtain data to prove the efficiency that CV technology may produce.

3.1.1 CONCEPTUAL DESIGN: EQUIPMENT REQUIRED FOR CONCEPTUAL ENVIRONMENT

To test the effect that the connected equipment may have on the operation and use of vehicles in a connected environment, an area large enough to consider testing the effect of connected vehicle capabilities will be selected. Based on the capabilities of the equipment (specifically, the operational range of DSRC devices), the roadside devices will be designed along the freeway sections to allow for constant connection between vehicles and infrastructure. Additionally, the market penetration of connected vehicles (the number of vehicles in the network that would be Connected Vehicles) will be varied to identify any relatable changes in the behaviour of traffic flow.

APPROACH

Based on the knowledge of the capability of connected vehicle equipment, the level of connectivity that needs to be in place and the roadside infrastructure network necessary to ensure that communications are established between traffic management agencies and vehicle owners, a conceptual design of the probable environment may be developed. The DSRC communication devices will be installed on selected infrastructure (light posts along the freeway) and the communication software installed in a varying percentage of live vehicles. The behaviour of these vehicles in this environment will later be simulated.

BENEFITS

An understanding of the operations and communications may be developed within South Africa. This would allow traffic management agencies to assess the effect of CV technology within current traffic management procedures and may thereafter provide motivation to pursue operations that include active traffic management.

OBSTACLES

It may be costly to incorporate into the traffic network. Ensuring the feasibility of a connected environment requires the input of both management agencies and the public. Additionally, the public will be responsible for attaining connectivity and making use of the technology regularly. Furthermore, the information obtained, transmitted and managed will require storage availability, which was not necessarily the focus of this investigation.

3.1.2 INVESTIGATION OF CONNECTED VEHICLE APPLICATIONS

This section is intended to investigate the effect of CV applications on the existing traffic network in Cape Town, Western Cape, with the specific intention of designing to improve traffic efficiency. The possibility of incorporating a single connected application may present beneficial results for the traffic network, investigating the collective effect that multiple applications may produce may provide sufficient motivation for deployment of these investigated systems. These applications will be selected based on their effect on the efficiency of the traffic network and will incorporate vehicle-to-infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication where possible.

APPROACH

The approach will be to explore the effect of connected vehicle applications for enhanced efficiency within the traffic network. This will be done by varying the percentage of vehicles in the network that are connected. The effect on efficiency of travel will be investigated with the consideration vehicles in the traffic utilising applications that influence efficiency and are intended to improve traffic flow (*Chapter 2, Section 2.2.3*). The applications that may be tested in a simulated environment for improving efficiency, focussing on the freeway traffic, are Dynamic Speed Harmonisation, Queue Warning and Cooperative Adaptive Cruise Control. The motivation for selecting more specific applications will be discusses in the methodology.

BENEFITS

The effect on the traffic network would be advantageous. Traffic may flow more efficiently, safely and effectively, resulting in cost and time savings and improving productivity of the economy, at least within the local realm.

OBSTACLES

The effect may be optimised to such an extent that it produces more traffic. To elaborate, some drivers may prefer to use public transport based on the time and costs spent in comparison privately owned vehicles; with a more efficient transport network, drivers may be inclined to use private vehicles. Furthermore, an increase in the throughput on freeways and related high-capacity roadways may increase the occurrence of bottlenecking and possibly, gridlock.

APPLICATIONS

As stated in the *Literature Review* (Chapter 2), a vast number of applications for Connected Vehicle technology have been identified by the USDOT (2016). The applications address all sectors of wireless connectivity, namely vehicle to infrastructure (V2I), to vehicles (V2V), to cell phones, tablets and similar wireless devices (V2X)

The focus of this study however, ties to the efficient operation of the transportation network within South Africa, that is, V2I communication. As a result, two applications were identified as presenting significant levels of improvement to the efficiency of traffic operations, and will thus be investigated to determine the impact of each application. These applications are:

- Queue Warning (Q-WARN)
- Dynamic Speed Harmonisation (SPD-HARM)

These applications will be investigated for implementation in light vehicles, and further motivation for their selection will be provided in *Chapter 4*.

3.1.3 CASE STUDY: SIMULATION

With the conceptual design of the environment in place and the applications for investigation selected, the following step would be the investigation of the traffic-flow behaviour through a simulated network. A simulated environment will be necessary since the testing may prove too large and complex for physical implementation and testing. Additionally, a simulated environment will serve as a basis for future potential deployment by highlighting focus areas and possible areas for more detailed consideration. Furthermore, the environment may be reduced and expanded according to the desired investigation area, and thereby provides more flexibility than a real-world investigation.

APPROACH

The simulation conducted will compare the effect of implementing CV technology within the traffic network. A comparison of the current behaviour of the traffic network in Cape Town will be tested against the behaviour of connected vehicles within this environment, to determine the effect on efficiency of a varying level of connected vehicles utilising CV applications. Ideally, the effect produced by CVs will be tested against increasing levels of penetration in the South African market – in this way, it may be determined that a minimal level of penetration is required to establish a significant improvement over the environment for an optimum result to be achieved. In light hereof, this level of penetration identified may be pursued, possibly encouraging vehicle owners to adopt this technology (possibly those vehicle owners above a specific level of income), with the aim of creating the envisioned change in traffic conditions in a reduced period of time.

BENEFITS

The benefit of simulating the desired environment is that a relatively accurate estimation of the environment may be gained. Furthermore, simulations can be conducted in a safe environment, at no cost and to the discretion of the investigating party, allows for a high level of flexibility, input and understanding of the environment for identifying possible improvements.

OBSTACLES

The simulation may not account for additional factors associated with driver behaviour (other than those included in the simulation model, refer to *Chapter 4, Section 4.1.1*), differences in the reaction times of drivers according to visual cues and driving skill level. These factors may be simulated but, at present, does not account for sufficiently different behavioural aspects of individuals.

Simulations are dependent on the information provided – accurate information, along with completed data and sufficient behavioural inputs and adjustments would produce a highly accurate simulation model that provides an excellent correlation to field tests. The input may therefore affect the output of the applications and should be as close to reality as possible.

3.1.4 COST BENEFIT ANALYSIS

A Cost-Benefit Analysis will be conducted to provide a comparison with the current payments made for existing infrastructure against the potential costs and benefits for deployment of Connected Vehicle equipment and associated environmental requirements. These costs and benefits will be weighed to provide motivation for a recommended alternative that benefits the users as well as traffic agencies.

APPROACH

The extended deployment of infrastructure, specifically VMSs and assisting infrastructure, involves maintenance costs and secondary costs related to construction and software updates (for example). The comparison to be investigated in this case is the monetary benefit of issuing technology to road users versus technology shared by the entire traffic network. Specifically, a comparison between issuing on-board units (OBUs) and connectivity equipment (DSRC devices) and managing the current VMS network will be formulated. The Cost-Benefit Analysis will be restricted to the conceptual environment developed in this investigation to ensure a fair comparison.

Essentially, all vehicles lacking centre touch screens would be provided with these units (for display of information) and DSRC devices (wireless connectivity) – this would be the "worst-case" scenario, as it may be possible that a significant number of vehicle owners also own cell phones that may be used to display road warnings. The related costs will be compared to the costs involved with VMSs.

BENEFITS

The benefit is that VMSs may not be necessary for deployment. The VMSs are useful for providing traveller information (such as arrival times and suggesting alternative routes), but may not be as effective as intended due to the development of technology (road users now have access to road network information in their vehicles). Additionally, drivers will remain focussed on the road and will be able to control the console at the centre of the vehicle's dashboard (more desirably through voice activation). With a larger number of vehicles with equipment gaining access to the internet and providing real-time GPS location information, VDSs may also become redundant, since vehicle speeds may be determined from this information and possibly, the volume of vehicles in the road network (this is not currently possible with probe data; but the possibility of achieving this may reduce the necessity for VDSs).

OBSTACLES

The cost of deploying the extensive amount of OBUs may exceed the funding used for VMS deployment and maintenance. Furthermore, drivers may choose not to make use of the in-car systems

– this will have a major effect on the levels of connectivity within the traffic network as the required level of penetration may be affected (i.e. if vehicles are allowed to make use of the in-vehicle systems by choice, the number of vehicles connected would fluctuate on a daily basis).

3.1.5 EXECUTION STRATEGY

Along with the conceptual design of the required environment, the testing of CV applications and the comparison within the Cost-Benefit Analysis, a proposed plan of implementation will be suggested as a possible addition to Sanral's Strategic Plan. The ideas for updating this document will be based on the findings of the study and the consideration of the current strategic plan (Strategic Plan 2015/2016 – 2019/2020)– this suggested plan will in no way reflect the ideas, proposals, endeavours or feelings of the investigated party (namely, Sanral).

The proposed strategy intends to address the following items:

- Context: Connected Vehicle technology
- Equipment: Infrastructure (Roadside Equipment) accommodating vehicles for V2I communication
- Information: Educating the public before initiating action
- Execution: Phases in which implementation might be necessary

The proposed strategy may be updated, changed and improved where identified as necessary, but will serve as a basic guide for the areas that may require attention regarding the deployment of a Connected Vehicle Environment.

3.1.6 CONCLUSION

The approach designed for the research is intended to provide an elaborate idea of the impact that CVs may have on the transportation network. As previously mentioned, basic applications will be investigated to understand the effects that are highly probable to be experienced in countries making use of this technology, especially with more stringent measures of implementation. Furthermore, the design intends to highlight areas that may be developed immediately as a result of existing technology. In light hereof, a plan of execution will be discussed and suggested in the concluding section of this thesis.

With the discussion of these aspects in mind, the following approach to executing the investigation to obtain a feasible outcome will be followed:

RESEARCH DESIGN PROCEDURE

The investigation of the feasibility of CV technology will be addressed in the following format and will be referred to throughout the study.

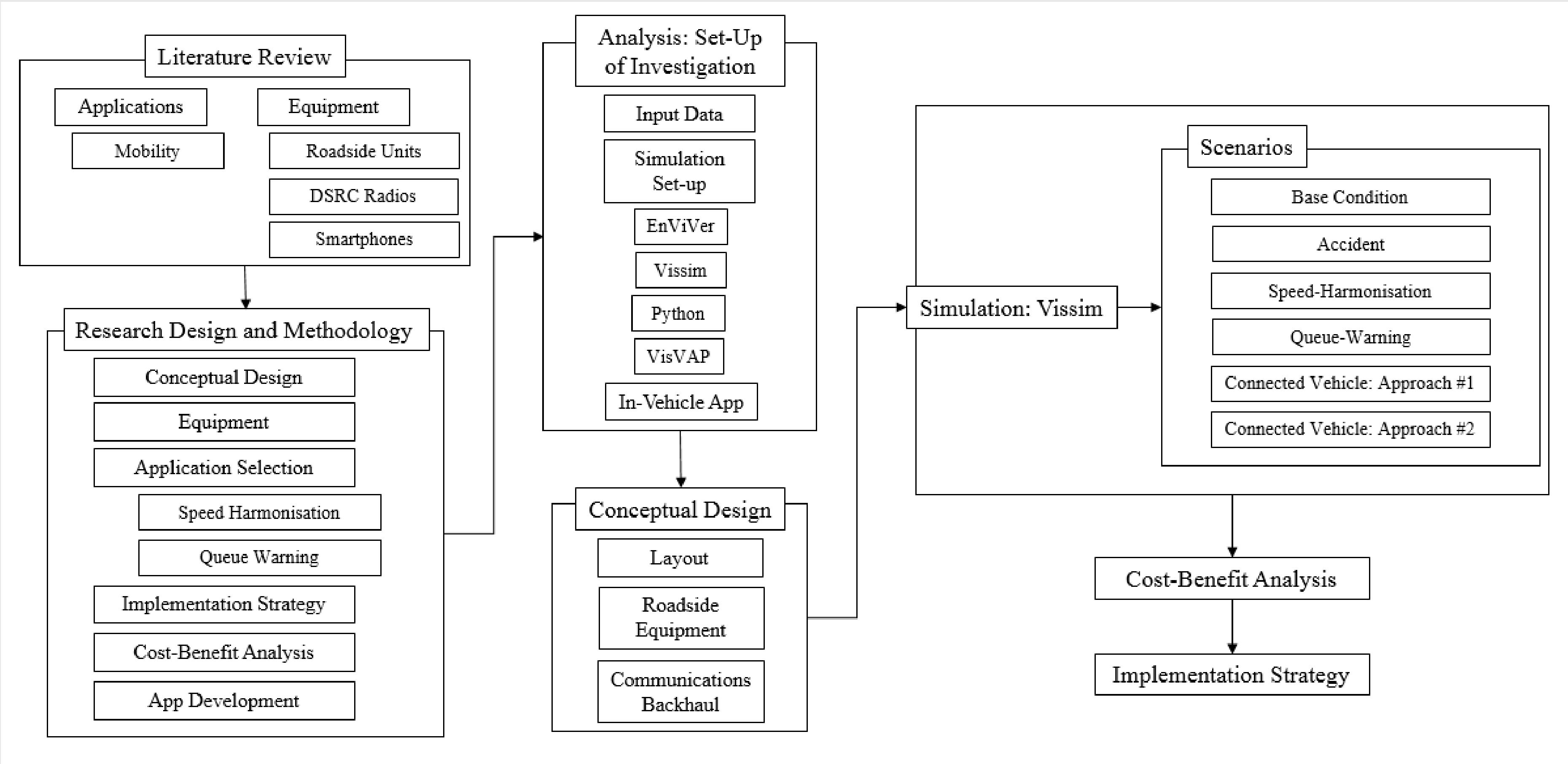


Figure 3.1: Research Design Procedure

3.2 RESEARCH METHODOLOGY

The research methodology will attempt to elaborate on the outlined research design, as described in *Section 3.1*. This section will provide context to the necessary equipment required within the realms of connected vehicles and connected technology. Thereafter, the vehicle and infrastructure communication will be discussed. The investigation of the applications related thereto will propose the expected impact of these devices. Once the applications are considered, a simulation will be considered to establish the probable impact in a pre-defined area and environment. The simulation, upon revealing the level of impact, will be followed by a Cost-Benefit Analysis. This analysis was deemed appropriate at this stage due to the perceived impact of the connected environment. Finally, a suggestion of an implementation strategy of these concepts will be presented to, in some way, ensure that Sanral and the associated partners consider the effects of an implementation strategy to optimise the operation of the traffic network.

3.3 PROPOSED ANALYSIS AND DATA COLLECTION

The approach for analysing the traffic conditions and the effect that a connected vehicle environment may present to the existing network will be discussed in this section. It will be necessary to conduct a simulated investigation of the current traffic conditions in comparison to various scenarios. The scenarios will consider traffic congestion and selected CV applications. These applications will be discussed in this section.

The first step will be the development of a conceptual design; to do this, an area in Cape Town will be selected in which the applications would be suitable for execution and testing. Thereafter, the development of the environment to assist connected vehicles based on these applications will be discussed. Upon completion, a Cost-Benefit Analysis will be conducted to determine the overall effect that the necessary systems, on-board equipment and level of management that will be necessary to establish a functional connected environment.

The following sections discuss the aspects considered relating to data collection, the conceptual design and the applications available to connected vehicles and the applications that will be used in this investigation.

3.3.1 CONCEPTUAL DESIGN

The approach to the conceptual design involved identifying sections of the road network in which the most congestion was experienced and delays frequently occurred. This information was found by analysing Google™ Traffic to identify the areas experiencing traffic capacity hindrances. The conceptual network was selected to include Intelligent Transportation Systems (ITS) infrastructure to create a comparison between the effects of the current network and a CV environment. The foreseen conceptual network will be developed on the area indicated in Figure 3.2 below. In the figure, the start and end point of the area to be simulated is indicated. The routes of travel that will be modelled in the simulation include the freeways N1, N2 and M5. An additional route follows a path along urban roads not monitored within the FMS – this route was modelled to include an alternative route for selection by traffic.

Figure 3.2: Area selected for Conceptual Design

As previously mentioned, the following routes were selected for modelling in the conceptual design and simulation:

- M5 and N1 – Route 1
- N2 – Route 2
- M57 and M176 – Route 3

A start point was selected to allow for selection of alternative routes that included two freeway sections as options, in this case, Route 1 and Route 2 – the area selected therefore provided the desired choices of freeway options while being manageable for a traffic model. Furthermore, the distance between the alternative routes presented an opportunity for an additional route – Route 3. This specific route was selected as it fits well between the N1 and N2 as an alternative path; although the route does not fall within the monitored bounds of the Freeway Management System, the Connected Vehicle technology offers an opportunity to establish operation beyond the FMS, and was included to investigate the feasibility of this opportunity. Figure 3.3 indicates the approximate locations of the existing VMS and VDS infrastructure within the design area of the road network:

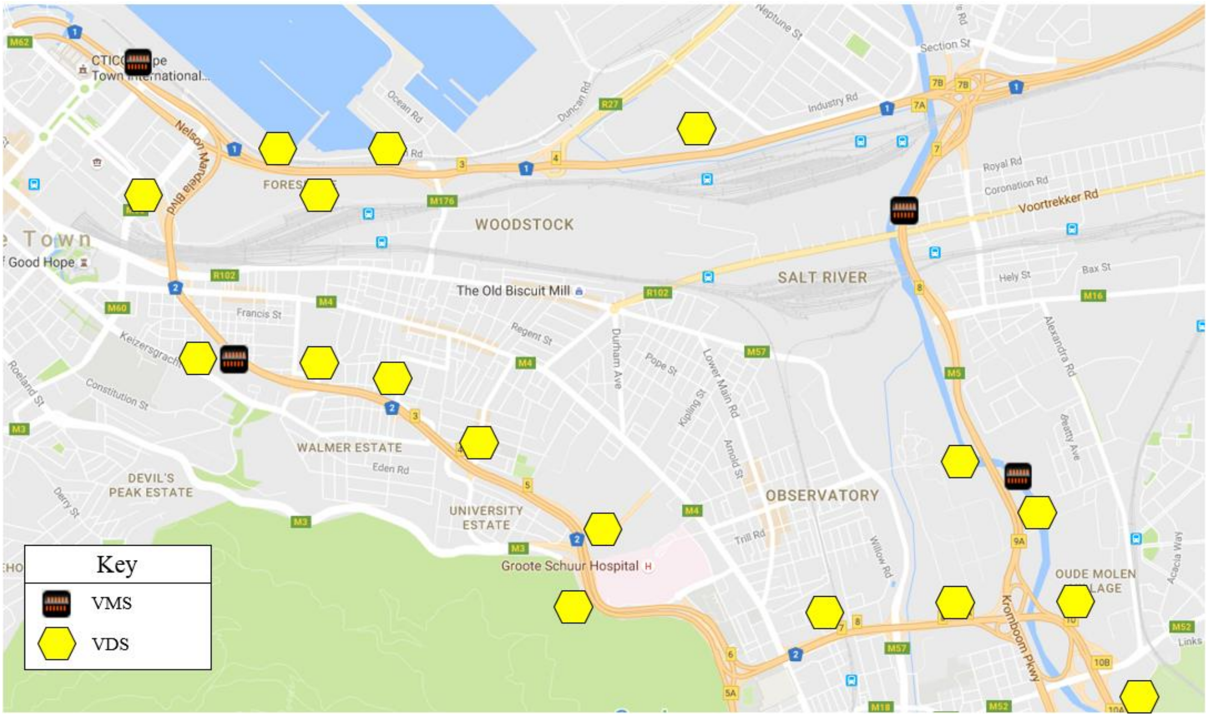


Figure 3.3: Approximate Locations of VMS and VDS Infrastructure on Existing Road Network (2015)

It should be noted that, while it cannot at this point be assumed that extensive probe data availability would reduce the requirement for VDS equipment, the VDS equipment will therefore not be considered in the Cost Benefit Analysis, and was provided in this section for future reference (i.e. if probe data allows for the prediction of the number of vehicles and provides vehicle class information, these VDSs may be considered for decommission).

The area indicated in Figure 3.3 was selected as it contains the high levels of congestion in Cape Town. An image from Google Traffic for the typical 8 AM Peak provides sufficient motivation for the selected area (Figure 3.4):

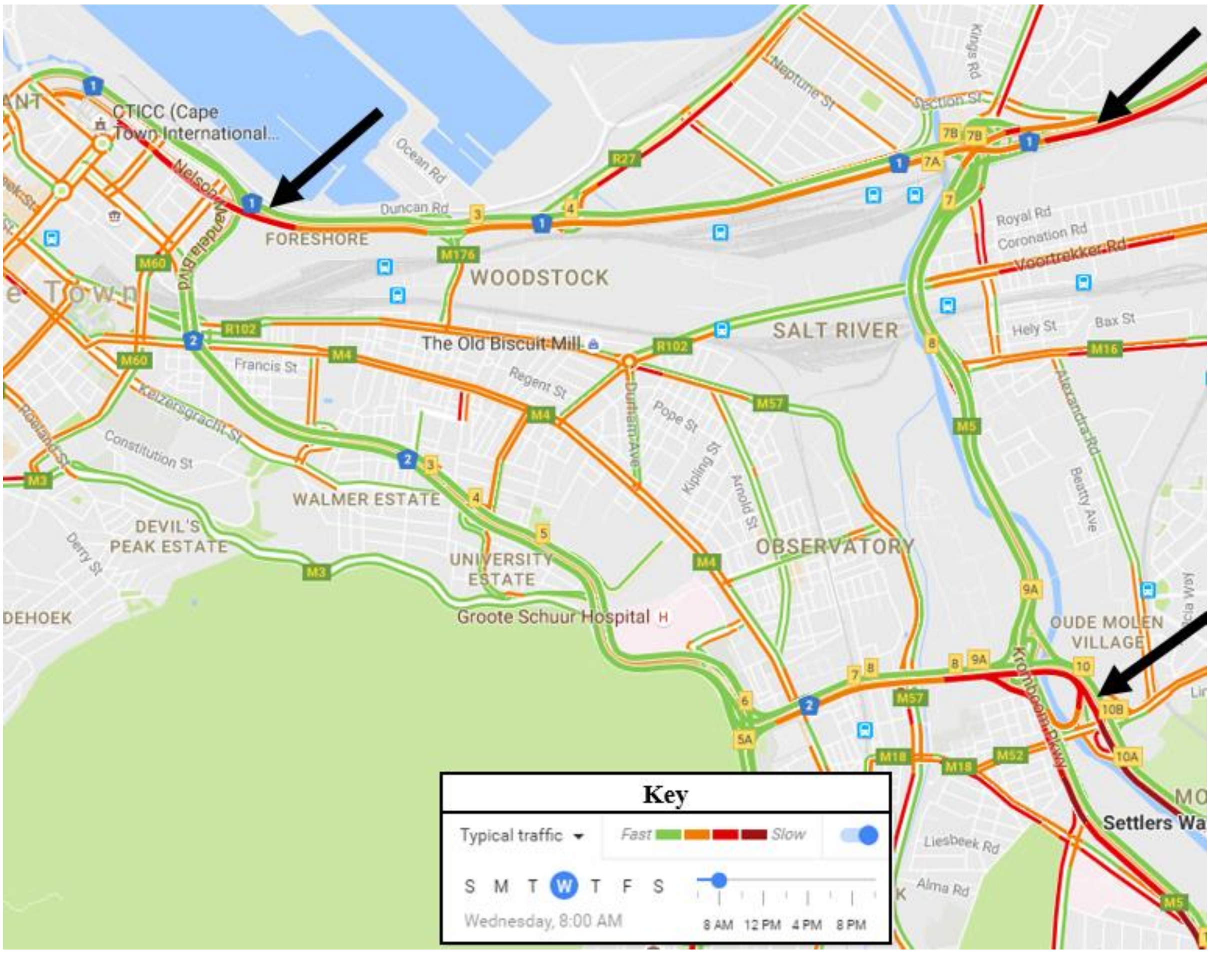


Figure 3.4: Congestion Indication along the Investigated Routes

The N1 and N2 (indicated in Figure 3.4) illustrate the extent of the concern regarding congestion and the necessity to address this problem (the image contains a key indicating the travel speed of traffic – red indicates that vehicles are moving slowly in comparison to free flow while green indicates a faster pace or optimal flow speeds). The N2 has separated sections of congestion (indicated with the dark red and orange sections – with red indicating a slow pace and orange a medium pace) while the N1 appears to be almost entirely congested in the morning period (continuous bands of red and orange indicating suboptimal flow for the 07:00 – 09:00 AM). These roads will therefore provide sufficient grounds for conducting an analysis for optimising traffic flow.

The additional equipment will be designed as being added to the existing network. Based on the relevance of the existing infrastructure (*Chapter 2, Section 2.1.7*), the conceptual environment will be designed to supplement this existing network as opposed to a replacement of the roadside infrastructure and possibly identifying infrastructure that may not be necessary, based on the potential of the conceptual environment. The supporting equipment will include the proposed Backhaul

Communications infrastructure (refer to *Chapter 2, Section 2.5.1* for a brief description of Backhaul Communications) for the information transferred within a connected environment. The following should be considered with the design of a Backhaul network:

Roadside Equipment Site Analysis:

- Location landscape and built environment: The design should consider the effect of the environment, such as high-rise buildings, variations in elevation/terrain and roadway geometry. The layout of the design will have a great effect on the signal transfer (ITS America/FHWA, 2015).
- Environmental consideration: the weather conditions of the desired location should be considered prior to deployment to determine if any additional measures are to be incorporated to ensure longevity of the device (insulation for wet conditions etc.).

Analysis of Radio Frequency in Designated Deployment Area (ITS America/FHWA, 2015)

- The potential area in which the roadside units would be deployed should be tested for potential interference with other wireless equipment in the area.

Additionally, DSRC equipment will be designed for installation along on the road network at critical points to allow for consistent communication between vehicles and infrastructure. This will be discussed further in Chapter 4.

3.3.2 SELECTING APPLICATIONS FOR TESTING

A host of Connected Vehicle applications was described in *Chapter 2* (*Section 2.2.3*), along with the relevance to local implementation. Among these applications - divided into focus on safety, mobility and environmental improvement – the selected focus was mobility, since the intention of this study was to investigate the improvement in efficiency of transportation through CV applications and a connected environment. This reduced the selection of applications to those applications focussing on improving efficiency, identified by the USDOT as high-priority mobility applications, focussing on vehicle throughput and crash reduction (USDOT, 2016). These applications are contained within the bundle referred to as Intelligent Network Flow Optimization (INFLO), focussed specifically on enhancing efficiency:

- Queue Warning (Q-WARN)
- Dynamic Speed Harmonisation (SPD-HARM)
- Cooperative Adaptive Cruise Control (CACC)

These applications comprise the INFLO bundle for improving mobility. For this investigation however, the focus was placed on Queue-Warning and Dynamic Speed Harmonisation. Cooperative Adaptive

Cruise Control requires extensive vehicle equipment to be pre-installed (such as Lidar/Radar and various other sensors – refer to Appendix C for a description on the operation of CACC); while this application may provide extensive improvements in freeway operations and allow for greater throughput of vehicles, the number of vehicles required to contain this level of equipment may not currently be present on the existing road network in the Western Cape (i.e. the average fleet age of vehicles on the road network in the Western Cape is approximately 11.9 years (Letshwiti et al, 2003)). Furthermore, vehicles with this capability would need to be in close proximity with one another, increasing the improbability of achieving a realistic level of implementation in the near future.

Queue-Warning and Speed-Harmonisation may possibly be utilised with existing equipment (Smartphones or Tablets for example), or additional equipment that may be relatively affordable to a larger group of vehicle owners (Equipping vehicles with DSRC equipment – costs discussed in Chapter 6).

3.3.3 SIMULATING THE CONCEPTUAL ENVIRONMENT: TESTING OF APPLICATIONS

The applications identified were required to be tested to illustrate the effect that these vehicles may have on the traffic network, specifically relating to the efficiency of travel. There are three viable options at this point for testing these applications.

For this investigation, a simulation of the applications mentioned above was tested to determine the effect on the existing environment. The simulation will involve a micro-analysis of the traffic network – the software applicable in this case is *PTV*'s *Vissim*, a traffic simulation software designed for analysing the behaviour and operation of traffic networks. *Vissim* has the capability of simulating large traffic networks and manipulating the behaviour of vehicles. With this software, it will be necessary to obtain all of the applicable data for creating a model that may be compared to field outputs, such as travel time. To ensure that the model constructed and the results of the simulation would be as close to reality as possible, the following sources would be necessary for acquiring the necessary data:

Geometry and Layout:

- Google Earth: The road network considered contains varying levels of elevation, Google Earth was therefore used to obtain the necessary heights for the entire road network.
- Bing Maps: Vissim incorporates Maps for constructing the layout of the test area. Bing Maps was therefore used as a base layer over which the test area was constructed.

Traffic Input Data:

- Freeway Volumes and Speeds: This information would be obtained from relevant traffic agency managing the road network (Sanral). The data would thereafter be calibrated for use in the simulated network.
- Urban Route Intersection Volumes: Urban data may be obtained from signalised intersections with conductive loops used to count vehicles – this information may therefore be obtained from the City of Cape Town (CoCT).
- Signal Phasing and Timing: The end of the freeway section, as well as the urban route contains multiple signalised intersections. This data may be obtained from Transport for Cape Town (TCT).
- Traffic Composition: This data may be obtained from eNatis (enatis.com, 2016). The vehicle composition may affect the flow of traffic and is therefore necessary for implementation in the simulation.

Output Comparisons:

- TomTom vehicle travel times: This information may be compared to the eventual output of the simulations to identify if the models conform to reality.
- Google Traffic travel times: This would be included as an additional option since this option is more freely available than TomTom data, and is possibly the travel time information that most cell phone users would be familiar with (refer to *Chapter 2, Section 2.4.3.3* for description of Smartphone penetration in Sub-Saharan Africa).

3.3.4 CONSIDERATION OF ALTERNATIVES

The purpose of connected vehicles is to establish communication with the surrounding environment, be it other connected vehicles, roadside infrastructure, Smartphones or sensors (*Connected Vehicle Basics – ITS JPO*, 2016) to enhance driver safety, vehicle and network efficiency and the environmental impact. This however, requires an intricate design of a network that would be able to provide the necessary communication benefits and strategies to increase the number of connected vehicles on the road. The network required would be a DSRC equipped infrastructure network and the strategies may include phasing in of vehicle technology through detailed designs or manufacturer agreements. However, it should be accounted for that this option may not be viable; consideration must therefore be given to alternative options available to South Africa.

A viable option available to South Africa may to utilise existing technology, in this case, Smartphones. Smartphones may be a more affordable option, easily accessible and add a benefit of application development. This may present a reduction in costs – Sanral as the responsible institution for traveller information dissemination may develop an application and provide information directly to the user of this proposed service. The alternative, for users with a mobile device that is not a Smartphone, would require Sanral to establish communication between their existing information backhaul and the backhaul communications of cellular network providers. The following alternatives will therefore be explored in this study:

- **Alternative 0: Do nothing**
  The approach would consider the effect of continuing with the current manner in which traffic management and operation is addressed. The focus for this investigation, while in consideration of the country as a whole, is on the Western Cape. The Do Nothing alternative therefore discusses the outcome of allowing the current intention of Sanral (according to the Strategic Plan 2015/2016 – 2019/2020) to expand the current ITS infrastructure network.
- **Alternative 1: DSRC environment**
  This approach would attempt to determine the design and deployment of a basic DSRC equipped environment. This includes the conceptual design of a DSRC network with the equipment required by these vehicles, the information that would be provided to the relevant traffic management agency and the information that the agency would provide.
- **Alternative 2: Smartphone application**
  This alternative would consider the development of an application and the manner in which information may be provided to users and the access to information that may be attained by the traffic agencies.
- **Alternative 3: Communications with cellular service**
  The alternative may consider the aspects that need to be in place for all mobile devices to gain instant access to real-time traveller information. This alternative will explore the option of a traffic management agency's centre of operations establishing connections to the existing cellular network communications backhaul to provide information to all network subscribers.

3.3.5 COST-BENEFIT ANALYSIS

For completion of the Cost-Benefit Analysis, the costs associated with the existing infrastructure deployed by Sanral will be compared to the costs and benefits of a conceptual deployment of in-vehicle units (OBU), such as navigation units or centre consoles (for example, the TomTom Bridge (Chapter 2, *Section 2.4.3.2*)), DSRC devices, backhaul communications infrastructure and roadside DSRC equipment.

As discussed in Chapter 1 and Chapter 2, Sanral owns and manages an extensive infrastructure network it intends to expand. Although this may be beneficial with regards to the provision of traveller information and identifying incidents, efficiency of the traffic network is not particularly addressed by the presence of these infrastructure components, nor is it currently the focus of deployed roadside infrastructure – this is especially true considering the rate of congestion in Cape Town is currently increasing at a rate of 1% per year (Chapter 1, *Section 1.4*). Providing an extended network of infrastructure may provide a more detailed interpretation of the network, but is possibly not the most effective solution to addressing congestion and management of the network. Therefore, the components of the network required to address traveller information will be considered in the analysis, along with secondary costs such as maintenance and software updates. The outcome of the Cost-Benefit Analysis may assist in concluding if the current approach, according to the Strategic Plan 2015/2016 – 2019/2020 (2015) is a sustainable solution.

Based on the discussion above, along with the alternative approaches mentioned in *Section 3.2.6*, the Cost-Benefit Analysis will consider the existing environment, particularly focussing only on the existing infrastructure within the conceptual area. Moreover, the costs and benefits associated with the conceptual design will be discussed, including the costs and benefits to both traffic agencies and road users.

3.3.6 IMPLEMENTATION STRATEGY

At this stage, the simulation and cost-benefit analysis would reveal information regarding the feasibility of connected vehicles in South Africa. This information may assist in providing a timeline for deployment of the most suitable suggestion.

The simulation is anticipated to reveal valuable results in terms of congestion, time savings and efficiency. Additionally, the Cost-Benefit analysis may present a sustainable solution in terms of deployment of infrastructure versus issuing vehicle equipment to road users. The combination of this information will provide context for a possible timeline in which to deploy connected vehicle equipment and infrastructure.

3.4 DATA ANALYSIS FORMAT

The following section provides a brief description of the approach to presenting the data obtained during the investigation.

3.4.1 SIMULATION:

The following table provides an illustration of the possible presentation of the results obtained from *PTV Vissim*. The results of the simulations will be presented as proof of the effect of CV technology applied locally. Additionally, the scenarios will be modelled with different rates of penetration of connected vehicles to determine the effect that an increasing Connected Vehicle fleet may produce. The penetration rates indicated in the table were chosen as a result of the simulation conditions and the requirement of the Queue Warning scenario (for Queue-Warning to work, a CV has to be involved in a crash to distribute the message to other Connected Vehicles).

Table 3.1: Possible Format of Simulation Results

Scenario		Travel Time	Fuel Consumption	Emissions
Base Condition				
Accident				
Speed-Harmonisation				
Queue-Warning				
CVs – Approach 1				
CVs – Approach 2	40%			
	50%			
	60%			

Two approaches were considered for testing the effect of Connected Vehicle applications – this will be discussed in Chapter 4. With the second approach however, the rate of market penetration is indicated in the table (40% to 60% penetration of CVs). These particular values were selected at random, with the intention of indicating an increasing population of CVs. The lowest value however was selected based on the explanation found above the table.

3.4.2 COST-BENEFIT ANALYSIS:

The Cost-Benefit analysis will consider the costs associated with equipment in vehicles and infrastructure along with the benefits of implementing CV technology. The following provides a suggestion of the format of the analysis:

Table 3.2: Possible format of Cost-Benefit Analysis sheet

Year	Costs			Benefits	Net B/C
	Capital	Implementation	Maintenance		
0					
1					
2					
3					
n					

3.4.3 IMPLEMENTATION STRATEGY

The strategic plan will be dependent on the results obtained from the components mentioned above. The envisioned presentation will consist of the consideration of the following items:

- Strategy going forward: Based on the results obtained, a plan of action will be proposed.
- Education: Travellers should be educated on the technology to be aware of their position and involvement in developing the environment.
- Environment: The location for implementing the first generation of roadside infrastructure devices.

- Timeline. Based on the cost-benefit results and the development of the technology, a projected timeline of implementation will be suggested

3.4.4 CONCLUSION

The information provided above are subject to dependence on the information obtained, progress achieved, results and conclusions drawn through the investigation process of the study. The tables and information provided in this section may not relate to the final presentation of the data, but are provided to ensure that a logical conclusion is drawn and that the information is presented in a systematic and coherent fashion.

3.5 POSSIBLE LIMITATIONS OF THE RESEARCH DESIGN

Although it is desirable for the research to run efficiently and produce the results hypothesised, the research will be subjected to various limitations hindering the ability to attain a succinct conclusion that incorporates every parameter and all the necessary information. This section will therefore elaborate on the possible limitations of this study, and will attempt to predict areas in which limitations may be presented.

3.5.1 APPLICATIONS

The applications are the focal point of the investigation as they will determine the effect of CV technology in the local context. For this reason, it is vital that they adhere to the requirements of the study. The following limitations can be identified in the study:

- Inconvenient to implement
- Predicted effect may not be applicable to all areas
- Effect of traffic may be too great to show a significant increase
- Level of applications anticipated to change the traffic network may be too complex for first generation application implementation

3.5.2 EQUIPMENT

The equipment will be necessary to ensure that the applications can be used. The study is therefore dependent on defining the exact equipment needed and affects the complexity of the desired analyses. The following limitations were identified with regards to requiring equipment:

- The equipment required will be specific to each application, to ensure that all applications are addressed, knowledge of the devices required must be faultless.
- Equipment may not be accessible, available or utilised locally.

- Devices may still be in development for aftermarket purposes

3.5.3 SIMULATIONS

The simulation is expected to provide an illustration of the procedure needed for a real-world conceptualization and indicate the level of improvement over the transportation system. For this reason, it will be crucial to make use of accurate data to present a reliable description of the effect that CV technology will present to the economy. The following limitations to the study were thus identified:

- Simulation may not present the anticipated results
- Simulation may not contain the correct information
- The infrastructure required may be extensive
- The simulations will only present data as good as the information inserted. Information concerning the geometry of the environment, layout, input parameters, vehicle volumes and speeds and traffic signal operations may each result in an outcome that does not reflect reality if the information is not available.

3.5.4 COST-BENEFIT ANALYSIS

The Cost Benefit Analysis is related to the provision of equipment, the expense of the technology and the amount of vehicles necessary. If the statistics are not provided by Sanral and the technology is in development, the analysis will be affected. The following limitations were therefore identified:

- May not include all necessary aspects as information may not presently be available.
- Companies may not provide information due to privacy concerns.
- Equipment may not be available locally, subjecting the devices to fluctuating costs for local availability (considering import costs, licensing, amount of equipment required, etc.)
- The costs for deployment, design, implementation, etc. may be under-estimated based on local conditions, availability of expertise to handle equipment installation and maintenance etc.

3.6 CONCLUSION

The research design and methodology provided a detailed discussion of the intended approach to the study. This approach provides a framework for further development and the identification of additional study areas. The direction for the study attempted to cover all facets of implementation, by discussing the required equipment, effect of applications, and execution with the assistance of simulations, followed by a Cost-Benefit Analysis to determine the feasibility of realistic implementation within South Africa. Further research may be developed from this approach, especially with the suggestion of limitations, which may be eliminated after development and globalisation of Connected Vehicles and connected technology.

CHAPTER 4 : ANALYSIS

This chapter discusses the approach and set-up to the models and scenarios considered with the aim of achieving results that correlate to existing behaviour, and thereafter to improve upon those results. The information presented below describes the avenues within the simulation environment, particularly with the software that was used to obtain the models that were required for analysis. The information is intended to allow the reader to understand the simulation software, the development of the network and the applications that were investigated in this study.

The approach will follow the research design outlined in Chapter 3, beginning with a description of the modelling process for the simulations conducted in Vissim will be discussed. Although the following software packages are not sub-sets of the Vissim simulation, they assisted with the development of the various scenarios modelled, these are:

- Vissig: Built-in Vissim software – used to model the traffic signal phasing and timing.
- VisVAP: Visual-Vehicle Actuated Programming – allows the user to build stage based actuated programmes in Vissim.
- EnViVer: Models individual vehicle emissions based on vehicle trajectories and simulated behaviour data.

Thereafter, the software used to develop the application interface will be briefly discussed.

4.1 TRAFFIC SIMULATION MODELLING: PTV VISSIM

Vissim is a simulation software that allows the user to model an environment to investigate and evaluate the responses of traffic and traffic movements. Various situations can be modelled to gain an understanding of the effects of changing the conditions of the traffic network. Depending on the level of detail required, three main types of models are available for analysis, namely, Microscopic, Mesoscopic and Macroscopic models. An additional type known as a Sub-Microscopic model was added to these options at a later stage, but is not available in Vissim. Macroscopic models require less detail, modelling the traffic as a compressible fluid with the main properties being flow, speed and density (Hueper, J., Dervisglu, G., Muralidharan, A. et al., 2009). Microscopic simulations consider the behaviour of every vehicle in the simulation, evaluating the interaction of vehicles in the network with the road and other vehicles (Mathew, T. and Rao, K. 2007). Mesoscopic simulations are generally understood as a simulation model between Macroscopic and Microscopic simulations. Mesoscopic simulations consider the high level of detail of Microscopic modelling with the details of traffic entities, and the low level of detail with regards to the vehicle interactions. Finally, Sub-Microscopic models extend the detail of Microscopic models in that, the interactions of vehicles with each other and the road network are evaluated, extending to evaluating the behaviour of the vehicle itself, such as considering the engine rotation speed in relation to the speed of the vehicle, preferred gear changes and engine component usage etc. (Theory/Traffic Simulation, Wikipedia, 2011). Figure 4.1 provides a graphical description of these models and the interaction that takes place.

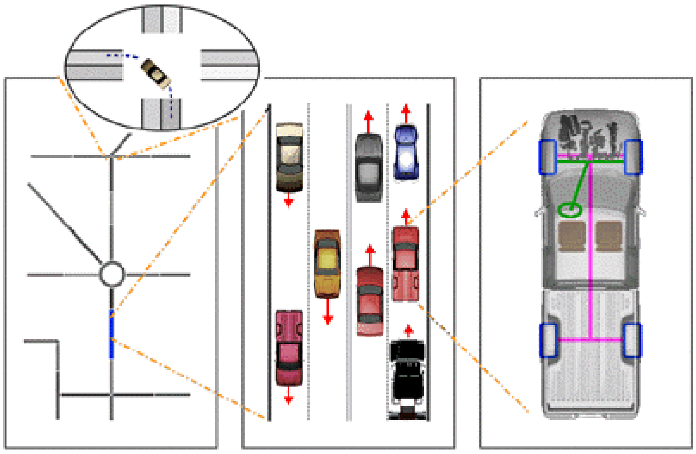


Figure 4.1: From Left to Right - Macroscopic Model, Microscopic Model, Sub-Microscopic Model Respectively (Mesoscopic Model in Circle) (Source: Theory/Traffic Simulations Wikipedia, 2011)

The Vissim model for the simulations considered in this investigation used a Microscopic approach, in which individual vehicle behaviour is investigated and varies stochastically (in behaviour) from other vehicles in the simulated network. This allowed for a detailed description of the environment and an understanding of the interaction between vehicles. The following sections provide details about the information required by Vissim, the sections that may be edited and the requirements in editing necessary to analyse the applications specifically studied in this investigation.

4.1.1 CAR FOLLOWING MODEL: WIEDEMANN '74 AND '99

The car following model is the manner in which the vehicles interact with one another. The Weidemann (1974) model was introduced as a means of describing the quality and efficiency of a simulation by modelling human driving behaviour. This behavioural description was established according to multiple older investigations about human perception during operation of a vehicle by Todosiev (1963), Michaels (1965) and Hoefs (1972) (Gupta et al., 2014). The driving behaviour was modelled according to the differences in behaviour with the following factors: Un-Influenced Driving, Closing Process, Following Process and Emergency Braking (Siuhi, S. 2009). Since each driver experienced a different change in speed and acceleration, each vehicle would display varying behaviour due to the differing perceptive abilities of individuals. These studies and factors considered, form the basis of the Weidemann (1974) model. An additional model was later developed by Weidemann, specifically applicable to freeways and expressways. The Weidemann (1999) model was more detailed, consisting of ten components describing the behaviour of individual vehicles. These factors are described in Table 1 (PTV Vissim, 2015, page 5.3).

Table 4.1: Description of Weidemann (1999) Model Parameters (Source: PTV Vissim Help, 2015)

Parameters	**Description**
CC0 (Standstill Distance)	Average standstill distance between two vehicles.
CC1 (Headway Time)	Distance in seconds which a driver wants to maintain at a certain speed. This can be described with the following equation: $$dx_{safe} = CC0 + CC1 * v$$ Where v is speed in [m/s] This is the minimum the distance the driver will maintain whilst following another vehicle.
CC2	Provides an additional restriction to the difference in following distance between vehicles. For example, if the distance is set to x meters, the new safe following distance would be (dx_{safe} + x)
CC3	Controls the start of the deceleration process
CC4	Defines negative speed difference during the following process
CC5	Defines positive speed difference during the following process
CC6	The influence of distance on speed oscillation in the following process
CC7	Oscillation during acceleration
CC8	Desired acceleration when starting from standstill
CC9	Desired acceleration at 80 km/h

Both the Wiedemann 1974 and 1999 following-models were used in Vissim to provide interaction between vehicles, allowing drivers to be aware of the presence of other vehicles to initiate appropriate responses depending on the constantly varying situations encountered within the traffic network.

4.1.2 DYNAMIC AND STATIC ASSIGNMENT MODELS

These types of modelling approached differ in the achievements of the simulations or the desired outcome of the final results to be determined. With Dynamic assignment, the model is based on a mathematical development, in that the user is required to create an origin destination matrix (discussed in the next section) for the vehicles to traverse a road network in a balanced manner, while the Static assignment consist of a selected number of vehicles at a specific location and travel along the network based on the decisions modelled. A detailed discussion of the requirement of each model is provided below.

4.1.2.1 STATIC ASSIGNMENT

Static assignment requires that the network be modelled with vehicle volume inputs based on the requirements of the network to be simulated. Once two routes are available as options, the model is required to consist of a decision where the vehicle will make a choice on the route to follow based on the Weidemann model discussed in the previous section. The flow rates may be distributed to the needs of the simulation allowing the user to control the relative volumes along roads. Incorporating time intervals allowed for changes in the vehicle movements, capacity and behaviour of the simulated network. This presented an opportunity for the simulation to present the effects of varying conditions within a single simulation. The drawback of Static Assignment however, is that its usefulness is limited to the evaluation of the present situation (future flow rates cannot be predicted) and, unless the traffic flow decisions are modelled correctly and with planned turning movements, the tedious work of assigning turning movements for a larger network may not present the correct results. Additionally, if attention is not granted to the distribution of traffic, it may become complicated to allow vehicles to flow in the desired direction.

4.1.2.2 DYNAMIC ASSIGNMENT

Dynamic Assignment requires that the user model the network with nodes, parking lots (called zone connectors) and multiple simulations. In the Vissim environment, nodes are calculation points and determine the behaviour of the vehicles at points of merging and diverging, assessing the behaviour of vehicles and allowing for the development and improvement upon performance in previous simulations. The information obtained from the previous simulations regards the turning movements and road volumes for improvement to travel time – the vehicles use the previous simulations to determine which path may present the best travel time. These vehicles enter from origin zone connectors and exit the network through destination zone connectors. An origin-destination matrix is therefore used to model the traffic flow along the network. The benefits of Dynamic Assignment include future traffic flow predictions, optimisation of traffic flow and accommodating varying traffic conditions and traffic volumes, while the limitations may be dependent on the description of the traffic demand size (Jayakrishan, R., Tsai, W.k. & Chen, A. 1995).

4.1.2.3 COMPARISON OF STATIC AND DYNAMIC ASSIGNMENT

It is widely recognized that Dynamic Assignment is, in general, the favoured option as it allows for variation in traffic volume (since the vehicles are free to select their routes multiple times) and considers every route, allowing the vehicles to determine the best route, which may be a closer approximation to reality; while Static Assignment models the flow of traffic according to the placement of turning decision points and volume distributions along the traversed route (i.e. if a decision point is placed at an intersection, specific volumes of vehicles are distributed to each of the available turning options at that intersection). For the purposes of this investigation however, Static Assignment was necessary for selection as the model type. This was due to the fact that the road volumes could be modelled and could remain consistent to compliment the traffic information used from field counts. Additionally, the applications tested may not work with Dynamic Assignment. For example, with Queue-Warning, once the accident occurs at the time interval selected in the first run of the simulation, the vehicles would reject this route in favour of a route with a better travel time. Even though this is the intention, vehicles in reality will never know the occurrence of an accident beforehand and should therefore not initiate evasive action before the accident occurs. Changes in volumes were, however, implemented to ensure variation in traffic interaction.

4.2 NETWORK MODELLING

This section discusses the external aspects of the Vissim software and the points of interest within the simulation model that should be noted. The area selected for the conceptual development of the Connected Vehicle (CV) environment was Cape Town in the Western Cape (Figure 4.2). This area was chosen to be modelled since alternative routes were available for selection, which may allow for the investigation of CV applications discussed later in this chapter.

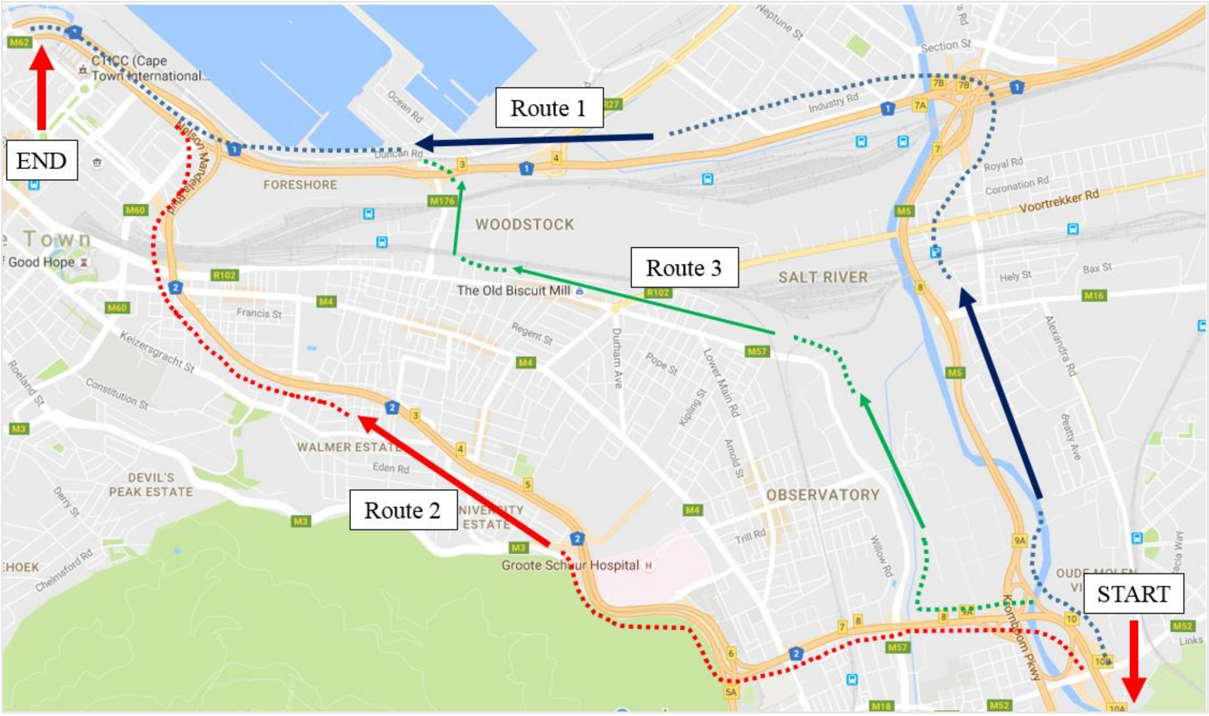


Figure 4.2: Selected Area for Simulation Model

Reasons for selecting this area include:

- Allows for the consideration of a starting and end point – this was required to allow the vehicles the option of selecting alternative routes. Queue-Warning, in Vissim, is a challenging application to model along a single section of road with no alternative options of route selection in a simulated traffic network, since the human response cannot particularly be illustrated. An alternative to modelling Queue-Warning along a single route would be to program the vehicles to display cautious driving behaviour – this behaviour is however present in the Speed Harmonisation application, eliminating the requirement for Queue-Warning along a singular road with no exit routes. Alternative route selection options therefore gives relevance to the Queue-Warning application.
- Contains ITS Infrastructure – This will be necessary for the Cost-Benefit Analysis. Furthermore, if the simulations conducted display behaviour similar to traffic data (such as TomTom Travel Time data), the simulated environment may serve as proof that the existing

infrastructure produces no significant effect on efficiency of the traffic network within the selected region (for example, the VMSs address mobility with the display travel time predictions and suggestions for use of alternative routes when necessary).

From Figure 4.2, the routes considered for the model include the N1, M5, N2, M57 and M176. The model was then divided into three routes. The first main route was the M5 and N1 starting from the Mowbray Golf Course (Route 1). The second main route was the N2 starting from Mowbray Golf Course (Route 2) and the third route was the M57 and M176, once again from Mowbray Golf Course (Route 3). All of the routes end at the Nelson Mandela Blvd/Walter Sisulu Dr intersection.

GEOMETRIC DATA

The layout of the model was constructed above a Bing Maps layout, accessible in the Vissim environment. The map was scaled to meters – this would allow the road widths and elevations to be modelled. From the maps, the following information was obtained:

Geometric Factor	Description
Road Geometry	Geometry modelled in accordance with the layout on Bing Maps
Lane Widths	Freeway (All): 3.5 meters
	Urban (Multiple): 3.5 meters
	Urban (Single): 3.5 – 4.0 meters
Number of Lanes	Freeway: 2 – 5 lanes
	Urban: 1 – 3 lanes
Locations of On-ramps and Off-ramps	Geometry modelled in accordance with the layout on Bing Maps
Auxiliary lanes	Geometry modelled in accordance with the layout on Bing Maps
Lane change zones	Geometry modelled in accordance with the layout on Bing Maps
Elevation	Google Earth
Bridges	5.2 – 5.9 meter vertical clearance (nra.co.za/content/Code, 2002)

For the majority of the freeway road network, only northbound traffic movement was modelled. For the freeways, barriers are constructed between opposing traffic; since negligible to no vehicle interaction would take place for this type of design, it was not necessary to model southbound traffic movement, especially to ensure that the speed of the simulations were not greatly affected.

With the layout provided by Bing Maps, elevations provided by Google Maps and bridge heights in place, the Vissim model was constructed (illustrated toward the end of this Section). The Vissim model was constructed under the assumption that the non-signalised traffic input provided negligible traffic input in comparison to the main route and signalised intersections (along the M57) – this would however only affect the section modelled between the Albert road and Lower Main road intersection and Albert road and Lower Church street (refer to Route 3 in Figure 4.2).

The model included all on and off-ramps that along the freeways, along with the major intersections for the urban route. Table 4.2 indicates the significant points in the model (shown in Figure 4.4):

Table 4.2: Main Points in Simulation Model with Map ID

Route	Name	Designation	Map ID
N2	Settlers Way (Mobray Golf Club)	Start	A1
	Settlers Way/Raapenburg	Interchange	A2
	Raapenburg	Main road Entrance and Exits	A3
	Kromboom Pkwy/Settlers Way	Interchange	A4
	Settlers Way/Liesbeek	On-ramps and off-ramps Signalised	A5
	Main Road/Settlers Way	On-ramp and off-ramp	A6
	Settlers Way/De Waal Dr	Interchange	A7
	De Waal Dr	Entrance/Exit	A8
	Rhodes Dr	On-ramp	A9
	De Waal Dr	Off-ramp	A10
	Ritchie Str	On-ramp and off-ramp	A11
	Upper Melbourne Rd	Off-ramp	A12
	Upper Adelaide Rd	On-ramp	A13
	Level St	On-ramp	A14
	Searle St	On-ramp and off-ramp	A15
	Newmarket St	Off-ramp	A16
	Hertzog Blvd	Off-ramp	A17
M5	Liesbeek Pkwy	Entrance/Exit	B1
	Berkley Rd	Off-ramp and on-ramp	B2
	Berkley Rd	Entrance/Exit	B3
	Koeberg Rd	On-ramp	B4
	M5 and N1	Interchange	B5
N1	N1	Start	B6
	R27	Off-ramp and on-ramp	B7
	M176	Off-ramp and on-ramp	B8
	FW De Klerk	Bridge and Exit	B9
M57	Liesbeek Pkwy	Entrance/Exit	C1
	Liesbeek Pkwy /Station Rd/Observatory Rd	Signalised Intersection	C2
	Liesbeek Pkwy/Fir Str exit Intersection	Signalised Intersection	C3
	Liesbeek Park Way/Malta Rd	Exit	C4
M57	Malta Rd / Albert Rd / Lower Main Rd / Spencer Rd	Signalised Intersection	C5
	Salt River Circle	Circle	C6
	Voortrekker Rd	Entrance/Exit	C7
	Durham Ave	Entrance/Exit	C8
	Salt River Rd	Entrance/Exit	C9

	Albert Rd/Church St/ Lower Church St	Signalised Intersection	C10
	Albert Rd	Entrance/Exit	C11
M176	Lower Church St/Beach Rd	Signalised Intersection	C12
	Beach Rd	Exit	C13
End	Nelson Mandela Blvd/Walter Sisulu Ave	Signalised Intersection	A18

With this information known, the network may be modelled in Vissim. Figure 4.3 indicates the items that may be used to model the network. Only those relevant to the construction of the model used for this investigation will be discussed:

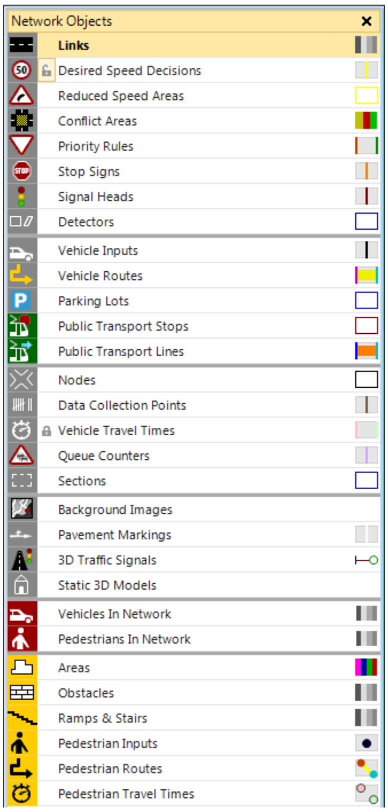


Figure 4.3: Vissim Network Objects for Modelling Traffic Network

The figure indicates the objects used to construct a network in Vissim. The relevant items may be described as follows:

- **Links**: Used to construct the road network.
- **Desired Speed Decisions**: Forces vehicles to travel at (or below) a specified speed along a section of the road network.
- **Reduced Speed Areas**: Forces vehicles to travel at a slower pace at challenging sections (sharp bends, on or off ramps).

- **Conflict Areas**: Ensures that traffic rules are in place to reduce conflict at exits/entrances and intersections (at a signalised intersection, a vehicle heading straight Southbound passes through if a vehicle heading in the opposing direction wishes to initiate a right turn).
- **Priority Rules**: Ensures that vehicles already travelling in a higher priority area are not interrupting by entering traffic (Yield zones, traffic circles etc.)
- **Signal heads**: Traffic signals placed in the network (works in conjunction with signal controllers)
- **Detectors**: May be used to count vehicles and manipulate the behaviour of traffic signals.
- **Vehicle Inputs**: Locations at which vehicles enter the traffic stream.
- **Vehicle Routes**: Used to proportionally distribute traffic flow into different directions.
- **Parking Lots**: May be used as origin-destination zones or allow vehicles to park along the roadway (may be extended to inclusion of a parking facility).
- **Vehicle Travel Times**: Measures travel time between two specified points.
- **Queue Counters**: Counts the number of vehicles remaining stationary for longer than a simulation second.
- **Pavement Markings**: Different markings may be used for illustrative purposes. Used to enhance visual experience.
- **3D Traffic Signals**: Traffic signals placed in the network (works in conjunction with signal controllers). Used to enhance visual experience.
- **Static 3D Models**: Includes buildings, trees, offices etc. Used to enhance visual experience.

With the use of these items described above, along with the real-world data, the following model was constructed:

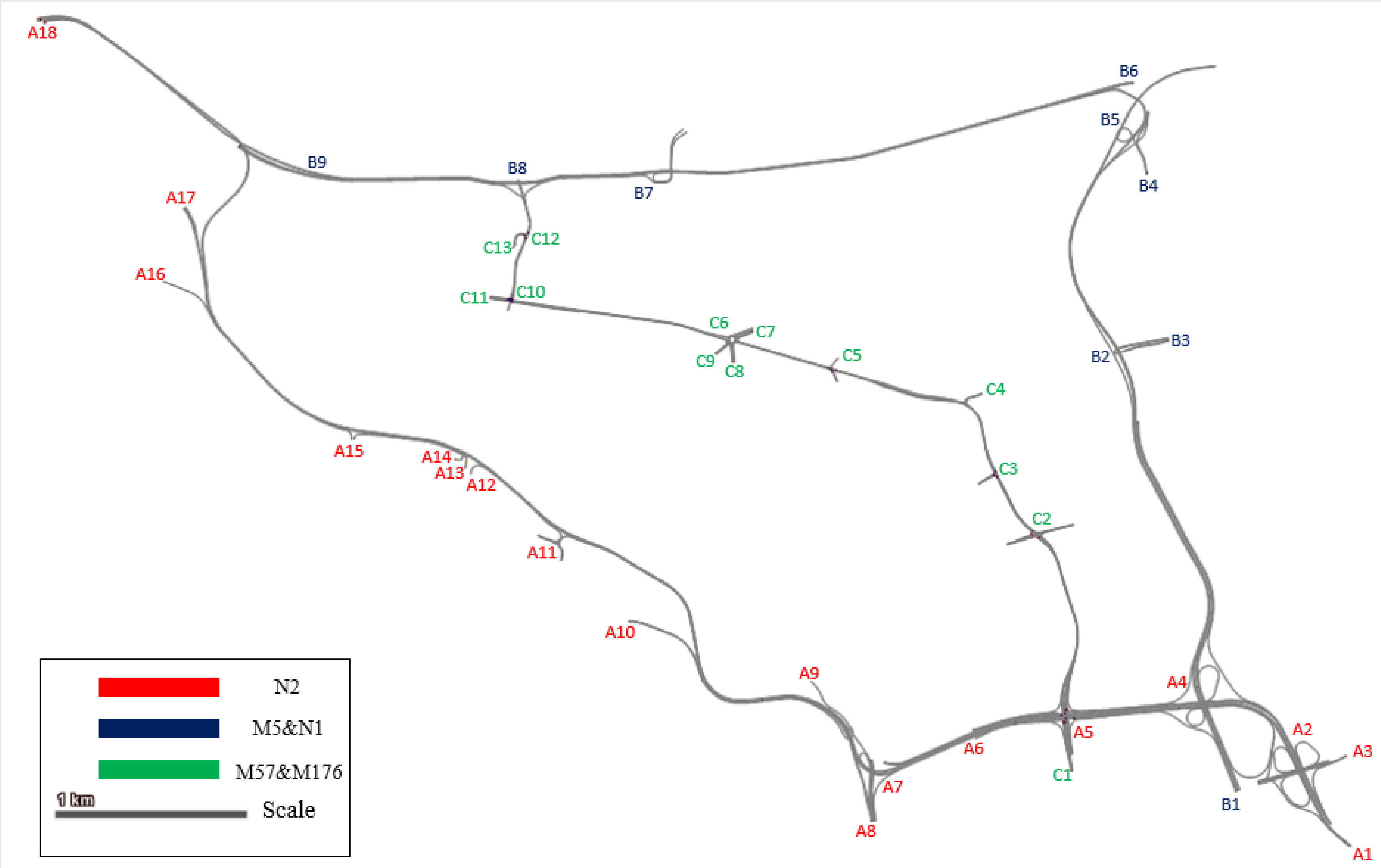


Figure 4.4: Vissim Model - Cape Town

The following sections discuss the information and modelling requirements that were necessary before testing of the simulations.

4.2.1 BASE DATA

The base data is the information that is available to the user for editing that are basic to every model and are changed to conform to the behaviour required to produce the desired output. The base data of the model determined the intricate details of the network and considers the distributions of speed, distance and time (Table 4.3). Furthermore, the behaviour of drivers and links are edited. The discussion that follows after Table 4.3 explains the more significant sectors of editing the model to the requirements necessary.

Table 4.3: Simulation Model Base Data

Base Data		Description	Example
Network Settings	Vehicle Behaviour	Driving behaviour of network	Left-hand/Right-hand drive
	Units	Imperial/Metric units	Imperial
	Display	Visual cues of simulation environment	Bing Maps; North Arrow
User-Defined Attributes		Required additions based on specific model requirements	
2D/3D Model Segments		Detailed Information regarding 2D/3D models used in Vissim	Vehicles, HGV, Pedestrians etc.
2D/3D Models		The 2D/3D models used in the Vissim simulation	
Functions	Maximum Acceleration	Graphical description of vehicles' maximum acceleration	
	Desired Acceleration	Graphical description of vehicles' desired acceleration	
	Maximum Deceleration	Graphical description of vehicles' maximum deceleration	
	Desired Deceleration	Graphical description of vehicles' desired deceleration	
Distributions	Desired Speed	Speed distribution ranges	70km/h (65 - 75 km/h range)
	Power	Distribution of power for 2D/3D models	Trucks require higher power than vehicles
	Weight	Distribution of weight for 2D/3D models	
	Time	Dwell times	Tolling stations; Public Transport zones
	Location	Allocates distribution of 2D/3D models	Passenger location in public transport vehicles
	Distance	Distribution between a point and a maximum distance	Waiting distance at traffic signal
	Occupancy	Distribution of occupants	Number of vehicle occupants
	2D/3D Model	Distribution of models use in simulation model	Cars: (Different Vehicle Models); HGV (Different Truck Models)
	Colour	Relevant for graphical display	
Vehicle Types		Different Vehicle models	Car: Volkswagen Passat; HGV: Mercedes-Benz
Driving Behaviours		Behaviour of network users	Car Following Model; Lane Selection; Lane Position

Link Behaviour Types		Road type	Freeway; Urban Road; Footpath
Pedestrian Types		Different pedestrian models	Man; Woman; Wheelchair
Walking Behaviours		Behaviour of pedestrians	Force of pedestrian interaction, Passing behaviour
Area Behaviour Types		Behaviour of pedestrians according to location	More forceful at public transport doors than along sidewalk
Display Types		Visual display of network items	Road surfaces, road markings
Levels		Elevation of roads	Bridge level
Time Intervals		Distribution of intervals within a simulation period	Separating a total simulation time into hourly intervals to change traffic input

4.2.1.1 TRAFFIC DATA

The simulations were conducted with two approaches in mind. The first was to simulate free-flow traffic, with the second approach being the simulation of peak-flow traffic. The reason for conducting the simulations in this manner was to address the applications that will be considered in this investigation, namely Queue-Warning and Speed-Harmonisation (discussed in *Section 3.1.2*). The application that presents this requirement is Queue-Warning. The premise of this application, as previously described, is to provide approaching vehicles a warning of the current or predicted occurrence of congestion – this would allow the approaching vehicles to consider alternative routes or to be cautious of the imminent conditions. This application is therefore beneficial in free-flow or pre-peak-flow conditions, where the driver would be able to benefit from the warning in terms of travel time savings or reduced fuel consumption. However, in peak flow conditions, the remaining option is for the driver to be cautious – this caution is the prime intention of the Speed-Harmonisation application. With this in mind, traffic data for free-flow and peak-flow conditions was required. The following sources were approached for traffic data:

- **Freeway Data**:
  - Traffic data for the freeway was required, since the model considered the flow on the M5, N2 and N1. The data was requested from permanent counting stations for the year of 2015 since the entire year's data would provide an elaborate picture of the change in traffic over an annual duration. Additionally, Sanral has deployed VDSs in the traffic network – these devices provide real time traffic information along the freeway, including travel speed, number of vehicles per lane per hour and vehicle occupation (Appendix D). Since the information for the permanent stations was requested for 2015, historic data from the VDSs in question was therefore required. A week of traffic data (during the third week in August (17^{th} August 2015 – 21^{st} August 2015) since there were no public holidays during this time) was obtained. This would provide an understanding of the change in traffic conditions throughout the week, if indeed a change was prevalent.

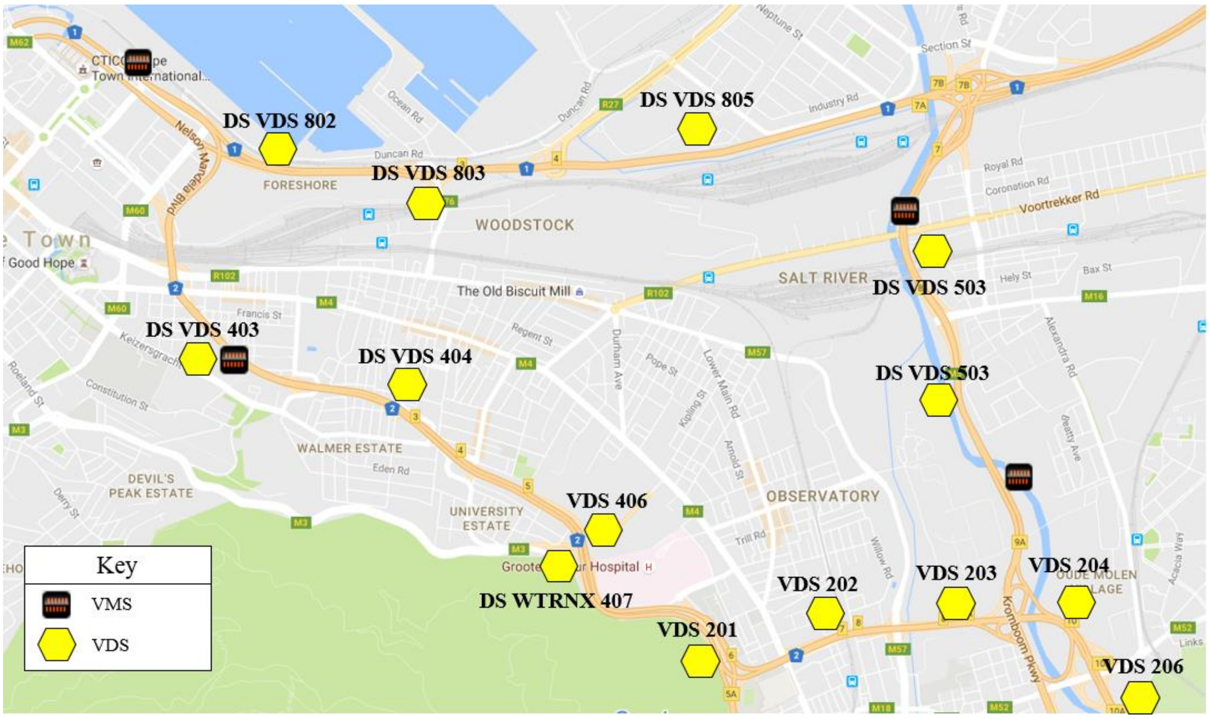


Figure 4.5: Approximate Locations of VDS Devices used for Traffic Volume and Travel Speed Data

- The VDS data is however only collected for the main routes (along the freeways) and does not consider the traffic entering the stream from on-ramps and the vehicles exiting via off-ramps – to accommodate for the unknown number of vehicles utilising the ramps, camera data was used to compile the traffic counts for the morning and evening peak hours. The data for the rest of day was averaged between the peak counts for the morning and evening. This data was counted in 15-minute intervals to establish a peak-hour factor – the counts were completed physically by counting the individual vehicles traversing the ramps and adding the data for the peak hours. The cameras required for these counts were located at the following intersections:
  - N2: Settlers Way exit to Raapenburg In Bound (Cam1)
  - N2: M5 South Bound after N2 (Cam2)
  - N2: N2 Median before M5 Interchange (Cam 3)
  - N2: N2 Out Bound before M5 Interchange (Cam 4)
  - N2: N2 Out Bound before Liesbeek (Cam 5)
  - N2: N2 In Bound at Hospital bend – M3 Interchange (Cam 6)
  - N2: M3 In Bound before Hospital Bend – M3 / Interchange (Cam 7)
  - N2: N2 Out Bound at Hospital Bend (Cam 8)
  - N2: N2 In Bound at De Waal (Cam 9)
  - N2: N2 In Bound at Roodebloem (Cam 10)
  - N2: N2 Out Bound after Searle (Cam 11)
  - N2: N2 In Bound before New Market (Cam 12)

- N2: N2 In Bound at New Market (Cam 13)
- N1: N1 In Bound at Lower Church (Cam 14)
- N1: N1 Out Bound at Marine Drive (Cam 15)
- M5: CCTV 501A (Cam 16)
- M5: M5 North Bound at Berkley (Cam 17)

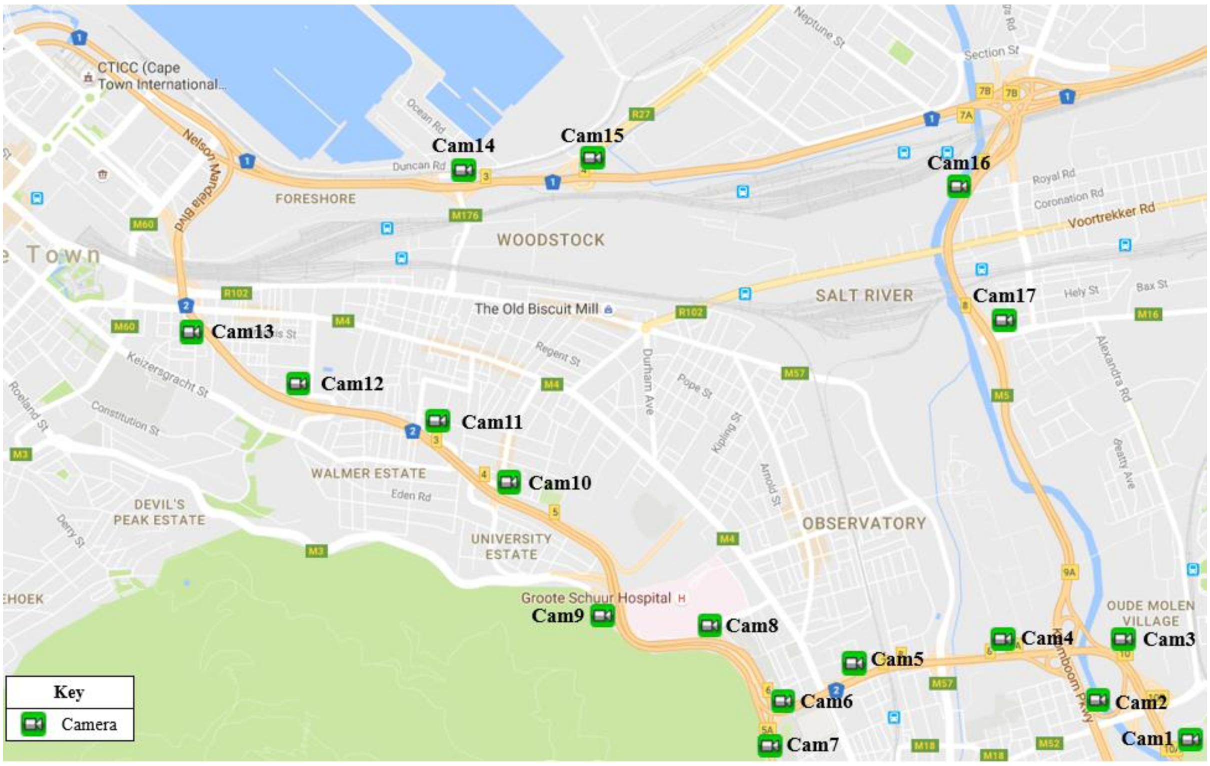


Figure 4.6: Cameras used in Traffic Counts and Distribution

  - Finally, Inrix speed data was obtained for real-time traffic for a Thursday morning between 07:30 and 08:30 (08 September 2016) to observe the travel speeds for comparison to the congested traffic model.

- **Municipal Road**: CoCT conducts traffic counts for local roads using loops at signalised intersection; since an urban road was modelled as an alternative route, it was necessary to obtain traffic data for this route. The data was obtained for the signalised intersections along the M57 and M176.

Additionally, the urban route (M57 and M176) contains traffic signals – this meant that it would be necessary to model the phasing and timing of the traffic signals along this route. This information was obtained from TCT (Transport for Cape Town) and was used to model the following intersections:

- Settlers Way/Liesbeek Pkwy interchange (N2 off-ramps – **A5** in Figure 4.4)
- Observatory Rd/Station Rd/Liesbeek Pkwy intersection (M57 – **C2** in Figure 4.4)
- Liesbeek Pkwy/Exit to Fir St intersection (M57 – **C3** in Figure 4.4)

- Lower Main Rd/ Albert Rd intersection (M57 – **C5** in Figure 4.4)
- Albert Rd/Lower Church St intersection (M57/M176 – **C10** in Figure 4.4)
- Lower Church St/Beach Rd intersection (M176 – **C12** in Figure 4.4)

Two additional signalised intersections were included (namely the FW De Klerk/Christiaan Barnard St intersection (end of **B9** in Figure 4.4: page 4.15) and the Nelson Mandela Blvd/Walter Sisulu Ave intersection (**A18** in Figure 4.4: page 4.15), however, only Northbound phasing was modelled since opposing traffic was not required at these locations.

The remaining data requested was accident data for the freeways in the Western Cape. The rate of crashes was not incorporated into the model, but was used to correlate the rate of accidents after deployment of the existing ITS infrastructure for freeway management and operation (refer to Chapter 1, *Section 1.4*). This data was obtained from Sanral for the year of 2015.

Information regarding the traffic counts along the urban roads (supplied by CoCT for the intersections considered in this investigation) was provided as indicated in Figure 4.7 (Observatory/Station Rd and Liesbeek Intersection).

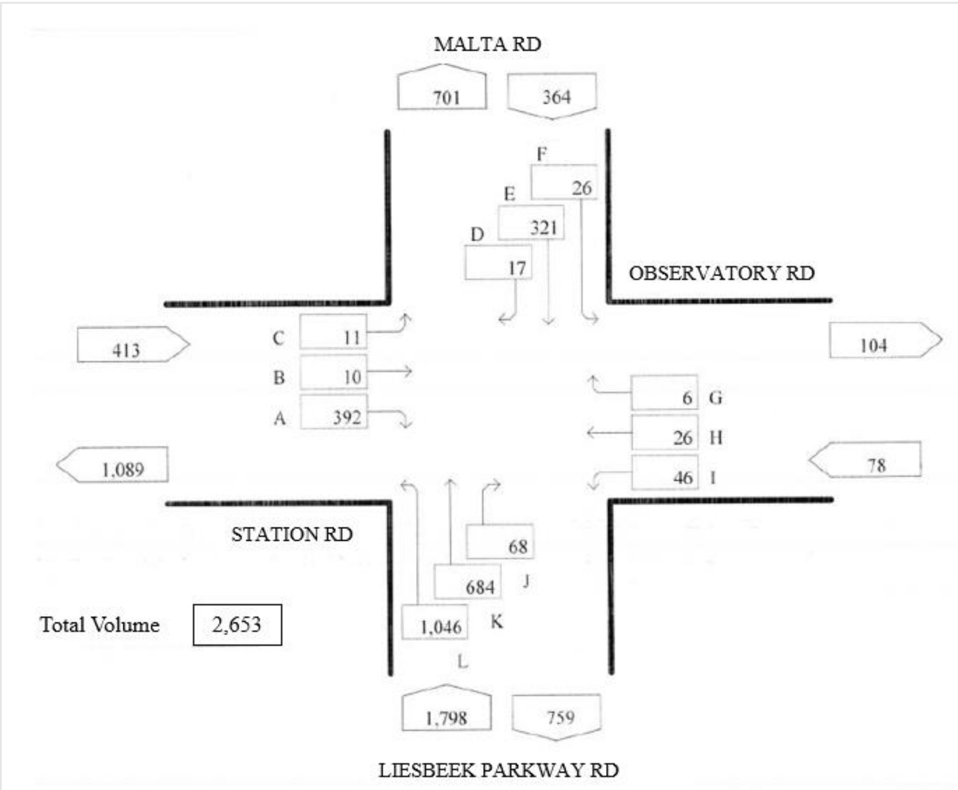


Figure 4.7: Format of Traffic Data (Source: CoCT)

Appendix D contains the distribution of all the intersections included in the investigation. These traffic counts were distributed in the necessary directions for the appropriate time interval, in this case, the

AM Peak traffic. The vehicle type distribution (Figure 4.7) was additionally provided and averaged across the entire network and thereafter added into the model.

4.2.1.1 TRAFFIC INPUTS

The traffic flow information obtained from Sanral was given by the VDS equipment installed along the routes considered. This provided information at various points along the travel routes. With the information provided in this manner, along with the use of a Static Assignment modelling approach, the following procedure was used to ensure that the traffic data used in the simulations would produce results similar to reality.

- **Vissim provides a single entry point (Vehicle Inputs)**: The issue that this single entry point presents (especially since volume does not automatically vary), is that the volume along the route may not be controlled to conform to the volumes and speeds identified by the VDS equipment. To address this, the volumes along the route, along with the speed, were converted to an equivalent volume of vehicles per hour travelling at free-flow speed (i.e. a VDS reading may indicate a volume of 1400 vph travelling at 30 km/h along the N1. Since the free-flow speed along the N1 is 90 km/h (tomtom.com/index, 2016), the equivalent number of vehicles per hour would be 4200):

$$\frac{VDS\_Volume(\frac{veh}{hr})}{VDS\_Speed(\frac{km}{h})} = EquivalentRatio(\frac{veh}{km})$$

$$EquivalentRatio\left(\frac{veh}{km}\right) * FFS(\frac{km}{hr}) = EquivalentVolume(\frac{veh}{hr})$$

Where *FFS* is Free Flow Speed for the relevant freeway route

The following graph indicates the fluctuating VDS readings along the M5 and N1 for a 5 hour period along with the equivalent adjusted volumes. These volumes will be used in Vissim to model the traffic behaviour:

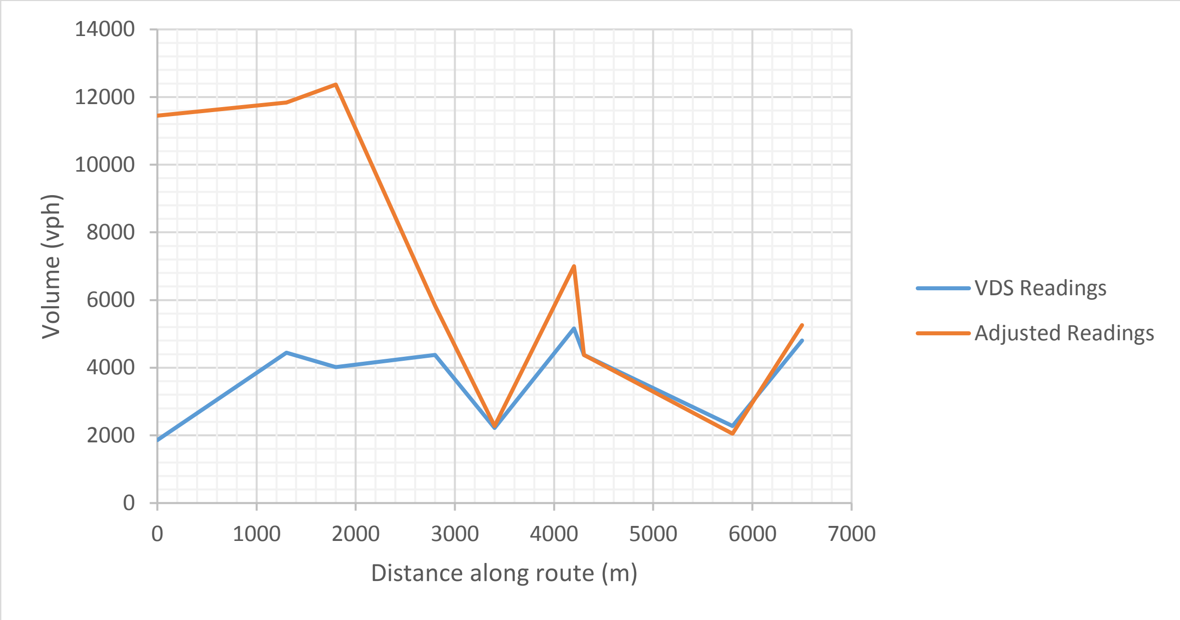


Figure 4.8: Adjusted Volume Data along M5 and N1for Vissim Input

This procedure was followed for all of the freeway routes considered – the input volumes may be found in Appendix D.

- **Static Assignment does not produce fluctuating volume**: Since the volumes used for the inputs do not produce varying volumes, the fluctuation of volumes was produced manually. This was accomplished by splitting the data inputs into 15 minute intervals. The information provided from the VDS readings relay information for every 10 minute interval. This data was aggregated into 15 minute-interval data and varied within the "limits" of the volumes indicated in Figure 4.8. The input data was adjusted for a day of travel including a warm-up period, morning and evening peaks (900 second warm-up period starting at 06:00 AM, Morning Peak Traffic starting at 06:30 AM and Afternoon Peak Traffic concluding at approximately 19:30 PM – a total of 13 and a half hours). The following figure indicates input volumes used for the Vissim model. The full list of volumes may be found in Appendix D.

Table 4.4: Vissim Input Volumes along Freeway Routes

Num.	Name (Map ID)	Volume (0)	Volume (3600)	Volume (7200)	Volume (10 800)	Volume (14 400)	Volume (18 000)
1	A1	500	1748	2011	2981	3166	3187
2	A3	1000	2230	2274	2393	2568	2781
3	A3	1000	2249	2295	2253	2156	2030
4	B1	1500	2284	2750	4213	4466	4147

The data however does not allow the user to observe the interaction of vehicles with zones. In the case of Dynamic Assignment, vehicles choose a route based on the easiest time to reach their destination, indicating that vehicles from these input locations desire to reach different locations – this information is generally only attainable with excellent traffic monitoring equipment, implemented in every area or through detailed empirical studies. The intersection movements were considered and distributed according to the percentages of vehicles travelling in specific directions. Figure 4.9 indicates this distribution:

Table 4.5: Distribution based on Volume Data

M5 Off-Ramp to N2 IB	1395	1594	1610	1505	1332	1134	947	796	698	661	683	756	858	963	1034	1023
M5 Distribution	0.70	3.02	4.14	6.43	7.02	7.26	7.54	8.03	8.28	8.41	8.44	8.15	7.56	6.57	7.06	7.69
M5 Off-Ramp Dis	9.30	6.98	5.86	3.57	2.98	2.74	2.46	1.97	1.72	1.59	1.56	1.85	2.44	3.43	2.94	2.31

The traffic flow data for the urban roadways was only available for signalised intersections. This was therefore acceptable for the purposes of this investigation – as previously stated, the section between C5 and C10 would be affected by the traffic flow and was assumed to present negligent flow to the traffic stream along the main route (M57). Figure 4.9 indicates the distribution of flow for the Observatory/Station Rd and Liesbeek Intersection.

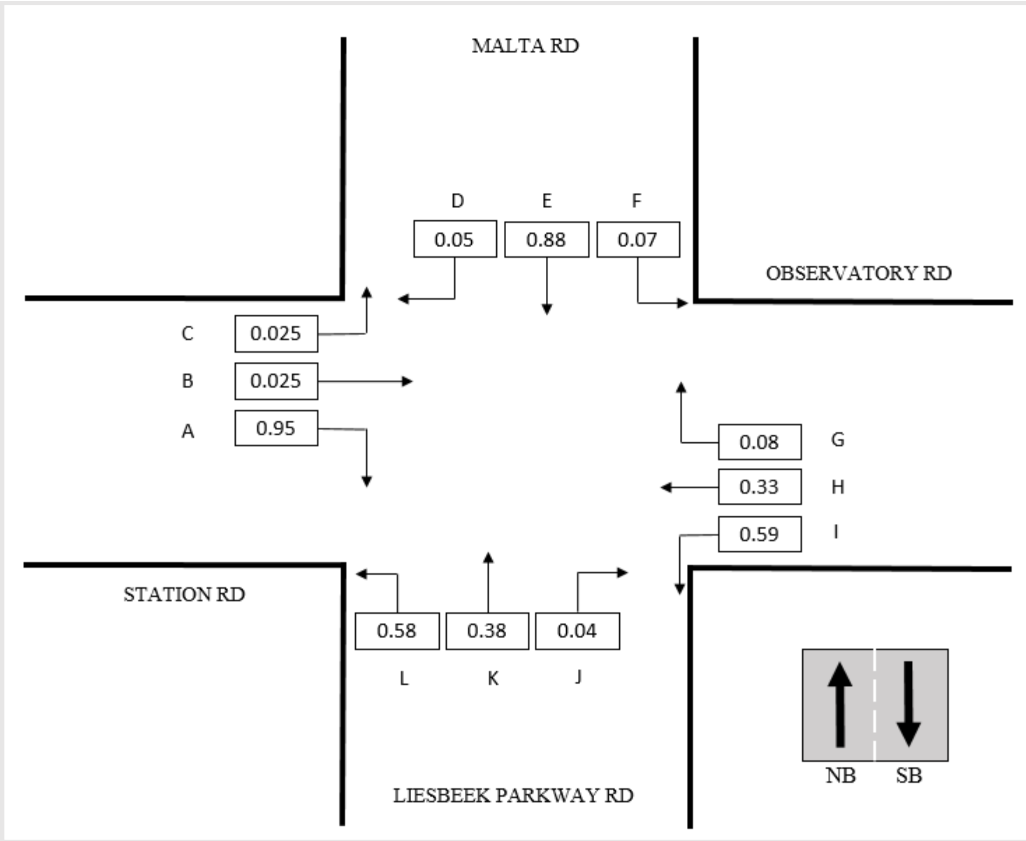


Figure 4.9: Intersection Vehicle-Route Distribution (Morning Peak)

This traffic input data was distributed according to the PHF provided and distributed according to turning movements (as indicated in Table 4.6). The following table provides an indication of the traffic input distribution for the North-Bound traffic stream on the Liesbeek. The traffic input data can be found in Appendix D and the attached flash disk.

Table 4.6: Partial Intersection Input data for Single Direction Morning Peak Hour

	Time	**07:45**	**08:00**	**08:15**	**08:30**	**08:45**	**09:00**
Direction K	Sim time	6300	7200	8100	9000	9900	10800
	PHF = 0.86	1	1	1	1	1	0.98
	Total	113	222	127	222	684	670
	Light	111	220	125	220	676	662
	Heavy	0	1	2	1	4	4
	Other	2	1	0	1	4	4

This procedure was followed for each intersection considered in this investigation (refer to Appendix D). Once the necessary traffic flows for each intersection was determined and distributed accordingly, the input of traffic was adjusted to allow for changing traffic volumes at 15-minute intervals for a total simulation time of 810 minutes (13 and a half hours), including Morning Peak and Evening Peak traffic.

4.2.2 SIGNALISED INTERSECTIONS

The model built in Vissim incorporates eight signalised intersections (page 4.17) that were modelled according to the phasing and timing schedule provided by the City of Cape Town (CoCT). The timing schedule was available for the morning peak, inter peak (period between the morning and afternoon peak traffic flow), afternoon peak and off peak traffic flow periods. Along with the phases and timings, the minimum time periods for each signal (Red, Amber and Green) was provided.

This information was used to model the behaviour of the signalised intersections with VISSIG, a built-in software package (built-in with Vissim) that allows the user to model the behaviour of traffic signals and traffic signal controllers. When the user chooses to add a signal control group, the following pop-up appears:

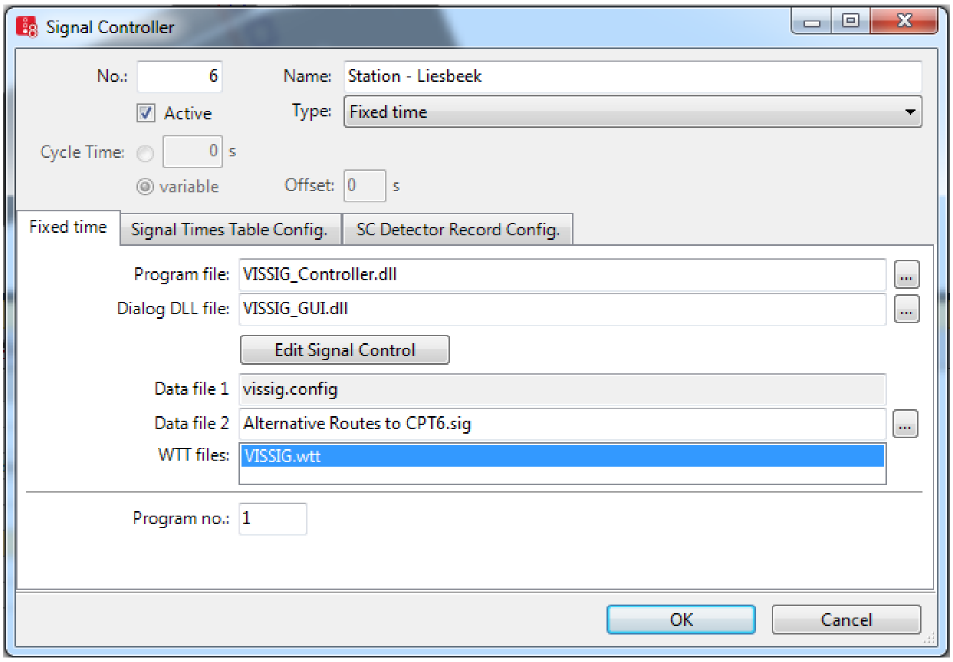


Figure 4.10: Signal Controller Menu

For a signal controller, the *Type* is *Fixed time* (since a cycle time would be used). Once the name of the intersection is entered, the user then proceeds by clicking the *Edit Signal Control* button – the information shown for the *Program file*, *Dialog DLL file*, *Data file 1*, *Data file 2* and *WTT files* are completed by VISSG automatically, and is not relevant to the discussion of the set-up of the signal controllers. The following section describes the software use and the set-up for a signalised intersection (once the *Edit Signal Control* button is pressed).

VISSIG: PROGRAMMING TRAFFIC SIGNAL CONTROLLERS

The information provided by CoCT for signal phasing and timing appears presentably and in a format that does not require further modifications or adjustments, and may be added directly into VISSIG. Figure 4.11 shows the user interface of the software:

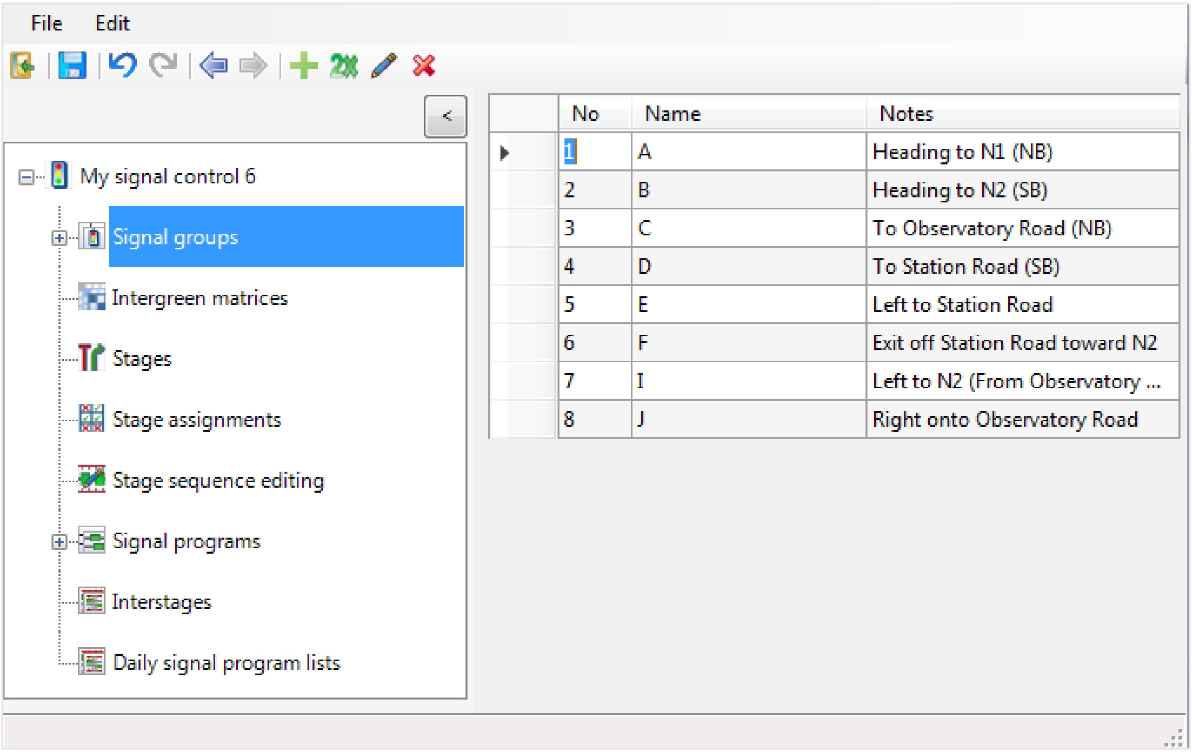


Figure 4.11: VISSIG Interface

The user interface shown provides an example of the use of the traffic signal data for the Liesbeek Pkwy /Station Rd/Observatory Rd intersection (**C2** in Figure 4.4). The items appearing in the user interface relevant to the study may be described as follows:

- **My signal control 6**: The traffic signal control identification number appearing in the list of signal controllers.
- **Signal groups**: The following information should be considered before a description of the information shown on the right in Figure 4.10 is given. Figure 4.11 indicates the turning movements for Liesbeek Pkwy /Station Rd/Observatory Rd intersection (**C2** in Figure 4.4):

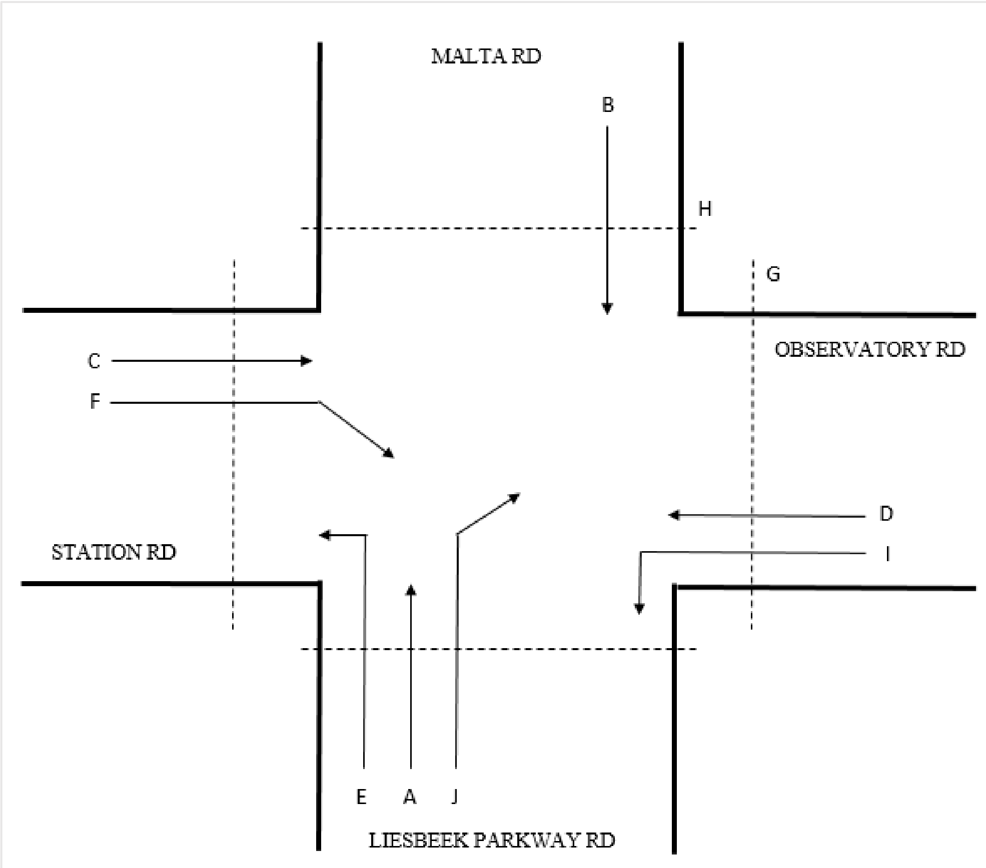


Figure 4.12: Intersection Movements and Signal Phases (Adapted from CoCT Signal Controller data)

From Figure 4.12, it can be seen that each turning movement is assigned an ID, which was used to identify the different signal groups – for this intersection, eight signal groups were present and added to the signal control. Once the signal groups are added, the sequence and phase duration times for each signal is added. Table 4.7 shows an adaptation of the phase durations provided by CoCT (refer to Appendix D for full phase duration data) and Figure 4.13 illustrates the added data into the specific signal group:

Table 4.7: Phase Durations for Intersection (C2)

Phase	**Run 1 (sec)**	**Run 2**	**Run 3**	**End Delay**	**Phase Yellow**	**Yellow Extension**	**Phase Red**	**Red Extension**
	Green	Green	Green	Green	Yellow	Yellow	Red	Red
A	7.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0
B	7.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0
C	7.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0
D	7.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0
E	5.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0
F	5.0	0.0	0.0	0.0	3.0	0.0	2.0	0.0
I	5.0	0.0	0.0	0.0	3.0	0.0	2.0	0.0
J	5.0	0.0	0.0	0.0	3.0	0.0	2.0	0.0

This data is then used for each associated signal group:

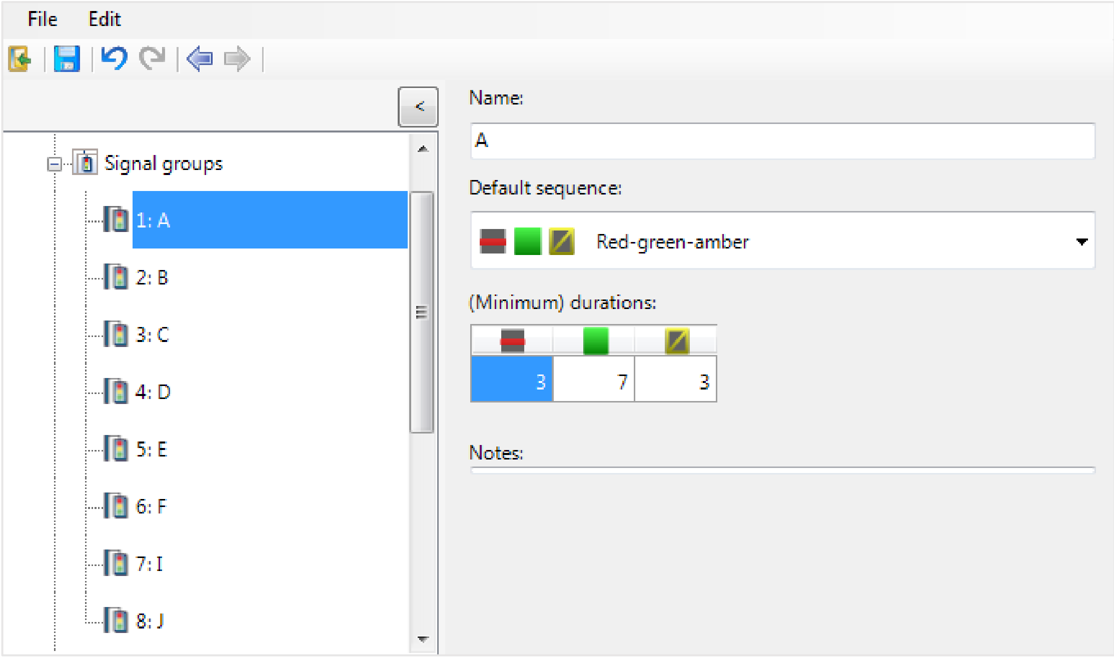


Figure 4.13: Signal group details

- **Intergreen matrices**: Used to improve stopping distance, intersection clearance times and pedestrian crossing times.
- **Stages**: Not used in this study.
- **Stage assignments**: Not used in this study.
- **Stage sequence editing**: Not used in this study.
- **Signal programs**: Multiple signal control timings may be programmed for daily operation. For this investigation, the morning peak, interpeak, evening peak and off-peak traffic flow was modelled – the signal controllers were therefore programmed accordingly for each of the intersections considered. For the Liesbeek Pkwy /Station Rd/Observatory Rd intersection (**C2** in Figure 4.4), the following signal plan for the morning peak (AM Peak) was programmed – the full list of signal programs for all intersections may be found in Appendix D:

Table 4.8: Plan Data for Liesbeek Pkwy/Station Rd/Observatory Rd intersection (AM Peak) (Adapted from CoCT Signal Controller data)

Plan Data for Stream 1							
Description	Am Peak						
Phase Profile Mapping	A B C D E F G H I J K L						
Cycle Time	108						
Stage	**Stage Max**	**Stage Min**	**Intergreen**	**Window Start**	**Window End**	**Can Start Early**	**Always Run**
1	35	34	0	40	Yes	Yes	Yes
2	10	7	40	40	---	---	---
3	28	7	57	57	---	---	---
4	10	7	91	91	---	---	---

The times for this intersection (Table 4.8) were used as ranges for determining the most appropriate times for the stages. The figure below (Figure 4.14) indicates the times used in each of the models for the Liesbeek-Station intersection (**C2** in Figure 4.4). As mentioned, the times vary between the minimum and maximum stage times:

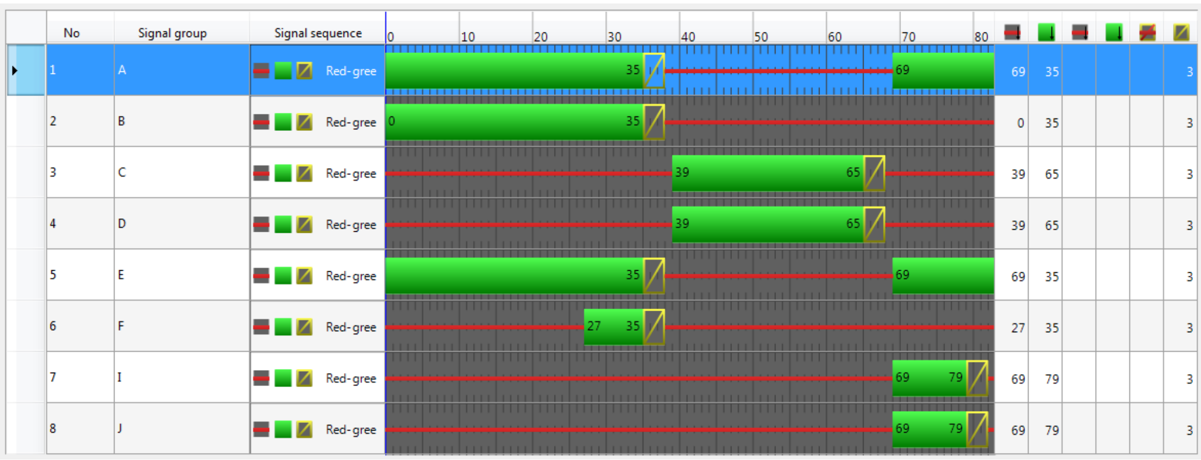


Figure 4.14: Signal Program for Liesbeek-Station (AM Peak)

- **Interstages**: Not used in this study.
- **Daily signal program list**: All of the signal programs used (AM Peak, Interpeak, PM Peak and Off Peak) are added to this list in the order required through the day based on the timing schedule of the peak traffic flow occurrences. Figure 4.15 shows the list along with the related times of peak traffic flow:

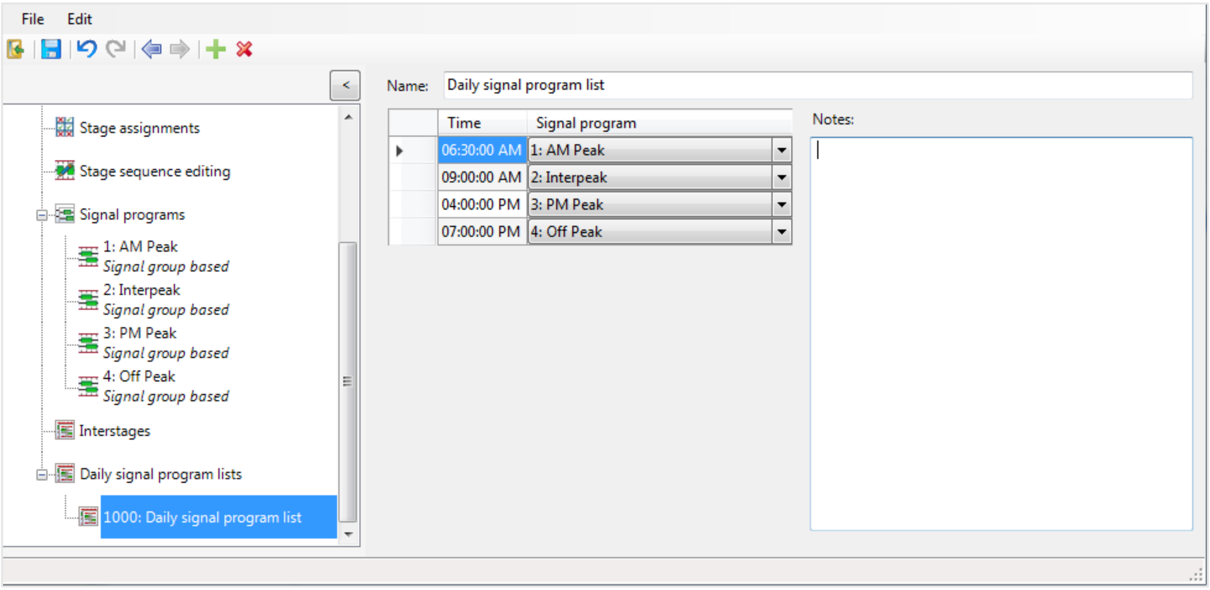
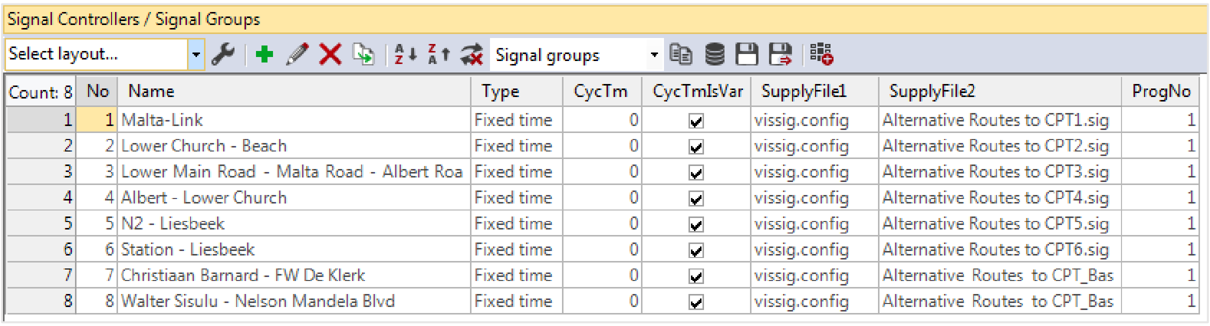


Figure 4.15: Signal Control Schedule for Single Day

This completes the procedure for modelling the signal control for a single signalised intersection. This procedure is then repeated to complete all of the signalised intersections before placement in the Vissim model. From Figure 4.4, these intersections were **A5**, **C2**, **C3**, **C5**, **C10**, **C12**, **B9** (end of exit) and **A15**. In Vissim:


Signal Controllers / Signal Groups

Select layout... Signal groups

Count: 8	No	Name	Type	CycTm	CycTmIsVar	SupplyFile1	SupplyFile2	ProgNo
1	1	Malta-Link	Fixed time	0	✔	vissig.config	Alternative Routes to CPT1.sig	1
2	2	Lower Church - Beach	Fixed time	0	✔	vissig.config	Alternative Routes to CPT2.sig	1
3	3	Lower Main Road - Malta Road - Albert Roa	Fixed time	0	✔	vissig.config	Alternative Routes to CPT3.sig	1
4	4	Albert - Lower Church	Fixed time	0	✔	vissig.config	Alternative Routes to CPT4.sig	1
5	5	N2 - Liesbeek	Fixed time	0	✔	vissig.config	Alternative Routes to CPT5.sig	1
6	6	Station - Liesbeek	Fixed time	0	✔	vissig.config	Alternative Routes to CPT6.sig	1
7	7	Christiaan Barnard - FW De Klerk	Fixed time	0	✔	vissig.config	Alternative Routes to CPT_Bas	1
8	8	Walter Sisulu - Nelson Mandela Blvd	Fixed time	0	✔	vissig.config	Alternative Routes to CPT_Bas	1

Figure 4.16: List of Signal Controllers for Intersections

The figure shows the added program for each intersection along with the details associated with each controller group. This concludes the modelling of the signalised intersections.

CONCLUDING REMARKS

With all of the information used to construct the model, manipulate the behaviour of the vehicles and network, and establish control over vehicle movements, the simulation may be run to determine the output of the model, in this case, for the Base Condition scenario (Discussed in Chapter 5).

4.3 ASSISTING SOFTWARE

Beyond the requirements of the Base Condition for the model built in Vissim, specific requirements for this investigation may not have been attained without the use of additional software packages to extract the necessary information. While Vissim provides multiple options for modelling traffic behaviour, further and more specific manipulation of traffic was required. For this study, the additional scenarios to be modelled were:

- Accident scenario: The occurrence of a crash would allow the model to generate congestion based on the stationary vehicles occupying a lane (or multiple lanes).
- Speed-Harmonisation scenario: This CV application would test the effect of reducing the traffic flow speed to accommodate growing traffic.
- Queue-Warning scenario: This CV application tested the effect of vehicles utilising alternative routes and making adjustments to their position based on information of the formation of a queue (applicable to the Accident scenario)
- Connected Vehicle scenario: CVs incorporated both the Speed-Harmonisation and Queue-Warning application to test the combined effect of the applications.

For the Accident scenario, the Network Objects available in Vissim was used and did not require assistance from external applications. The Speed-Harmonisation application however was required to determine the number of vehicles travelling along a specific route in real-time – this was necessary to determine the appropriate speed for vehicles to reduce congestion and possibly increase throughput; to assist with this, a software package called VisVAP was used. This software will be discussed below (*Section 4.3.1*). The Queue-Warning scenario did not require the assistance of external software, this application was modelled using the existing Vissim network objects.

The Connected Vehicle scenario was modelled with two approaches. The first employed the combined manipulations used to model the Speed-Harmonisation and Queue-Warning scenarios. The second approach however, used a more elaborate technique to manipulate the behaviour of the vehicles in the network. To model this second approach, it was necessary to make use of a Script-File. This will be explained in *Section 4.3.2*.

Finally, modelling a network with a Static Assignment approach reduced the ability to determine the emissions and fuel consumption of vehicles in the network. To account for this, a software package called EnViVer was used to determine the emissions data of vehicles modelled all of the scenarios. An explanation of the software follows in *Section 4.3.3*.

4.3.1 VISVAP

VisVAP is a traffic detector and signal modeller that can be used for additional functionality to the model. The applications that may be explored with this software include modifications to signalised intersections, VMS modelling, ramp-metering, traffic counts, and related ITS traffic operations. In this case, VisVAP was used to model a VMS board to provide a visual effect for the use of a Smartphone, i.e. since smart phones cannot be modelled in Vissim and displayed in the vehicles, the VMS was used to indicate the status of the CV application test during a simulation. The VMS modelled should not be confused with the existing VMS infrastructure in the real-world network – the VMS modelled for this investigation will therefore be referred to as VMS-SP (Smartphone).

The use of VisVAP in this case was for the Speed Harmonisation application discussed in the following section. VisVAP contains multiple functions for use to provide the functionality necessary; the functions used in this investigation are indicted in Table 4.9:

Table 4.9: Parameters used in VisVAP for Programming Detectors and Signal Controllers

Parameter	Description
desSpeed	Desired Speed: Initially set by Vissim
Set_des_speed	Change Speed to new value
Set_sg_direct	Change the Signal Indicator
Front_ends	Count the front ends of vehicles once they pass
Clear_Front_ends	Clear the front end counter
Record_value	Record of the counter
	Start and End of Flow Chart
	Statement
	Condition (Yes / No)

Appendix D contains the VAP file displaying the procedure followed to provide the desired operation.

4.3.2 SCRIPT-FILES

Vissim allows the user to incorporate script files into the analysis of a model. Script files consist of hard-coding that may be completed in an acceptable (to Vissim) coding language (Such as Java, Visual Basic, C++, C#, Python) that may be used to manipulate the behaviour of the vehicles in the network, construct the network or include behaviour that is not standard to the Vissim environment. This was completed by accessing the Vissim Library (location of the files and code used to produce the network items and environment), and adjusting the behaviour of the vehicles according to the requirements of the simulation.

For this study, the behaviour of the vehicles in the network would be adjusted to accommodate the CV applications investigated, namely Queue-Warning and Speed-Harmonisation. As previously stated, access to the Vissim Library would be necessary to change the necessary variables under specific conditions. The following table provides a list of the most important variables used in the Connected Vehicle scenario:

Attribute	Label in Script file	Meaning
Vehicle Attributes	RoutDecType	Route Decision Type
	RouteDecNo	Route Decision Number
	VehType	Vehicle Type
	No	Vehicle Number
	DesSpeed	Desired Speed
Location	PositionXYZ [0]	
	PositionXYZ[1]	
	distDistr	
Boolean Statements		

These attributes were the most relevant for modelling the CV scenario. The specific script-file used to model the scenario will be discussed in *Section 4.4.4*.

4.3.3 ENVIVER

EnViVer is a mathematical software model that uses the results obtained from Vissim simulations and complex algorithms to determine the emissions of vehicles within the simulated network. This allowed for the study of vehicle emissions and fuel consumption based on the adjusted conditions of the various network models. EnViVer required the results from Vissim and calculated the emissions of the vehicles in the network based on the output of the relevant simulations. The information required by EnViVer is shown in the table below:

Table 4.10: Vissim Parameters Required by EnViVer for Analysis

Parameter	Description
Simsec	Simulation Time [s]
Number of Vehicles	Number of vehicles in the network
Link Number	Number of the Link or Connector
Lane Number	Unique number of the lane
Position	Position of the vehicle along the Link
Position (Lateral)	Position of the vehicle within the lane
Speed	Speed at the end of the time step
Vehicle Type	The type of the vehicle
Vehicle Name	Name of the vehicle
Vehicle Number	Unique number of the vehicle
Acceleration	Acceleration at the end of the time step
Coordinate of Front	Coordinate of the front of the vehicle at the end of the time step
Time in Network (total)	Total time spent in the network
Simulation time	Simulation (time of day) [hh:mm:ss]
Lane Gradient	Gradient of the lane (%)
Power	Power of the vehicle (HGV)
Weight	Weight distribution of the vehicle (HGV)

This information is obtained upon completion of the simulation. Thereafter, the file may be imported to EnViVer for analysis. EnViVer requires information about the network relating to the distribution of vehicles, vehicle fuel types, fleet age and average CO_2 emission distribution. The program requires the use of European legislation[2] to determine the emissions factors – these are legal requirements governing the release of pollutants by vehicles into the atmosphere. Figure 4.17 indicates the information required by EnViVer before the commencement of the analysis:

[2] Six different European Legislations were in place for acceptable emissions standards. Vehicle ages determine the applicable legislation – for example, the oldest vehicles would conform to European Legislation for 1992 (vehicles in the network from this date).

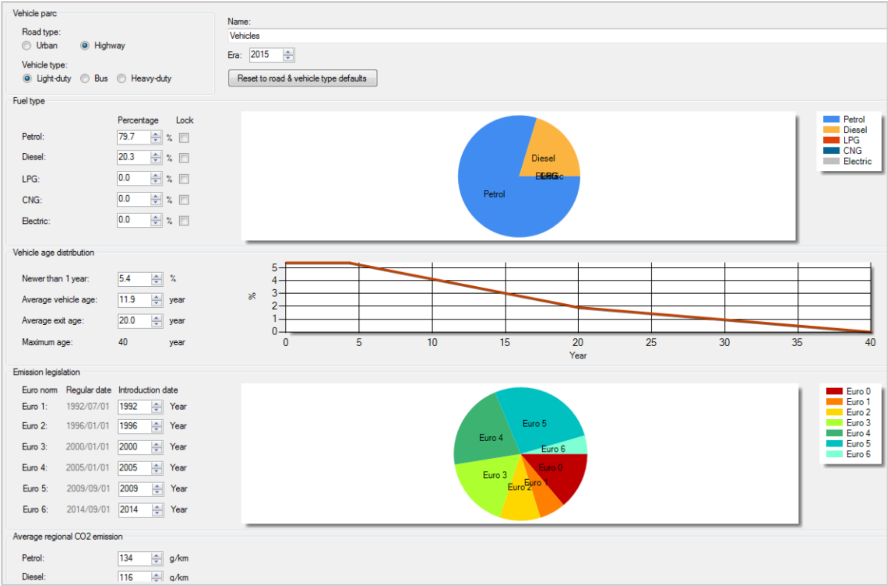


Figure 4.17: Format of Data Provision for Vehicles in Network (EnViVer)

The information required, as indicated in the figure above, may be described as follows:

- Vehicle parc: Used to allocate the vehicle type to a specific road environment.
- Fuel Type: Distinguishes the various fuel types with the percentage of vehicles in the network (Iol.co.za, 2014).
- Vehicle Age Distribution: The age of vehicles distributed on the road. Average out age is the scrappage age of vehicles. This information was obtained from various websites describing the vehicle age applicable to South Africa (Letshwiti, V., Stanway, R.A. & Mokonyama, M. 2003: pg. 5).
- Emission Legislation: Laws vehicle performance is expected to abide by depending on the vehicle age.
- Average regional CO_2 emission: The average emissions of vehicles in the network. This was determined using the most popular vehicles in South Africa (Naamsa.co.za, 2016).

Once the information is completed for each of the vehicle types in the simulation (Vehicle, HGV, Bus etc.) the analysis was initiated for the desired results. EnViVer then calculates the CO_2 emissions, particles emitted (PM10) and Nitrogen Oxide Particles (NO_X) released per vehicle (Discussed in Chapter 5 and Chapter 6). The area investigated may be adjusted for a single road or to the requirements of the output of a specific section of the area investigated.

REMARKS

Thus far, discussions concerning traffic signal control in the Vissim model, the various network objects and the additional software required to manipulate different driving behaviours have been provided. Figure 4.18 indicates the relationship between the software discussed above, the information required and the scenarios addressed with these items. Thereafter, the applications and scenarios modelled in this study will be discussed.

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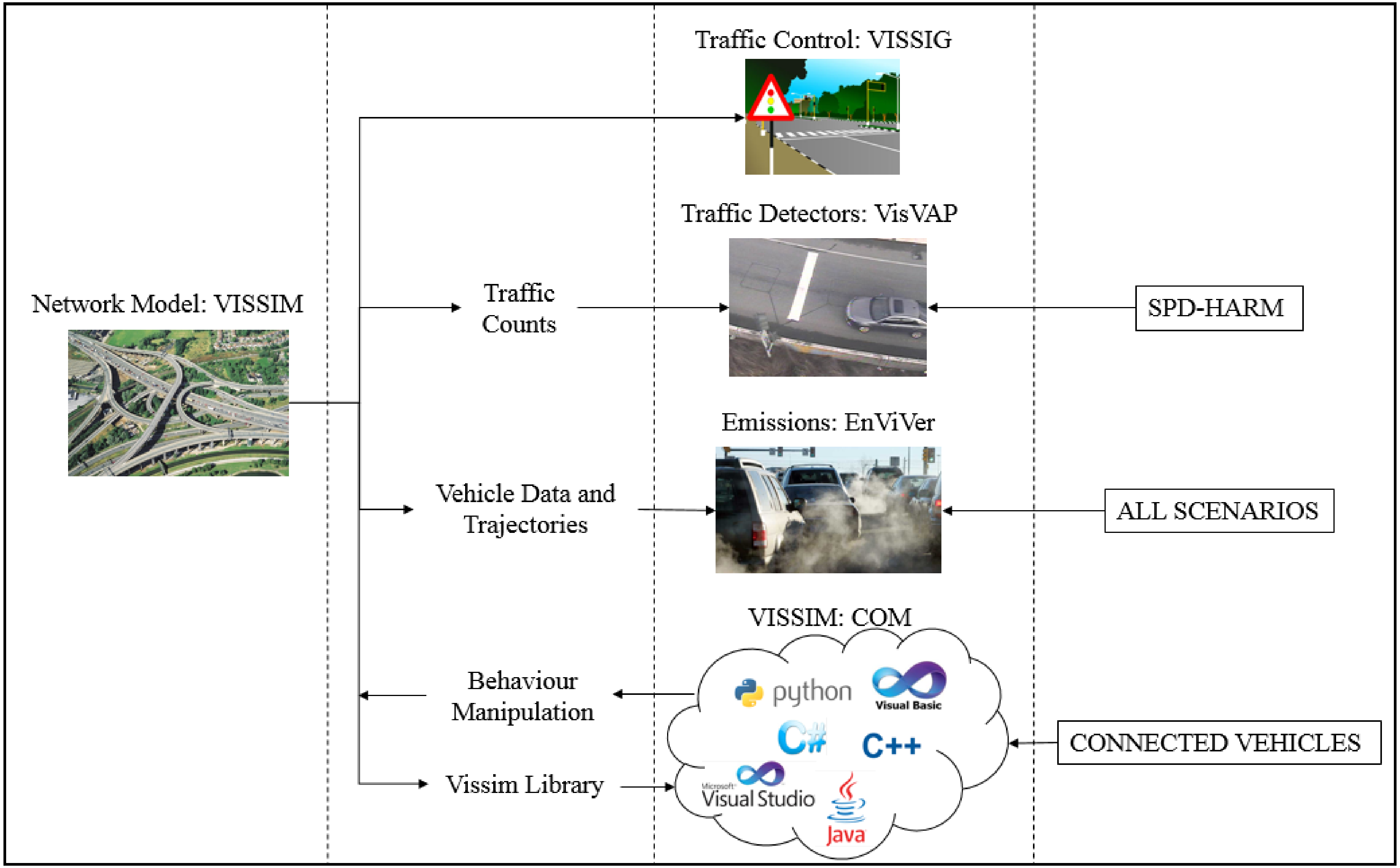

Figure 4.18: Software, Information and Scenario Relationships

4.4 MODELLING THE SCENARIOS

This section discusses the approach to building the various scenarios that were tested for this investigation. As previously mentioned, the following scenarios would be modelled:

- Base Condition (Descriptions up to this point are sufficient to initiate this scenario - no additional construction to the model was necessary)
- Accident
- Speed-Harmonisation
- Queue-Warning
- Connected Vehicles Approach #1
- Connected Vehicles Approach #2

These scenarios will be discussed below. The intention of this section is to allow the reader to be aware of the adjustments that were made to produce the desired reaction from the simulation models. In addition to discussing the applications, two approaches to modelling connected vehicles were incorporated to provide an impression of the probable effects that may be achieved with either approach.

4.4.1 ACCIDENT SCENARIO

A crash was modelled in this study to generate congestion within free-flow conditions – the purpose will be clear with consideration of the CV applications modelled (discussed in the following sections). The crash would allow for the consideration of congestion along a route compared to free-flow conditions.

This scenario was modelled using the Parking Lot Network Object in Vissim. Two parking lot allocations were modelled to convey the visual effect of a crash. An arbitrary location along the N1 was selected (Figure 4.19) – the parking lot is first placed at the desired location before the edit pop-up appears:

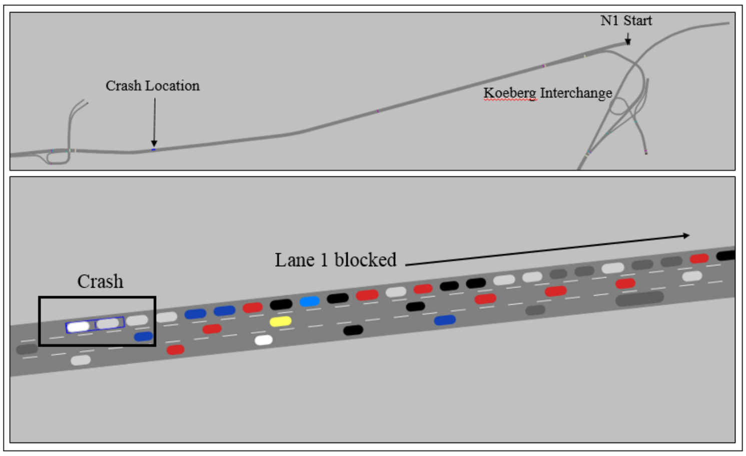

Figure 4.19: Location and Occurrence of Crash along N1 Route

Once the parking lot is placed, the following pop-up menu appears:

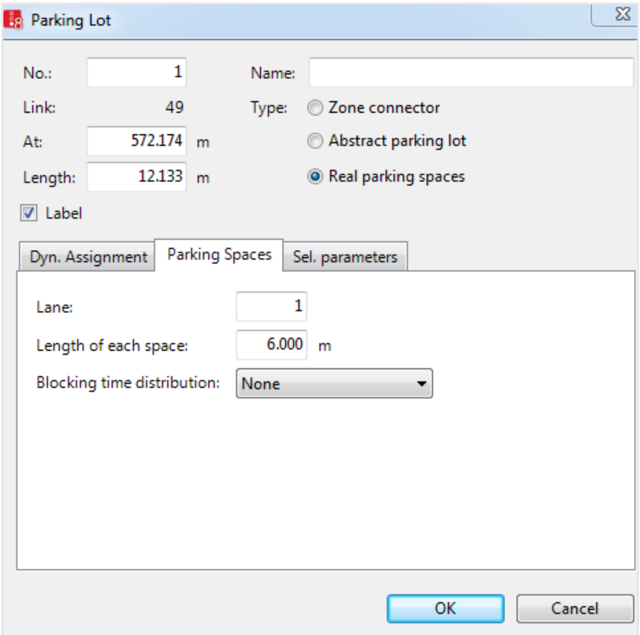

Figure 4.20: Modification to Parking Lot Properties

The edits to be made include checking the Real parking spaces option and defining the length of the parking spaces. The parking spaces were specified as six meters. Finally, the time in which the vehicles will occupy the parking spaces should be included. This was done by placing a Routing Decision before the parking lot and allocating a time at which the spaces would be filled:

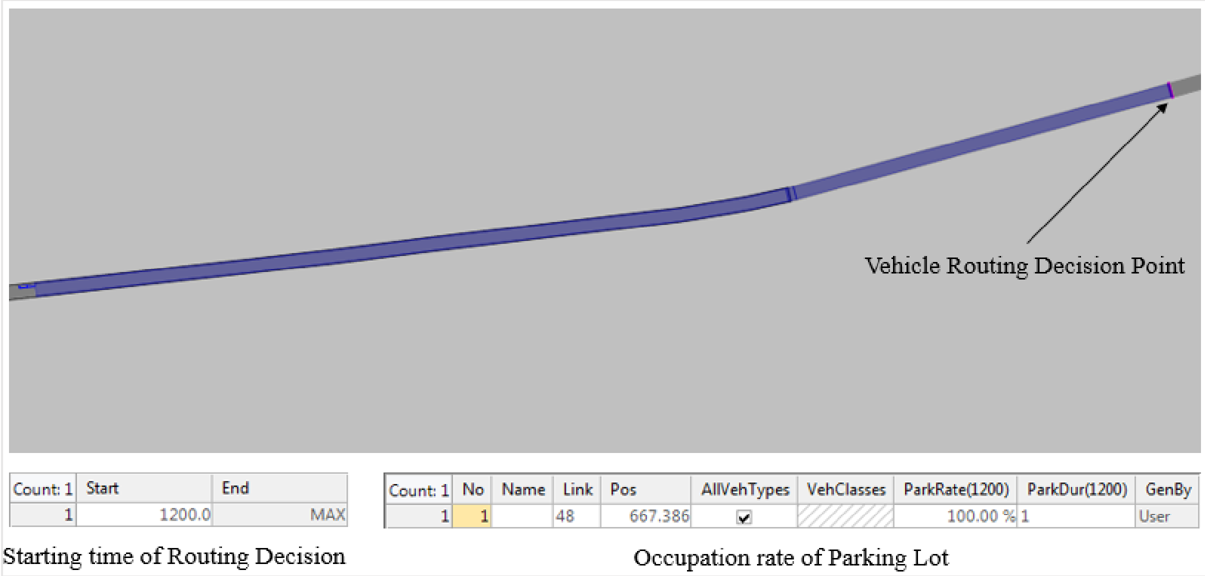

Figure 4.21: Routing Decision Location and Parameters

From the figure, it can be seen that the crash would take place after 1200 seconds (20 minutes) after the start of the simulation, and would be occupied for the duration of the simulation.

Thereafter, the simulation may be initiated to observe the effect of the accident on the flow of the traffic network (discussed in Chapter 5).

4.4.2 SPEED-HARMONISATION

Speed harmonisation is one of the applications that falls under the INFLO (Intelligent Network Flow Optimisation) category, a group of applications specifically aimed at enhancing traffic efficiency (Chapter 2). Briefly, Speed Harmonisation is an application that starts with a traffic flow analysis completed by the relevant traffic management agency, in which they have investigated the real-time traffic flow. Based on the calculations to determine the correct flow to be achieved, the speed along a certain road section can be adjusted. This application has been used in the United States but is implemented with the use of VMSs in which the speed changes depending on the time of day and traffic flow. In this case, the number of vehicles passing a certain point are counted with loop detectors installed under the road surface and, provided the number of vehicles passing over these detectors meet the criteria of a predefined capacity threshold, the travel speed for the traffic stream along that route will be adjusted (speeds are generally reduced with increasing capacity). This may relieve congestion somewhat, allowing vehicles to travel more smoothly and, with the prevention of traffic jams, may improve the throughput of vehicles and consequently reduce fuel consumption and GHG emissions. Figure 4.22 indicates the placement of the equipment for the Speed-Harmonisation scenario:

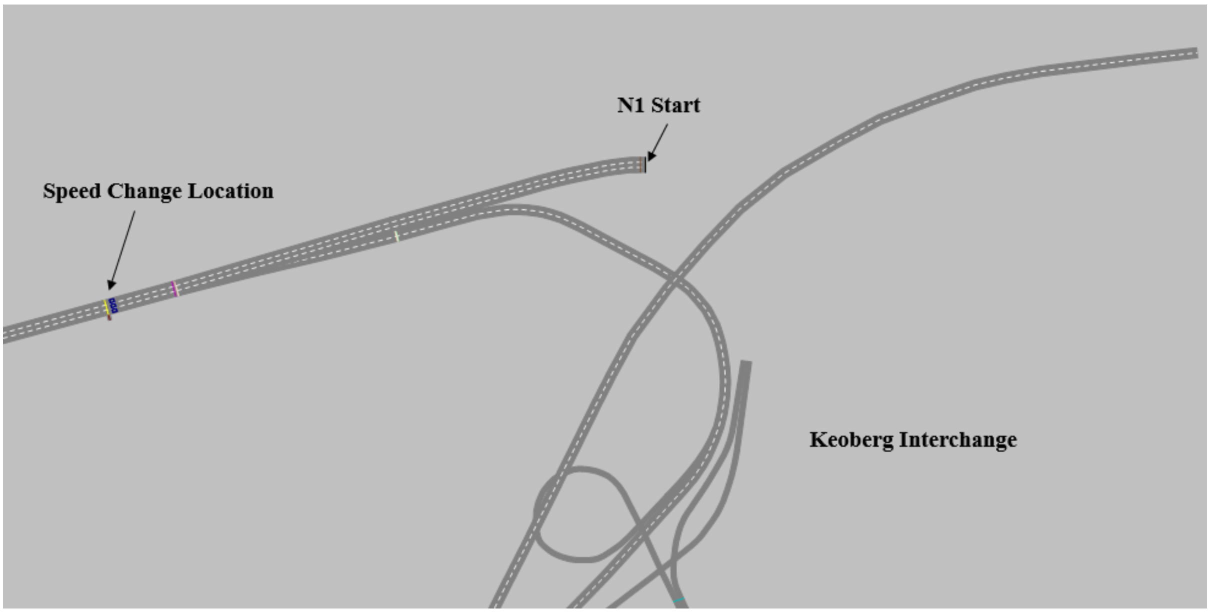

Figure 4.22: Location of Speed-Harmonisation implementation

During operation, Figure 4.22 shows the location of the desired speed change, along with the VMS-SP indicating the speed to be travelled, which was applicable to representing the use of Smartphones in vehicles. The VMS-SP once again was only used for illustrative purposes – the VMS-SP represents the smart phone that would provide the in-vehicle information to the users along the route.

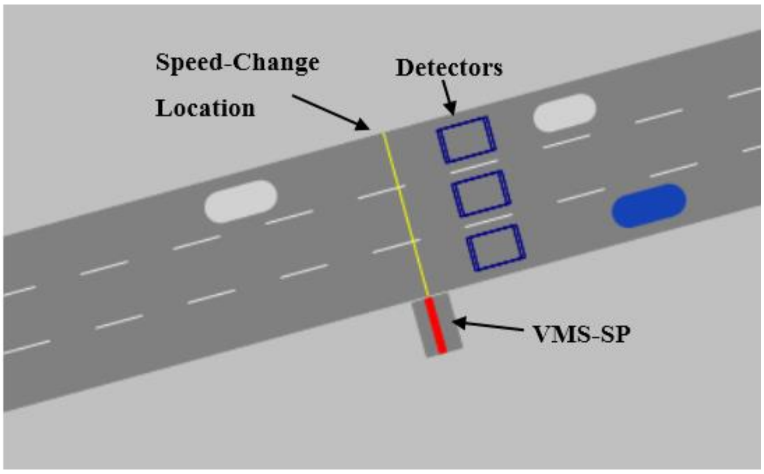

Figure 4.23: Speed Harmonisation along the N1 (Red indicating that capacity exceeds predefined number of veh/hr)

The detectors measure the real-time volume of the road as vehicles pass over. Once the parameters set out by the VisVAP model are met, the speed changes accordingly. The following figures show the important sections the VisVAP program for the detectors (Adapted from Vissim Example: *Active Traffic Management (ATM – Variable Speed Limit)*) (The full sequence can be found in Appendix D):

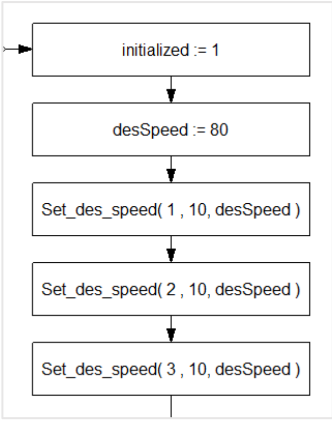

Figure 4.24: Label and Settings of Detectors

Figure 4.24 shows the setting of the initial travel speed along with the label for each detector along the route. This figure allocates the desired speed to a single detector in a single lane – the procedure is repeated for HGVs.

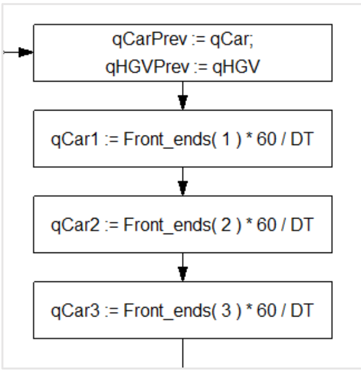

Figure 4.25: Set-up for Counting Vehicles

Figure 4.24 indicates that the front ends of each passing vehicle will be recorded for each simulation second. Setting the previous vehicle count to the current vehicle count (qCarPrev := qCar) ensures that the counting procedure continues as a new vehicle's front end passes over the detector.

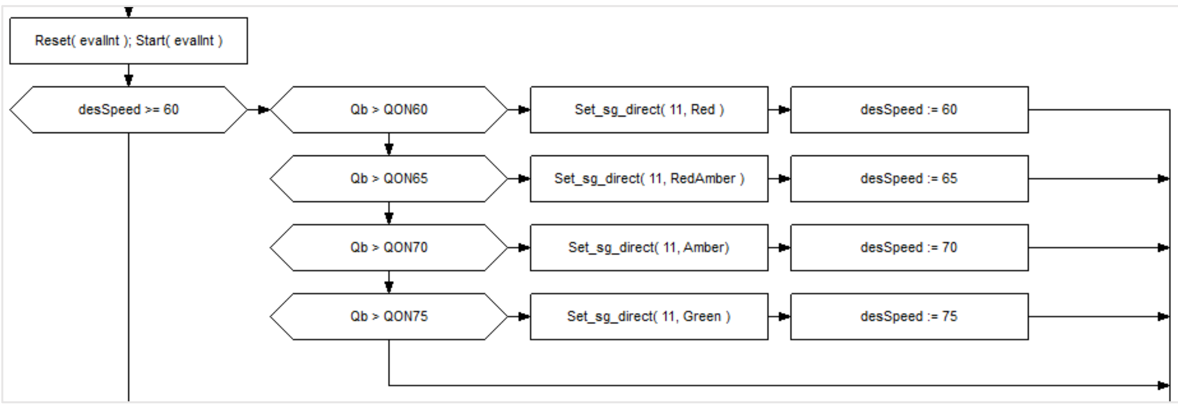

Figure 4.26: Speed Adjustments based on Capacity

Once the vehicles are counted in real time, the process in Figure 4.25 is initiated. The figure indicates the applicable speed allocation depending on the changing volume of vehicles passing the loop detectors (these volumes are predefined by the user – refer to Appendix D). Additionally, the speed change is allocated a specific colour to indicate the changing travel speed in the network (also see Table 4.11 below).

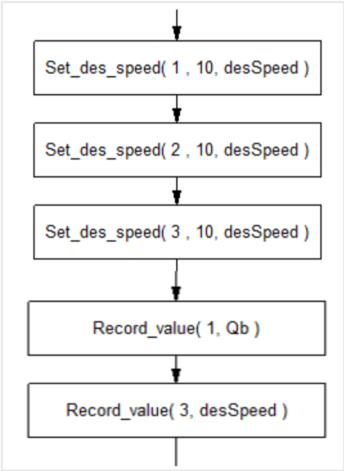

Figure 4.27: Changing the Travel Speed and Recording Network Output

Figure 4.27 indicates the setting of the speed change based on the information obtained during the network operation (real-time vehicle volumes for all lanes) in Figure 4.25. Additionally, the number of vehicles and current travel speed is recorded and may be viewed during the simulation run

The application operates in the following manner: In the first instance (when the simulation is initiated), the vehicles travelling along the route are less than the initial capacity limit (less than 3 800 veh/h from Table 4.11), and therefore the vehicles are allowed to travel at the maximum speed limit (at and below 90 km/h). However, once the conditions of the volume limits are met (once the vehicle capacity increases beyond 3 800 veh/h), the speed is adjusted, along with the lighting of the VMS to indicate the speed that is applicable at a specific time interval (from Off initially to Green/Amber/Red). The volume limits along with the desired speed are indicated in the table below (Table 4.11):

Table 4.11: Parameters for Signal Controller (Managing Traffic Flow)

Capacity (veh/h) (OFF)	**Speed (km/h)**	**VMS-SP Indicator**	**Capacity (veh/h) (ON)**	**Speed (km/h)**	**VMS-SP Indicator**
Capacity < 3800	90	Off	Capacity > 4000	80	Green
Capacity < 4800	80	Green	Capacity > 5000	70	Amber
Capacity < 5800	70	Amber	Capacity > 6000	60	Red

The table provides the following description: If the number of vehicles travelling along a certain route were less than 3 800 vehicles per hour for all lanes, the vehicles would be travelling along the route at 90 km/h and the VMS-SP would be off. Thereafter, the route would be subject to changing traffic volumes. When the flow capacity increased to 5 000 vehicles per hour, the VMS-SP would be switched on. In this case, the condition to check would be ON. The condition that would be met is that the capacity exceeded 4 000 vehicles per hour, but was less than 5 000 vehicles; the VMS-SP would therefore be switched on to Green, and the vehicles would be expected to reduce the travelling speed to 80 km/h.

Chapter 5, *Section 5.2* discusses the results obtained from implementing Speed-Harmonisation along the N1.

4.4.3 QUEUE-WARNING

Queue Warning is an application that exists within the INFLO framework, indicating that the application is applicable for the enhancement of efficiency. In this case, the CVs located in a queue would warn the other vehicles through V2V communication in the network that a queue should be expected and that the vehicles following should be aware of the road conditions and may suggest either adjusting travelling speed accordingly or following an alternative route. This communication has limited reach with vehicles, and would be enhanced with the V2I communication which would consist of communications devices along the road that would extend the message to vehicles further upstream of the route. The would allow vehicles to save on travel time by using alternative routes (if warned with suitable allowance for time), may reduce congestion and the occurrence of accidents, maximising the flow of the traffic network and increasing the efficiency of the network. Additionally, with the reduction of stop-start traffic, vehicles can improve fuel consumption and reduce carbon emissions.

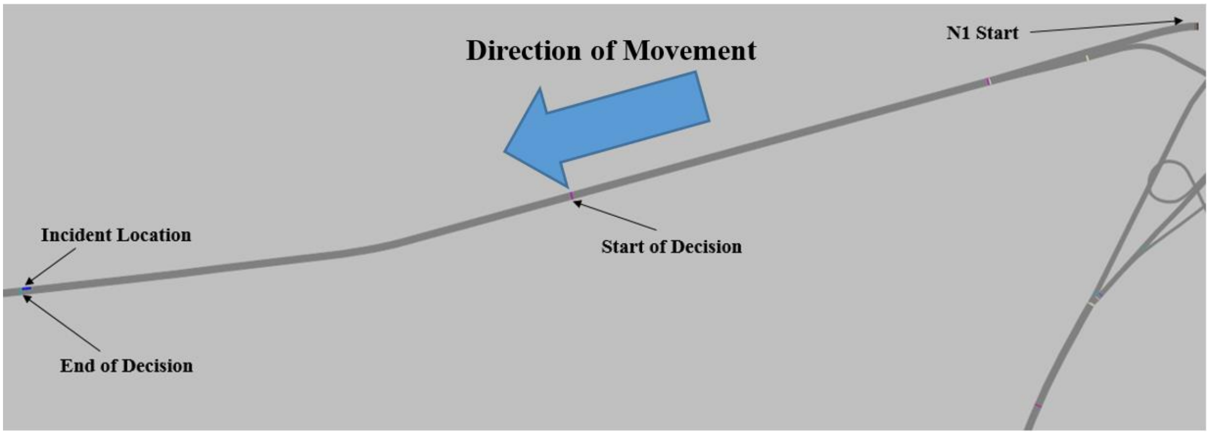

Figure 4.28: Placement of Queue-Warning scenario decisions

Figure 4.28 indicates the set-up of the Queue-Warning scenario along the route of the incident. In addition to the placement of decisions, a *Partial Route* was created. A partial route is constructed by placing an additional section of roadway alongside the incident (super-imposed with the existing roadway) to ensure that vehicles utilise only the remaining open lanes – this is to prevent queueing behind the vehicles involved in the crash.

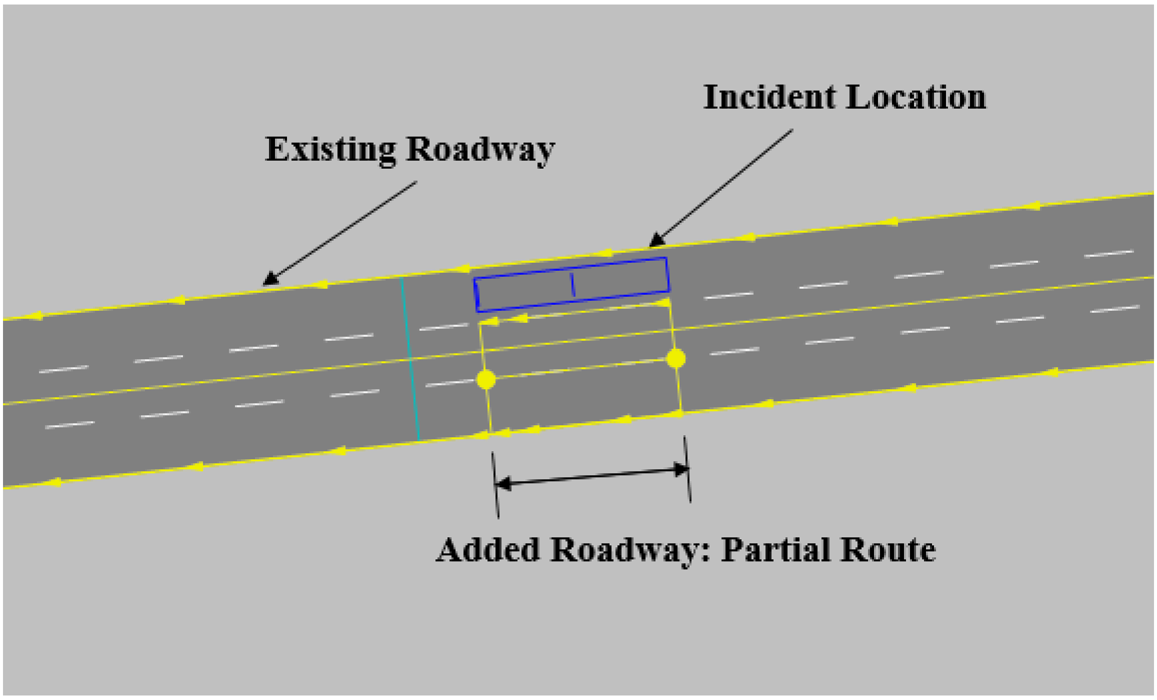

Figure 4.29: Placement of Partial Route

Figure 4.29 indicates the placement of the partial route. A partial routing decision is executed once the incident occurs, that is, at the 1 200 second (20 minute) mark during the simulation (refer to Accident scenario, *Section 4.4.1*).

Before the occurrence of the incident, the vehicles are free to use the three lanes. At the 20-minute time interval however, two vehicles were involved in an incident – this scenario was used to model the Queue Warning application. Once the incident occurred, the information of the event was detected and sent out to the relevant parties. Once the traffic agencies identified the issue, the information could be passed to the vehicles within the traffic network or those vehicles intending to take the route along which the incident occurred. This would relieve congestion along the road immediately after the occurrence of the incident and would allow to Emergency Response Units to gain access to the route within a reduced time interval. Once the information was sent out to the vehicles, they would be provided with an alternative route that may indicate a more efficient route on which to travel.

The results obtained from this application are discussed in Chapter 5, *Section 5.2*.

4.4.4 CONNECTED VEHICLE APPROACH #1: TETHERED CONNECTIVITY

Tethered connectivity incorporates the use of Smartphones or On-Board Units (OBUs). With the improvement of technology, the ability to receive information faster may allow for extensive enhancements in application usage and may have a great impact on the traffic network if incorporated. Smartphones (or cell phones) are particularly of interest as they are able to provide the users with the functionality desired by the traffic agencies, the rate of penetration may be sufficient and further control over their use in vehicles may be established. The applications modelled in this investigation may be applicable to smart phones and could provide an improvement to the traffic network that allows for a transition into a more sustainable and effective manner of managing traffic.

For the simulation of the Smartphones, the model was adjusted to allow for a difference in observation of Tethered connectivity (versus Integrated/Embedded CVs). For Speed-Harmonisation it may be assumed that, once the incident occurs, the capacity along the route would naturally increase per time interval as vehicles upstream would slow down and more vehicles would be located on the detectors per second, resulting in the change in speed once the incident occurs – this was modelled with the use of the VMS-SP to allow the vehicles to reduce their speed (refer to *Section 4.4.1*).

Queue-Warning was modelled by indicating that decision to make use of only the two lanes along the road while the message was additionally sent to other vehicles in the network proceeding towards the incident. To account for the difference in latency between cellular communication and DSRC communication, the message was modelled to only be received 5 minutes and 10 minutes after the occurrence of the incident for other vehicles in the network (refer to *Section 4.4.2*).

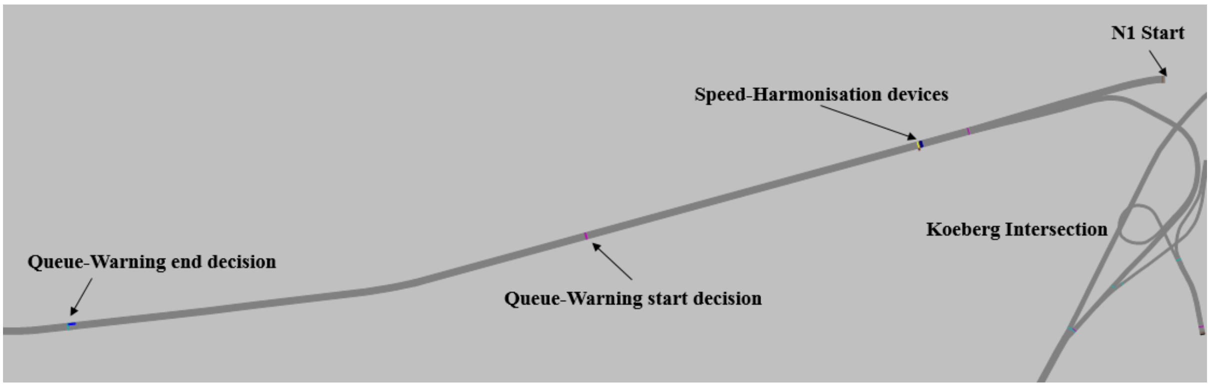

Figure 4.30: Tethered Connected Vehicle Operation Scenario

Figure 4.30 indicates the set-up for the Tethered Connected Vehicle approach – the set-up may be more easily understood as a combination of the previously discussed CV applications (*Section 4.4.1* and *Section 4.4.2*)

4.4.5 CONNECTED VEHICLE APPROACH #2: INTEGRATED/EMBEDDED CONNECTED VEHCILES (V2V AND V2I COMMUNICATION)

Connected Vehicles were the focus of this investigation to determine the impact that these vehicles may provide to the traffic network. In this case, the vehicles were modelled using the script files referred to in *Section 4.3.2*. It is understood that CVs would receive the message of a queue immediately given the short latency and the fact that the vehicles communicate with each other and the environment immediately (with minimal assistance from traffic agencies). Vehicles were therefore re-routed immediately to take alternative routes to avoid the accident and thereby increase their average travel time.

The Speed-Harmonisation was completed with the CV involved in the accident, warning vehicles upstream of the incident. The limitation however, is that a CV was required to be involved in the incident to be able to send the message; this would conform to the requirements that a vehicle would be in a queue when sending a warning message. Therefore, a relatively high percentage of CVs were to be used in the simulation to indicate the effect. This meant that the starting percentage of vehicles in the network was required to be 40% CVs. The code, which was completed with the coding language Python, was used to change the speed of the vehicles upstream once the incident occurred (refer to Appendix D). For this simulation, the speed was changed to 80 km/h once the incident occurred, the vehicles were forced to use the two available lanes to provide space for incidence response and the vehicles in the network proceeding towards the accident were provided with an alternative route. By observation, using the two extra lanes indicates that the vehicles were aware of the incident and were able to execute evasive action with sufficient time.

To comply with the approximate communication distance of 500 meters for DSRC devices within vehicles, the Distance distribution (refer to Table 4.3) in Vissim was set to 500 meters:

Table 4.12: Distance between CV in Accident and CVs in Network

Number	Name	Lower Bound	Upper Bound
1	C2X Messages	0	500

Figure 4.31 illustrates this range and the condition under which the vehicle would distribute the necessary BSM (refer to Chapter 2, *Section 2.2.5.4*):

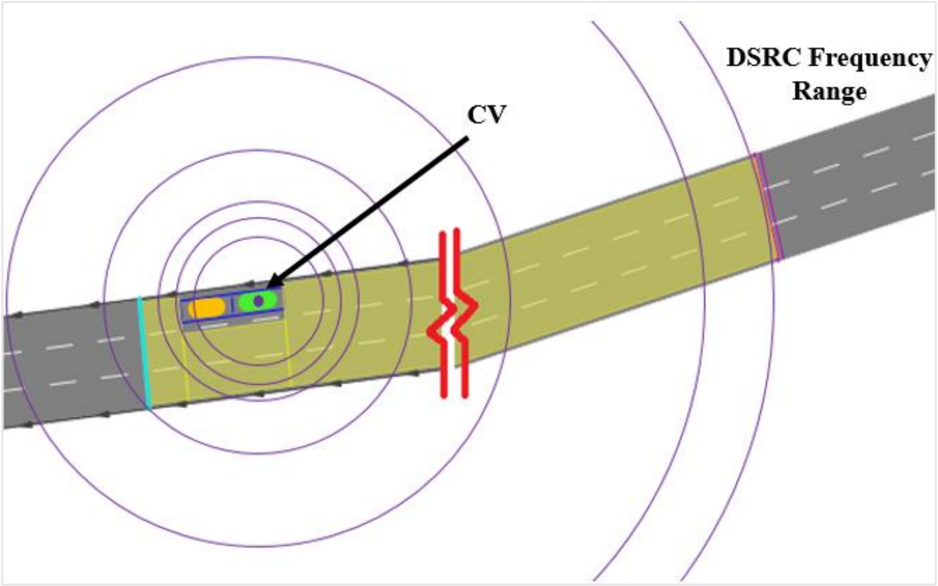

Figure 4.31: CV Sending BSM during Incident

The concentric circles in the figure illustrate the range of the DSRC device – vehicles within the range will receive the BSM message warning of the incident details.

In this case, script-files provided by Vissim were used to allow the vehicles to communicate with each other for the simulation of V2V behaviour. The requirement was to allow the vehicles to send a message and to allow the user to observe the message being sent. This was completed according to the following code:

```
if (veh_type_cur == Vehicle_Type_C2X_no_message or
veh_type_cur == Vehicle_Type_C2X_HasCurrentMessage) and pos_cur < Pos_Veh_SM and Pos_Veh_SM > pos_C2X_cur:

    if des_speed_cur == speed_incident:

        Veh_attributes_Rec_Message[cnt_Veh_Rec_Message]
        = tuple([int(Vehicle_Type_C2X_HasCurrentMessage), 1, Pos_Veh_SM, 'Breakdown Vehicle ahead!', speed_incident, des_speed_old_cur])

    else:
        Veh_attributes_Rec_Message[cnt_Veh_Rec_Message]
        = tuple([int(Vehicle_Type_C2X_HasCurrentMessage), 1, Pos_Veh_SM, 'Breakdown Vehicle ahead!', speed_incident, des_speed_cur])

else:
    Veh_attributes_Rec_Message[cnt_Veh_Rec_Message] = atts_current[1:]
```

Figure 4.32: Changing Speed of Connected Vehicles Based on Location

Table 4.13 defines the items seen in Figure 4.34, thereafter an explanation of the code is given.

Table 4.13: Description of key items In Script File for CV Model

Python Code	Meaning
veh_type_cur	Vehicle type of a single vehicle instance
Vehicle_Type_C2X_no_message	Parameter: CV that has not received message
Vehicle_Type_C2X_HasCurrentMessage	Parameter: CV that has received message
pos_cur	Vehicle Coordinates
Pos_Veh_SM	Position of the vehicle sending the message relative to the link on which it is located during incident

pos_C2X_cur	Origin of the message (location)
des_speed_cur	Speed the vehicle is travelling at, which may be its previous speed if the vehicle is not a CV (see speed_old_cur) or the new travel speed if the vehicle is a CV (speed_incident).
speed_incident	Applicable speed once incident occurs
Veh_attributes_Rec_Message[]	
cnt_Veh_Rec_Message	
1	Used if vehicle has message, otherwise use 0.
'Breakdown Vehicle ahead!'	Details of message sent
speed_old_cur	Speed a vehicle was travelling at before the message was sent

The use of the information contained in Figure 4.31 (as well as Table 4.13) is described below:

- Green Bounding Box: Checks if the vehicle involved the crash is a Connected Vehicle that has received the BSM message
    - (if **veh_type_cur == Vehicle_Type_C2X_no_message)** – this is known as a statement; this statement checks if a vehicle in the simulation of a specific type (**veh_type_cur**) passing the Distribution distance (Table 4.12) is a CV that has received the message.
    - (**and pos_cur < Pos_Veh_SM and Pos_Veh_SM > pos_C2X_cur**) This statement must be implemented with the statement above. This checks the position of a CV in the network versus the position of the CV sending the message (**pos_cur < Pos_Veh_SM**) (it will only be valid if the CV receiving the message is upstream of the incident) and checks the position of a vehicle that has received a message (**pos_C2X_cur**) to determine if the message sent may conflict with an existing message.
- Blue Bounding Box: The if statement (**if des_speed_cur == speed_incident:**) checks if the adjusted speed is applicable based on the status of the incident i.e. if the incident is active, the speed applicable to an incident will then be active.
    - The first section (within the if statement – **Veh_attributes_Rec_Message [cnt_Veh_Rec_Message]**) allows the speed travelled to remain the same, since the speed at which the vehicle would be travelling would be the incident speed (**speed_incident** is then considered allocated, and **des_speed_old_cur** is used, meaning the vehicle will remain travelling at the applicable speed)
    - In the else statement, the desired speed is changed to ensure that the CVs travel at the incident speed (**speed_incident** is then allocated, and **des_speed_cur** is applied).
- The final else statement within the Green Bounding Box means that the vehicle is not connected and therefore no changes to the vehicle speed will be made.

Appendix D contains the script-file displaying the procedure followed to provide the desired operation

Once the incident occurred, the message would be sent to the vehicles in the network. As a visual indication that the vehicles were indeed receiving the message and were adjusting their speed according to the speed required for the simulation, the CVs were modelled as Yellow vehicles, while vehicles without CV capability were modelled as white. Once the incident occurred and the CVs were located within the radius of the communications signal (see Table 4.12), the vehicles colour would change from Yellow to Green, indicating that the message had been received and that the vehicle was complying with the message sent by the CV involved in the incident. When the vehicles pass the incident, the colour changes from Green to Yellow, indicating that the vehicle completed the activity of complying with Queue-Warning and Speed-Harmonisation, the vehicle was thereafter able to travel under normal conditions. Figure 4.33 illustrates the change in status of the CVs.

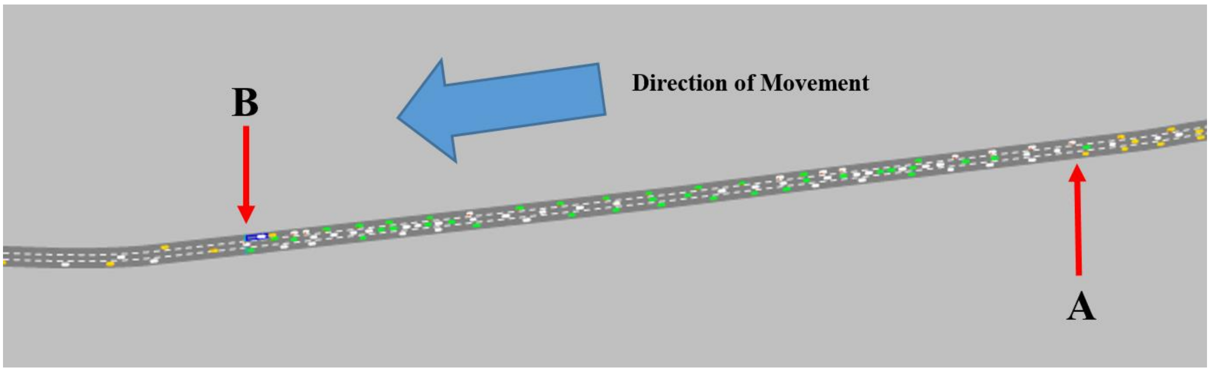

Figure 4.33: V2V Communication - CVs within 500m Range received Message (Green)

The figure indicates that, at point A, the message about the occurrence of the incident and the location was received, the vehicles were then required to initiate the Queue-Warning and Speed-Harmonisation applications. Approximately 500 meters upstream, the CVs change from Yellow to Green (at point A), indicating that the message had been received. The vehicles then adjust their speed and proceed with evasive action. Once the incident is passed (at point B), the CVs then change from Green to Yellow to travel under normal conditions downstream.

4.4.6 ADDITIONAL APPLICATIONS TO CONSIDER SPECIFICALLY FOR ENHANCING EFFICIENCY

The applications explored with this investigation were considered in detail and provided a basis for a comparison between the technologies currently available and the technology that may be implemented within a pre-determined period. There were however, additional applications that may be tested to determine the extent to which traffic efficiency may be achieved. These applications are briefly discussed below. Additional information may be found on the Connected Vehicle Reference Implementation Architecture (CVRIA) website (Iteris.com, 2016).

4.4.6.1 COOPERATIVE ADAPTIVE CRUISE CONTROL (CACC)

This is one of the most investigated applications of Connected Vehicles given the immediate benefits that may be achieved. This application (more applicable to freeway) may improve traffic flow efficiency by an approximated 17% (Strategic Platform for Intelligent Traffic Systems, 2014). This improvement fluctuated depending on the study and the conditions imposed, but has remained consistently positive in achievement. The application involves the use of Connected Vehicles, in which CVs communicate with each other to form platoons, increasing throughput, decreasing drag, improving vehicle efficiency and efficiency of the traffic network entirely, depending on the rate of penetration.

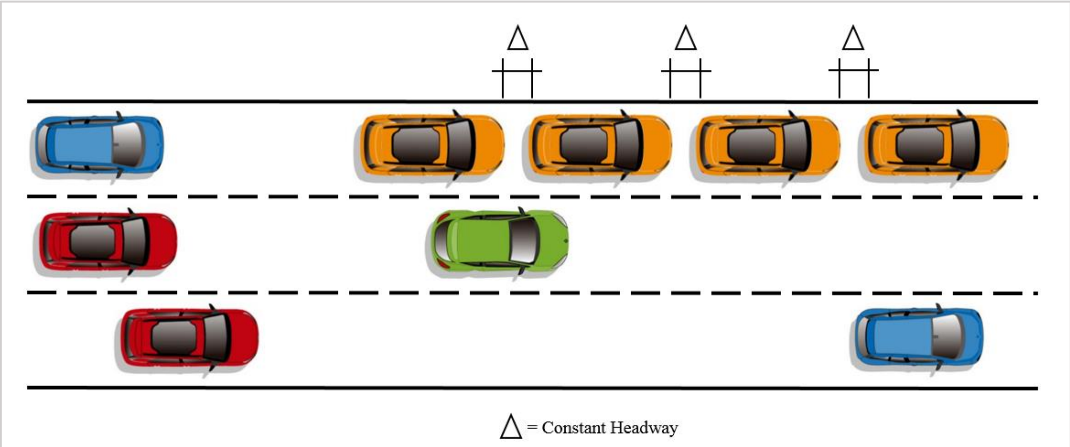

Figure 4.34: Platoon of Connected Vehicles (Orange Vehicles) with Constant Headway

Figure 4.34 indicates the application of CACC compared to normal traffic flow. According to (Kumar, A. 2008), the information is transferred between CACC vehicles at a rate of 20 milliseconds, meaning that the information is relayed fast enough for quicker responses from the vehicles, allowing for reduced headways and a higher throughput of these vehicles.

The advantage of this application may be clear, however, the number of vehicles necessary to incorporate this technology is significant - above 60% (Van Arem, B., Van Driel, C.J.G & Visser, R. 2006), as it would only be advantageous if a great number of these vehicles are within proximity to each other. Additionally, if the vehicle was not manufactured with the technology, it may not be cost effective to retro-fit the entire system to a standard vehicle.

This application may be excellent for implementation provided the rate of penetration of CVs reached a suitable level. Alternatively, if the technology becomes more affordable or highly applicable with Smartphones (if possible), a comparison between the alternatives should be investigated (i.e. Integrated/Embedded and Tethered CVs).

4.4.6.2 EMERGENCY VEHICLE PRE-EMPTION (EVP)

EVP is an application that grants priority to Emergency Response vehicles. Facilitating emergency vehicles and traffic signals with the equipment necessary to provide movement through intersections would reduce the time for these vehicles to gain access to incident locations. In cases of congestion, it may be more difficult for emergency vehicles to pass intersections and subjects the emergency vehicles to danger as the traffic priority may be granted to the opposite direction. Chapter 6 discusses the cost of equipment for both vehicles and infrastructure; it would therefore only be necessary to model the behaviour of the emergency vehicles in congested traffic and with the priority application. This application provides efficiency to emergency vehicles. Reducing the total time that accidents/incidents occupy the road space would ensure that traffic flow resumed operation under normal conditions.

4.4.6.3 FREIGHT SIGNAL PRIORITY (FSP)

FSP may ensure that HGVs and commercial vehicles pass through signalised intersections, reducing delays, stops and reducing travel time. The reduction in travel time may not only be applicable to freight vehicles – heavy vehicles are subject to greater start-up times, reducing the time that light vehicles have to pass through an intersection; with more heavy vehicles travelling in a specific area, the overall travel time would increase for all vehicles within that area. Allowing heavy vehicles to pass through intersections may provide an increase in efficiency for all vehicles.

4.4.6.4 TRANSIT SIGNAL PRIORITY

Transit Signal Priority communicates with the driver once a request for signal priority has been sent – in this case, the vehicle is informed whether or not the request was granted. The provision of this information may allow transit operators to increase operating performance. This enhanced performance of transit vehicles may positively affect the efficiency of all traffic modes.

4.4.6.5 INTELLIGENT TRAFFIC SIGNAL PRIORITY (I-SIG)

I-SIG makes use of vehicle location and movement information from connected vehicles and infrastructure measurements to gain information from non-equipped vehicles to determine the most appropriate operation of the traffic signals. The application allows for assessment of the traffic network to provide enhancements in the operation of traffic movement, allowing platoons to move through intersections and ensuring priority to directions with greater demand. This application serves as the over-arching system for the previously mentioned signal priority application, enhancing the movement of light vehicles, freight (FSP), emergency (EVP) and transit vehicles.

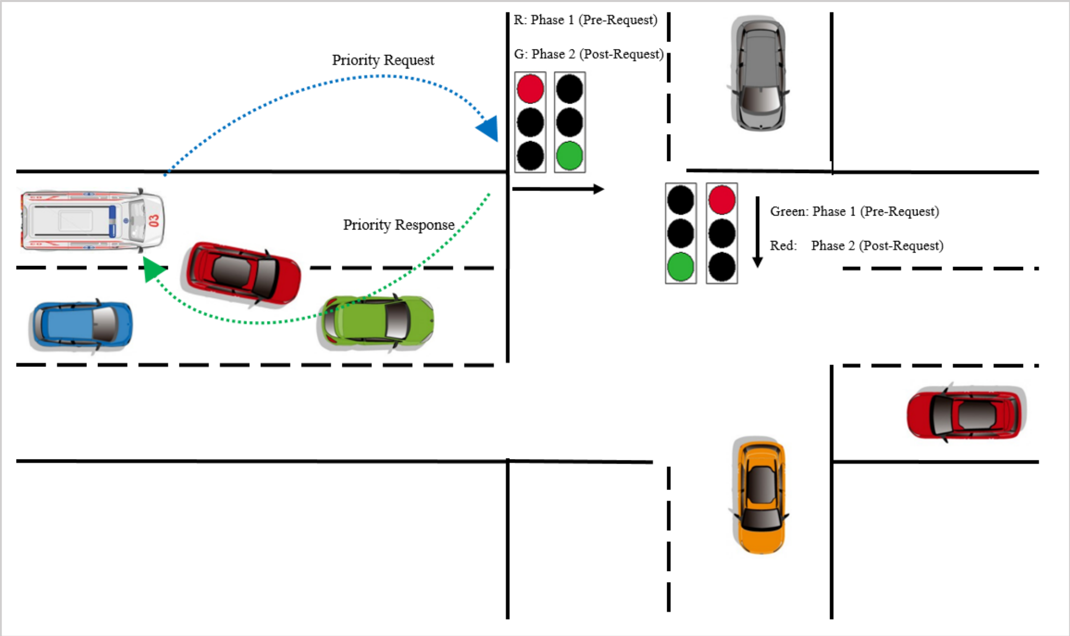

Figure 4.35: Emergency Vehicle Pre-emption (EVP), Subset of Intelligent Traffic Signal Priority (ISIG)

Figure 4.35 demonstrates the use of the application. The benefits of this application may be clear to identify in terms of efficiency and safety.

4.5 CONCLUSION

This section discussed the software, procedures and applications that were used in the investigation of Connected Vehicle technology, giving premise to the results achieved in the following chapter. In this chapter, explanations discussing the software, vehicle behaviour, types of simulations, information required and the processing of the information was provided. Furthermore, the sources of the data were provided to ensure that the information was correct and as close to reality as possible – Appendix D may be consulted for confirmation. Information regarding the procedures for execution of the applications were also provided, allowing for duplication as well as avenues that may not have been explored. This section served as the basis for the model and the conditions of the models. The following chapter provides the results of the scenarios previously discussed

CHAPTER 5 : RESULTS

The information presented in this section follows from the description in the previous chapter and will present the results of the models and simulations by considering the base condition, the Connected Vehicle applications and thereafter a comparison between the alternative choices with regards to in-vehicle equipment. The scenarios considered the effect on traffic flow efficiency of two Connected Vehicle applications, namely Speed-Harmonisation and Queue-Warning. The scenarios modelled for this investigation were:

- Base Condition
- Accident Scenario
- Queue-Warning Application
- Speed-Harmonisation Application
- Cellular-equipped Connected Vehicles
- DSRC-equipped Connected Vehicles

Chapter 4 discussed the set-u for each of the scenarios modelled, the results obtained from the simulations are presented and discussed in this chapter. The results obtained from the simulations was used to determine the changes in travel time, fuel consumption and carbon emissions in comparison to the Base and Accident scenarios. These measurements may be quantified to determine the extent of the various scenarios tested and will be discussed in the sections that follow.

5.1 INTRODUCTION

To determine the effect of efficiency within the network, the travel times, emissions and fuel consumption was considered to illustrate the difference in the scenarios modelled. As previously mentioned, the Connected Vehicle applications investigated were Speed-Harmonization and Queue-Warning. In consideration of the nature of these applications (notification applications), a comparison may be considered between Cellular and DSRC-enabled Connected Vehicles, since either alternative requires a visual display (On-Board Unit) to provide the user with traffic information.

In this chapter, focus will be given to the design area and the various locations along the three routes utilized to conduct the investigations. The design area and routes traversed is therefore provided below for convenience:

Figure 5.1: Design Area and Routes used in Investigation

In the figure, the Freeways consist of the N1 and M5 (Route 1) and N2 (Route 2), and the arterial included consists of the M57 and M176 (Route 3). A discussion regarding the selection of the area, routes and set-up of the model constructed in Vissim can be found in Chapter 4.

Two approaches were taken in modelling the traffic flow within the design area. The first involved the input of vehicles to allow for free-flow conditions. The input for the free-flow traffic was obtained from AADT traffic flow data obtained from Sanral along the Freeway routes (N1, N2 and M5) while the arterial (M57 and M176) used traffic demand data obtained from the City of Cape Town (CoCT) at the signalized intersections along Route 3. The traffic input values were then adjusted based on observation.

These input values were adjusted until a suitable free-flow of traffic was observed. The traffic inputs used may be found in Appendix D.

The second approach modelled congestion by using a daily traffic flow plan beginning at 05:00 AM and ending at 21:00 PM. The data used for the traffic input flow was obtained from Sanral, but used data obtained from the Vehicle Detection Systems (VDSs) which provided daily traffic flow in 10 minute intervals for the month of July (the locations of these VDS devices are shown in Chapter 4, p. 4.22). This data is provided along the main routes of the freeway and not along the off-ramps. The off-ramp data was obtained by counting the number of vehicles in 15-minute intervals using CCTV cameras positioned at the off and on-ramps to the freeways modelled in this study (the locations of these CCTV cameras are shown in Chapter 4, p. 4.23). The arterial data was once again used from the signalized intersection data obtained from CoCT. The input data from these sources were then used in Vissim to model traffic flow for an entire day. This input data may be found in Appendix E.

In the sections that follow, the following layout for the plotting of Travel Time data versus Distance will be observed:

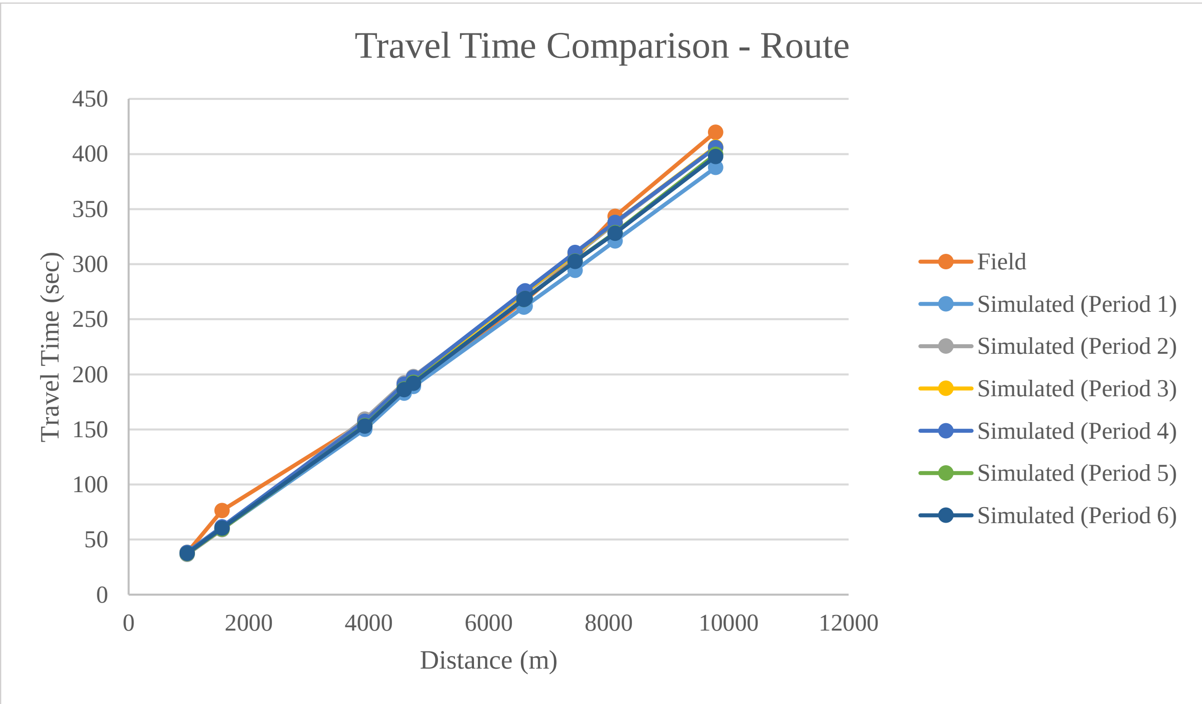

Figure 5.2: Example of Layout for Travel Time Plot

The heading in each figure (Top) indicates that the comparison is between the travel times obtained in the simulated scenarios and the route to which the comparison is relevant. In the plot area, it can be seen that the lines plot are separated with dashed lines. These dashed lines indicate the positions along the route in the simulated models at which travel time collection markers were placed. The placement of these markers were random along each of the paths. Figure 5.2 indicates the travel time plot for the M5 and N1 (Route 1). These points are shown in Figure 5.3 along Route 1:

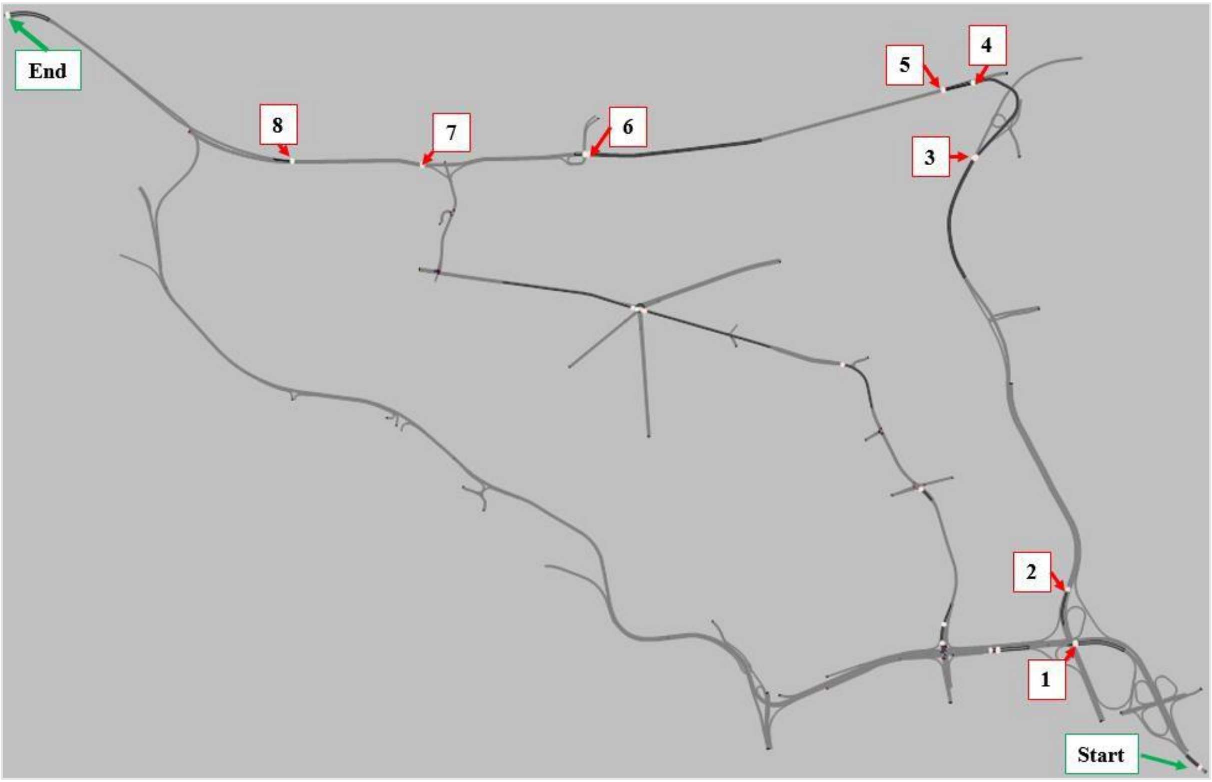

Figure 5.3: Locations of Time Collection Markers along Route 1

The travel times along Route 2 and Route 3 were collected similarly.

The legend (Right) in Figure 5.2 indicates three distinct sources for the travel times. The first field in the list is the travel time along the route obtained from the TomTom database (refer to Appendix E). The distances along the routes of the TomTom travel time data were plot against the distances along the relevant routes (in this example, along the M5 and N1). The field thereafter was the travel time obtained from Google Traffic. This was obtained by selecting a starting point and an end point correlating to the travel time collection marker locations (i.e. the time from the *Start* point to point *1* in Figure 5.3 would provide a travel time). The cumulative times were plot against the travel times obtained in Vissim for all of the scenarios modelled. The remaining fields describe the travel times determined in the simulated scenarios.

In the legend, it can be seen that the Vissim travel time results were plot in periods (Simulated (Period 1), Simulated (Period 2), etc.). These periods, divided into 10 minute intervals, separate the fluctuation in volume that was introduced to determine the behaviour of the simulated vehicles with fluctuating traffic volumes. The travel time plot for these periods therefore indicate the variation in travel time based on the changing vehicle volume in the network. The following sections describe the behaviour of the scenarios modelled along the routes indicated in Figure 5.1, within the design area indicated in Figure 5.2, with the format indicated in Figure 5.3.

5.2 SUITABILITY OF BASE MODEL

The following figures illustrate the travel time results of the Base Condition scenario compared to the travel time obtained from TomTom and Google Traffic along the three routes modelled in the design area. These routes were the N1, M5, N2, M57 and M176.

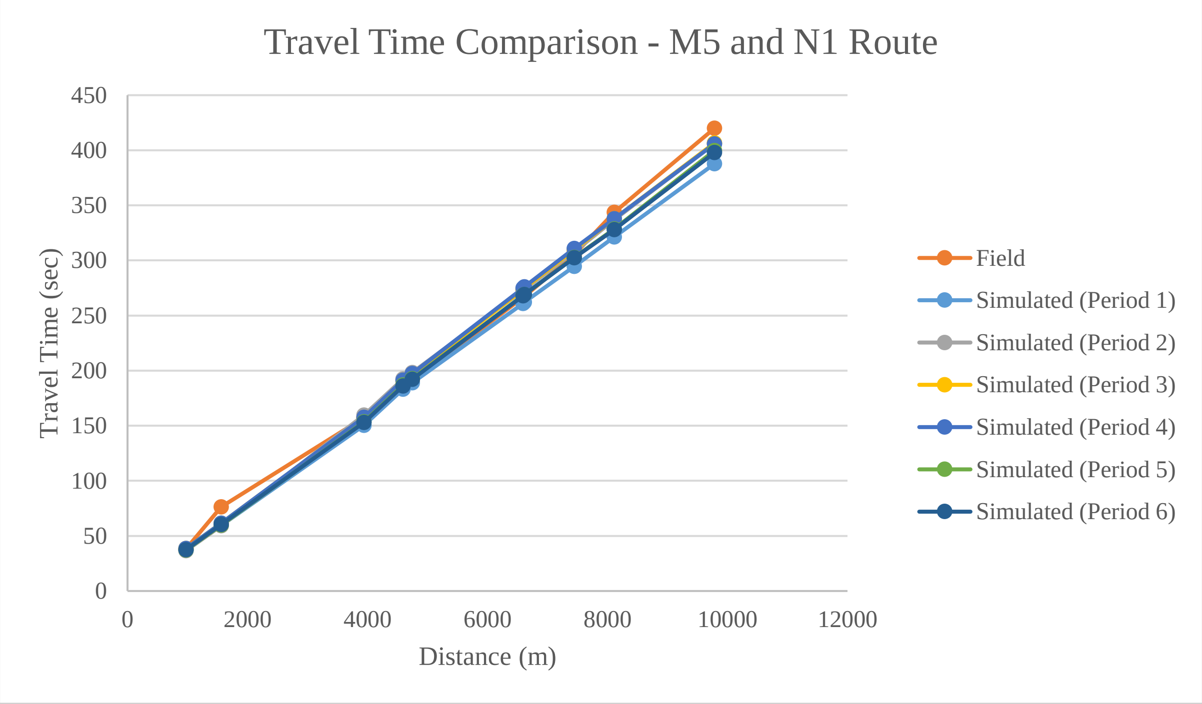

Figure 5.4: Travel Time of Base Model along M5 and N1 Compared to Google Maps Average Travel Time

From Figure 5.4, it can be seen that the Base Condition along the M5 and N1 performs similarly to the average travel time available from Google Maps – the Base Model was therefore accepted as the results produced confirmed the required output. Figure 5.5 provides a comparison between the simulated Base Condition and the average travel time indicated by Google Maps for the N2:

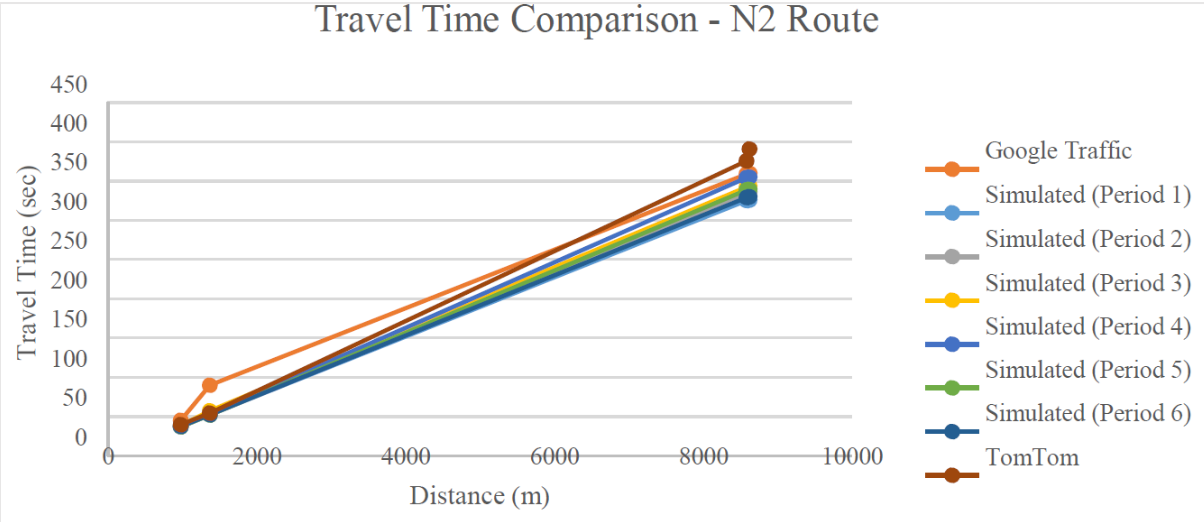

Figure 5.5: Travel Time of Base Model along N2 Compared to Google Maps Average Travel Time

The travel times along the N2 for the Base Condition compare favourably to the travel times obtained from the TomTom output and Google Traffic predictions. It can be seen that the *Field* plot displays an increased travel time at the 1 400m mark – in the network, this point is located at an on-ramp from the M5 (Kromboom Parkway Road) and an off-ramp to the M57 (Liesbeek Road):

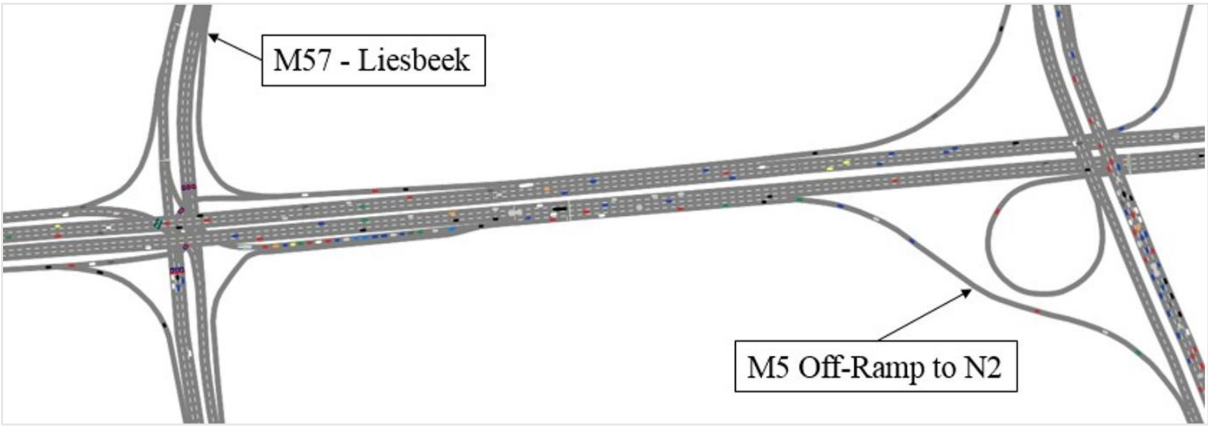

Figure 5.6: M5 On-Ramp to N2 In-Bound and Off-Ramp to M57

The disruption to traffic flow may be simplified in the Base Condition while a reduction in speed may be experienced according to the TomTom and Google Traffic travel time output. The travel time along the N2 for the modelled network however, compared favourably to the Field plot overall, since the total travel time approximates to the desired output (i.e. Google Maps output). Figure 5.7 compares the travel time for the M57 and M176 in the Base Condition to the average travel time obtained from the TomTom database and Google Traffic:

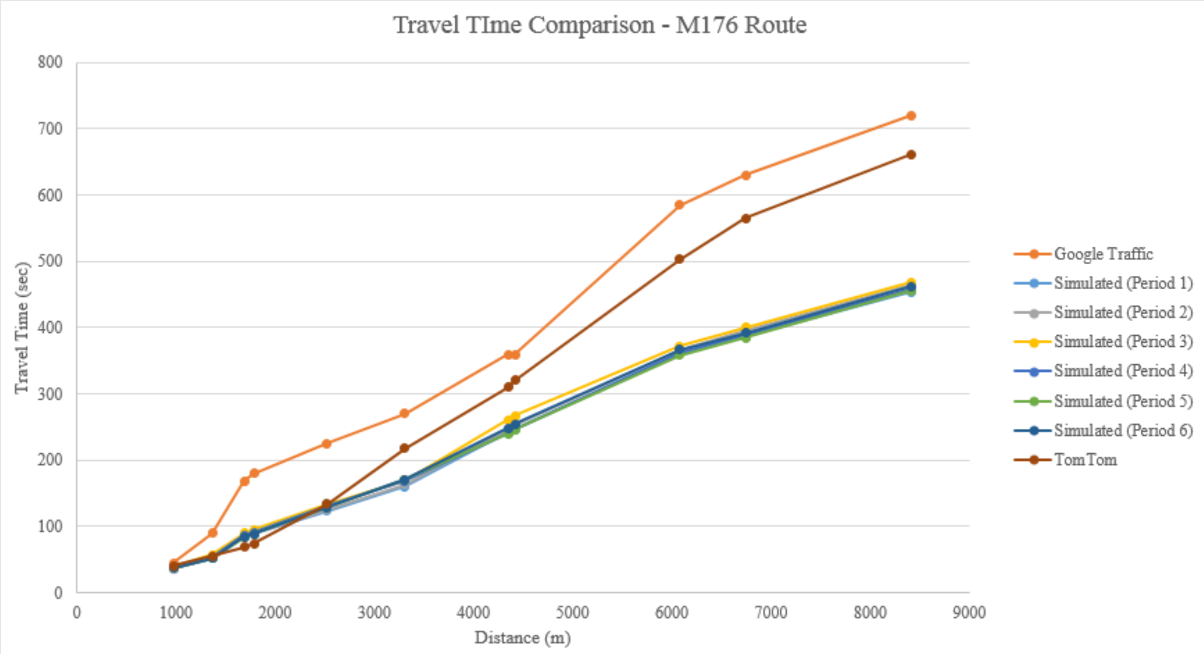

Figure 5.7: Travel Time of Base Model along M57 and M176 Compared to Google Maps Average Travel Time

CALIBRATION OF ARTERIAL ROUTE – ROUTE 3

It may be observed from Figure 5.7 that the travel times for either of the simulation periods yields relatable results to the output of Google Maps. A comparison of the average speed profiles indicates the reason for the difference in travel times for the M57 and M176 route. Vehicles travel at a higher speed along these routes to accommodate the Desired Speed Distribution (refer to Chapter 4, *Section 4.2.1*) of 90 km/h. This distribution allows vehicles to travel at speeds ranging between 85 and 120 km/h, which satisfies the flow velocity of vehicles travelling along the freeways, but unrealistically reduces the travel time along the arterial route (Route 3,Figure 5.1). The average travel speed along the M176 route in the simulated model is approximately 25 km/h faster than the average travel speed along the arterials in reality, resulting in the distribution illustrated in Figure 5.8:

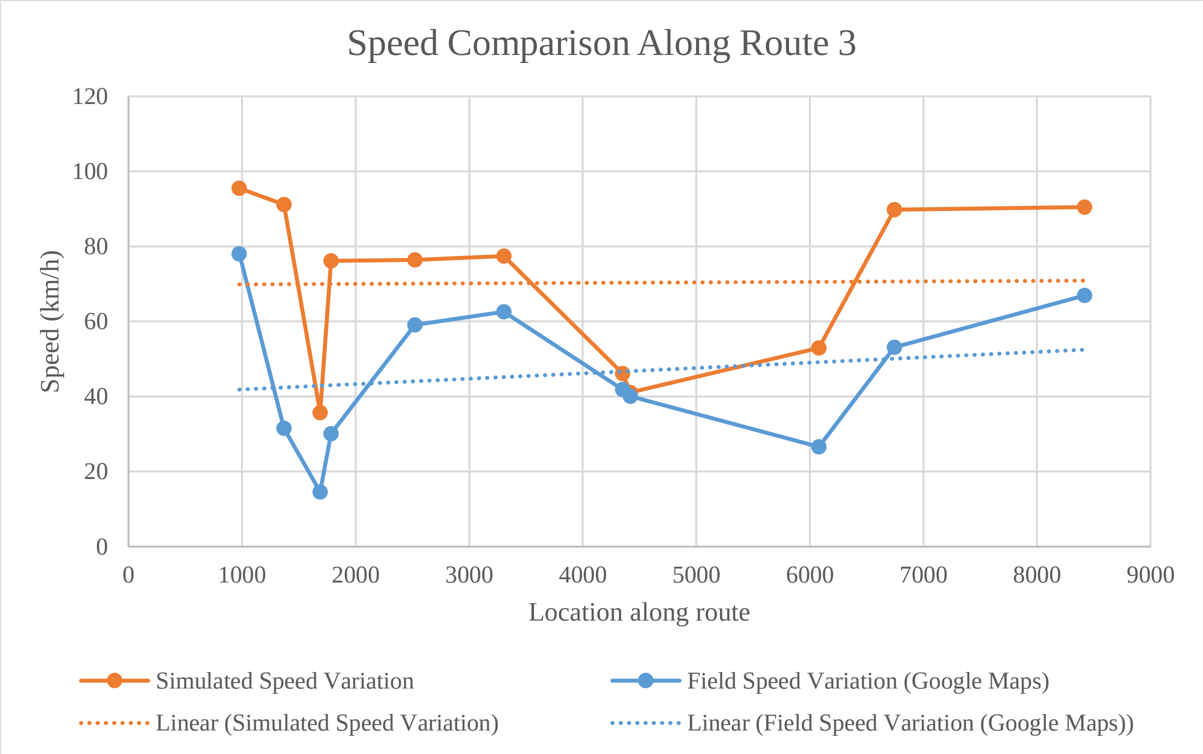

Figure 5.8: Vehicle Travelling Speed for Simulated and Field models

The concern in this case is that Vissim only allows the user to insert a single approximate speed for the vehicle composition, the vehicles then travel along the network according to the traffic conditions and the network behaviour. In this case, vehicles travel faster along the route since the Desired Speed Boundary is limited at 120 km/h – this produced an inconsistent profile along the M157 and M176 as the vehicles were not able to obey the speed limit along this route, however, the vehicles do conform to the speed limit along the N1 and N2, the main considerations for this investigation. The travel times along the M176 route may be adjusted to conform to travel times determined in the field for completion, whilst keeping the travel times of the freeways unchanged. Two approaches were considered for the base condition. The first was to adjust the average speed of the entire network, which affected the travel times along the freeways (M5, N1 and N2), while the M57 and M176 route only experienced an increase in travel time of approximately one minute. The second approach was to implement desired speed decisions within the route, the desired speed set to 60 km/h. This however, produced an identical result to changing the speed of the entire network, only increasing the travel time by one minute. Figure 5.9 and Figure 5.10 illustrate the effect described:

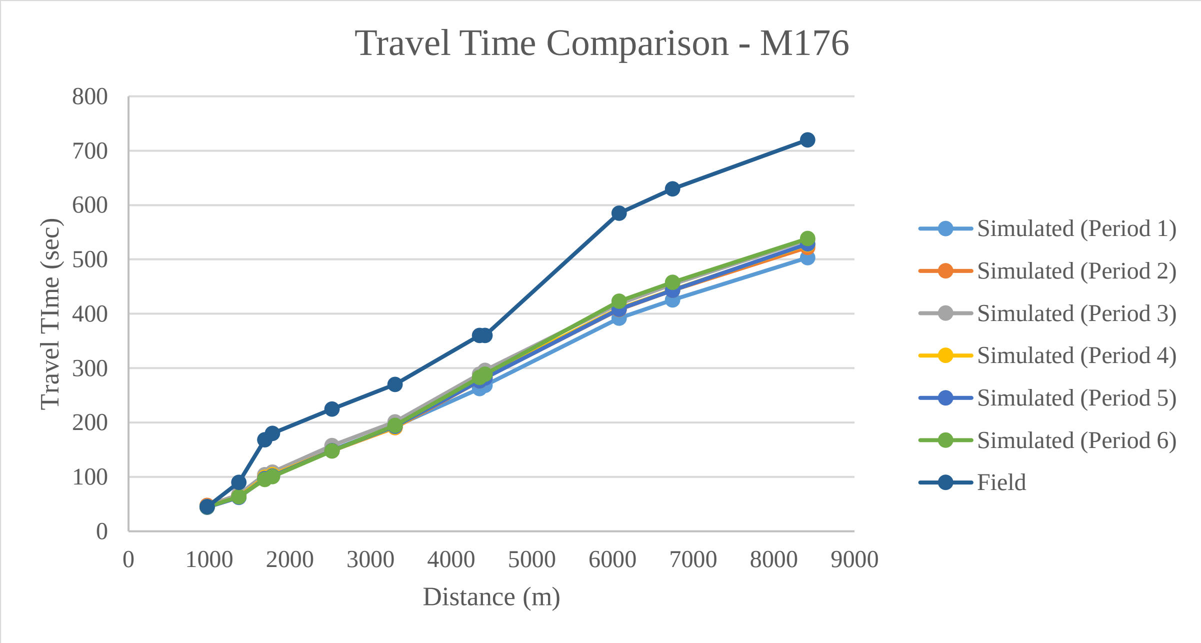

Figure 5.9: Adjusted Travel Time for Base Model along M57 and M176 by Adjusting Traffic Signal Configurations

Figure 5.9 indicates that the travel time has increased slightly (in comparison to Figure 5.7).

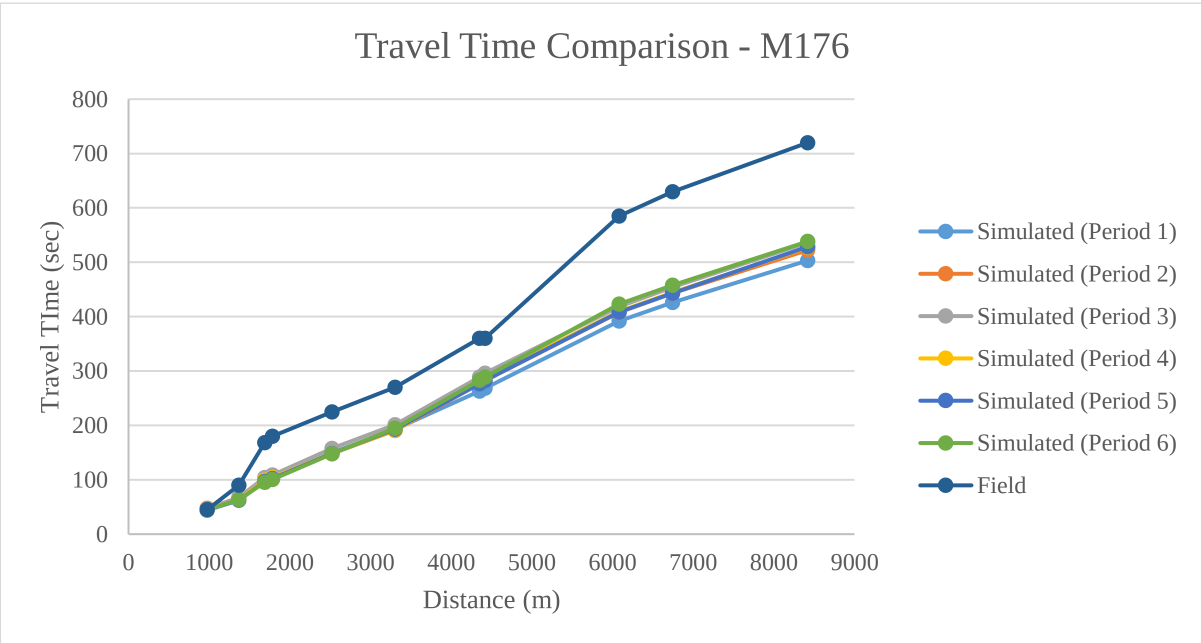

Figure 5.10: Adjusted Travel Time for Base Model along M57 and M176 by Adjusting Average Travel Speed

Figure 5.10 indicates a similar increase in time with the change in desired travel speed along the M57 and M176.

It should be noted that the traffic signals along the M57 and M176 were programmed for peak flow conditions, allowing for maximum throughput of traffic along the main road, this allowed traffic to pass through Route 3 more easily. This approach was taken based on observations of the behaviour of vehicles in the network, in which unrealistic congestion was caused due to vehicles being stuck at signalised intersections. The network map is referred to below for convenience (Figure 5.11):

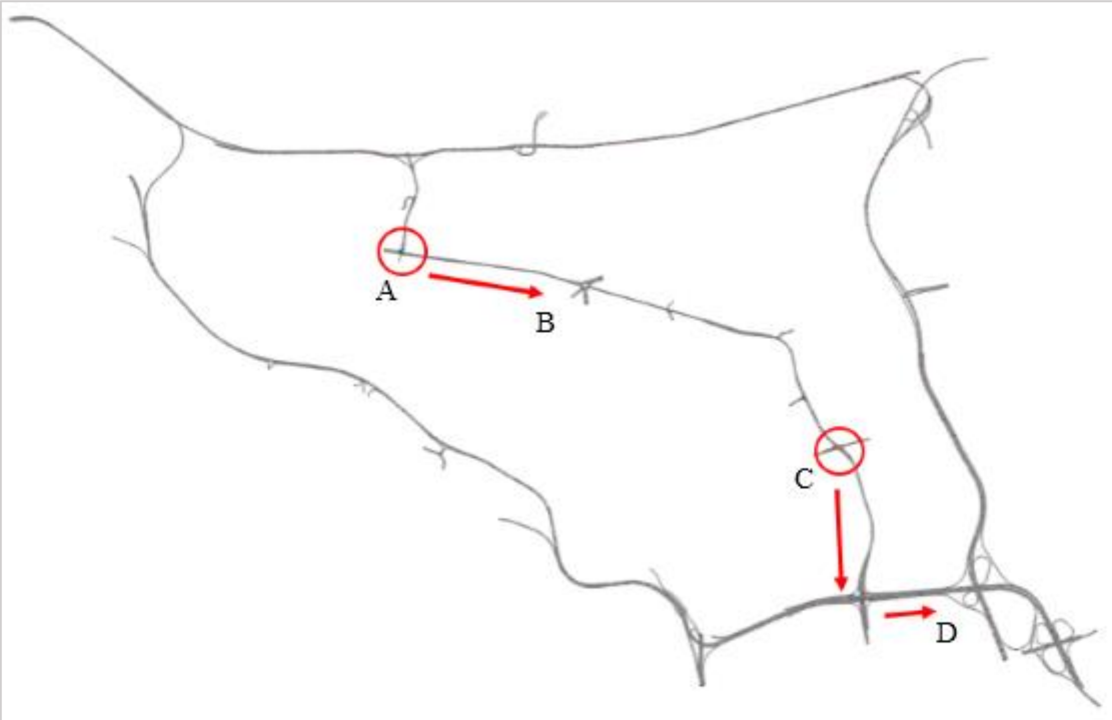

Figure 5.11: Formation of Queues from the points indication

Figure 5.11 indicates the locations of signalized intersections that produced undesirable results due to the off-peak Signal Controller times. Based on the simulation and the unpredictability of the behaviour, the traffic signal times were adjusted within the boundaries obtained from TCT (Transportation for Cape Town) based on observation of the traffic behaviour (refer to Appendix D for Traffic Signal programs). The times were adjusted to ensure that the M57 and M176 route was given priority. This was necessary as the formation of queues (beginning at the Liesbeek Parkway-Station intersection – point **C**) would extend into the N2 and Liesbeek intersection (point **C** to point **D**), as well as from the Lower Church Road intersection (point **A**) to the Salt River Circle (point **B**).

Given that the travel times were determined on the following-behaviour of the vehicles in the network, specifically in accordance with the Weidemann models, allowing for variations in travel speed, lane changing decisions and intersection control, the model was accepted as sufficient for the purposes of this investigation. Additionally, since the simulated freeways produced suitable results (the main focus of this investigation), the various scenarios investigated in this study would be satisfied with comparisons to the Base Condition.

5.3 APPLICATION: SPEED HARMONISATION

As mentioned in Chapter 4, Speed-Harmonisation is an application under the INFLO category with the intention of improving efficiency in traffic. Speed-Harmonisation suggests a travel speed based on the conditions of the network to reduce congestion, increase throughput of vehicles and traffic flow (refer to Chapter 2, *Section 2.2.3*). Figure 5.12 provides a comparison between the Base Model and the Speed-Harmonisation Model (Abbreviated SPD-HARM) for the first period during which the network capacity is 20% less than the peak-flow:

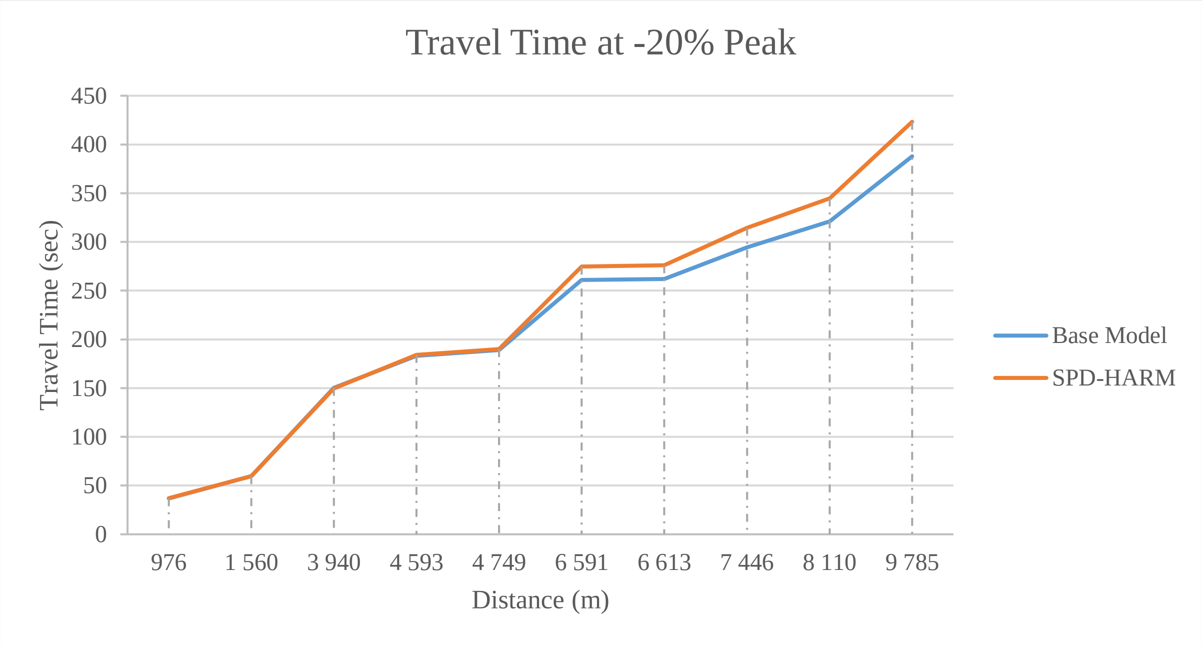

Figure 5.12: Travel Time Comparison of Base Model and Speed-Harmonisation Model during First Period

The first figure illustrates that the volume within the network does not require much adjustment to flow at a specific speed since both compare similarly, this is therefore the base case for the Speed Harmonisation scenario. The traffic flow then continues until peak traffic volumes are reached. Figure 5.13 indicates this comparison at peak-flow:

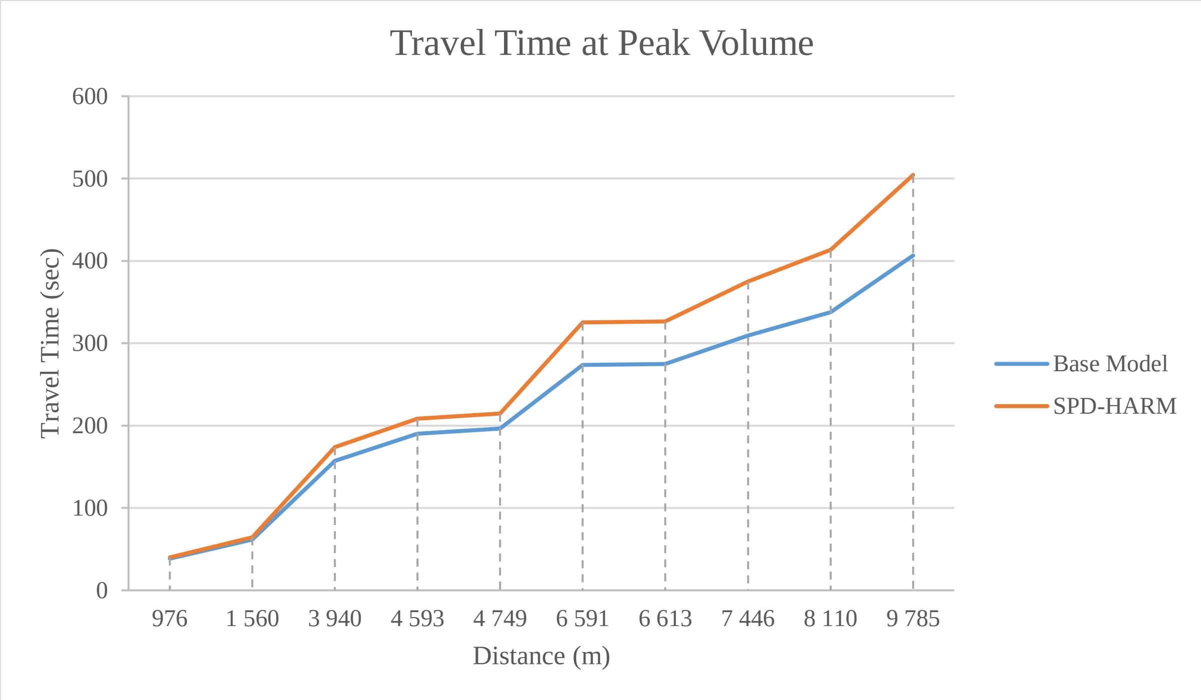

Figure 5.13: Travel Time Comparison of Base Model and Speed-Harmonisation Model during Peak-Flow Period

The graph in Figure 5.13 indicates that the Travel Time of vehicles in the network increases as a result of the application, which is to be expected as the vehicles are travelling at a lower speed. The vehicle flow capacity increases and as a result, suggesting a reduced travelling speed for vehicles along the N1. However, the application is expected to reduce congestion and produce improvements in fuel efficiency, carbon emissions and the reduction of stops and delays. An additional advantage is the reduction of accidents under these conditions as drivers would have an increased period of time to react. The following table indicates the improvements produced from the simulated model in Vissim as a result of Speed Harmonisation in comparison to the Base Condition.

Table 5.1: Comparison of Efficiency between Base Model and Speed-Harmonisation Model

Attribute	Base Model	Speed Harmonisation	Percentage Improvement (%)
Average Delay per vehicle (All) (sec)	24.87	21.10	17.87
Average Delay per vehicle (Vehicles) (sec)	24.88	21.02	18.36
Average Standstill Time per vehicle (All) (sec)	7.38	6.09	21.18
Average Standstill Time per vehicle (Vehicles) (sec)	7.39	6.11	20.95
Total Delay (All) (sec)	596 145.13	512 106.21	16.41
Total Delay (Vehicles) (sec)	584 760.56	500 143.84	16.92
Total Standstill Time (All) (sec)	176 960.70	147 953.56	19.61
Total Standstill Time (Vehicles) (sec)	173 693.92	145 350.81	19.50
Total Vehicles Arrived (All)	23 093	23 471	1.64
Total Vehicles Arrived (Vehicles)	22 643	23 009	1.62

Table 5.1 indicates that, on average, vehicles experience fewer delays in the network and stop for shorter periods of time. Additionally, more vehicles arrive at their destination as a result of the reduced delays and stops. A reduced speed would allow vehicles to initiate safe overtaking manoeuvres with minimal reductions in speed of the vehicle slowing down, reducing the possibility of creating shockwaves and endangering other road users.

In addition to the improvements in delays, fuel consumption is reduced along with the reduction in carbon emissions. Table 5.2 provides an indication of the improvement obtained from the simulated network in comparison to the Base and Accident models:

Table 5.2: EnViVer Output of Emissions per Simulation Model

Application	CO_2_g_km	NO_x_g_km	PM_{10}_g_km	Fuel Consumption
Base Model	159.7	0.4918	0.02734	6.883621
Accident	157	0.4796	0.02713	6.767241
Speed-Harmonisation	156.8	0.5084	0.02674	6.758621

Where

- **CO_2_g_km** – Carbon Dioxide emissions, measured in grams per kilometre
- **NO_x_g_km** – Nitrogen Oxide particles emitted. measured in grams per kilometre
- **PM_{10}_g_km**– Particulate Matter (10 micrometres or less in diameter), measured in grams per kilometre

Similarly, the evaluation was conducted for the N1 Route (shown in Table 5.3), since the accident was simulated along this section of road to observe a probable change in results. The following results were obtained:

Table 5.3: EnViVer Output of Emissions per Simulation Model along N1

Application	CO2_g_km	NOx_g_km	PM10_g_km	Fuel Consumption
Base Model	147.9	0.4666	0.02646	6.375
Accident	150.1	0.469	0.02666	6.469828
Speed-Harmonisation	143	0.5222	0.02519	6.163793

In both cases, it can be seen that Speed Harmonisation produced a reduction in carbon emissions and a reduction in the fuel consumed during the trip. The average achievement in either case is an approximate improvement of 3% in carbon emission reduction and fuel consumption reduction.

5.4 APPLICATION: QUEUE-WARNING

Queue-Warning (as mentioned in Chapter 4) is an application within the INFLO category dedicated to improving traffic efficiency – Queue-Warning informs road users in the network of the location of queues, provided the vehicle sending the message is in the queue. In order to prove that the implementation of CV technology may establish an improvement in traffic flow conditions, an accident was modelled to produce peak flow on the N1 Route, creating congestion to enable the queue application (refer to Chapter 4, *Section 4.4.1*). The Accident scenario was compared to the Base Condition to determine the influence and effect of the queue formed. Figure 5.14 indicates the queue formed during the accident scenario at the beginning of the 20-minute period of the simulation:

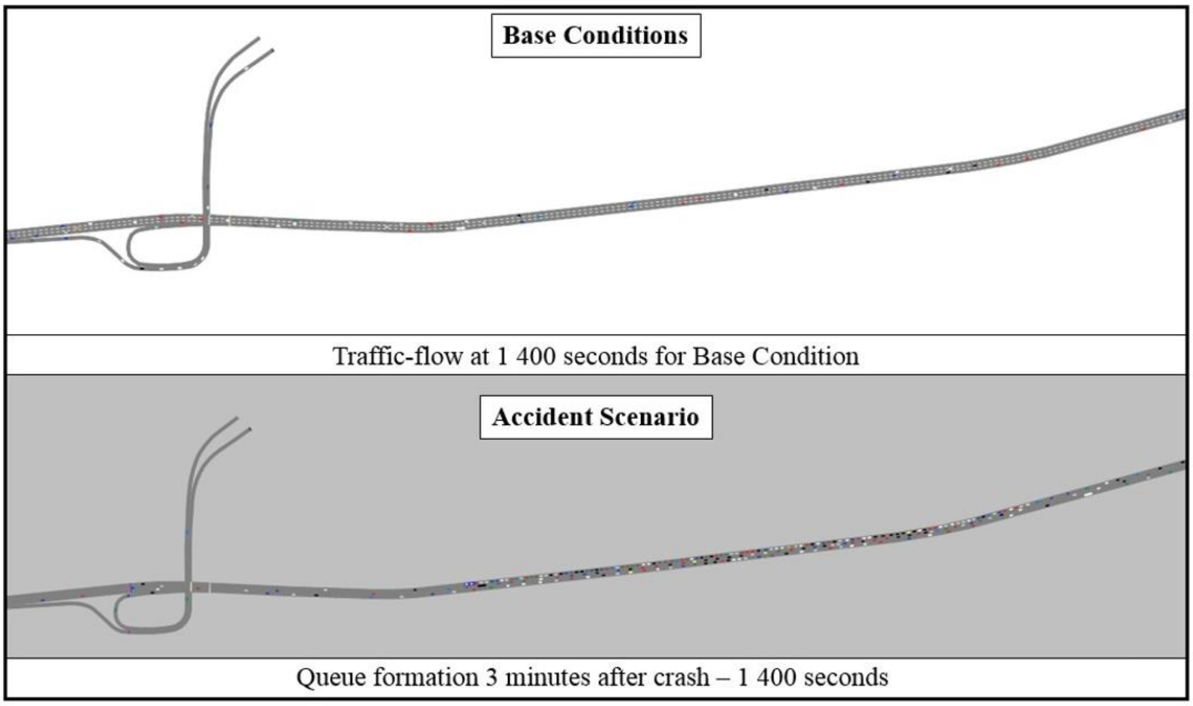

Figure 5.14: Base Condition Flow versus Accident Scenario Flow after Occurrence of Crash

The following figures were included to illustrate change in travel times based on the duration of the simulation. The first figure indicates the performance of the Base Model, Accident Model and Queue-Warning model for the first period at which the traffic capacity is at 80% of the peak-flow.

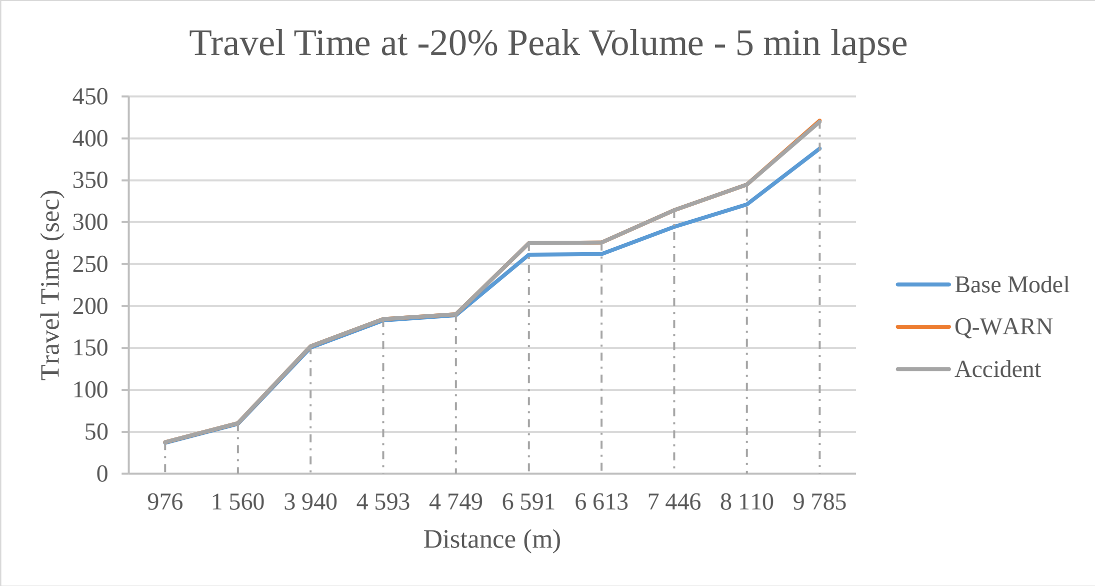

Figure 5.15: Travel Time Comparison of Queue-Warning to Accident and Base Model along the M5 and N1

Figure 5.15 indicates that traffic behaves similarly at the beginning of each scenario; this simply shows that the model behaves as expected since the imposed conditions have not taken effect at this stage of the simulation. The difference in times is simply a result of the differences in driving behaviour as well as the variation of the frequency of vehicles entering the network. More specifically, at the 4.6km mark, the M5 Route merges into the N1, resulting in the gap that forms at the 6.6km mark since the vehicles are slowed down unpredictably as a result of the merge. The difference however is acceptable for the conditions of the network. Figure 5.16 indicates the change in behaviour as a result of the increased capacity and the occurrence of the accident.

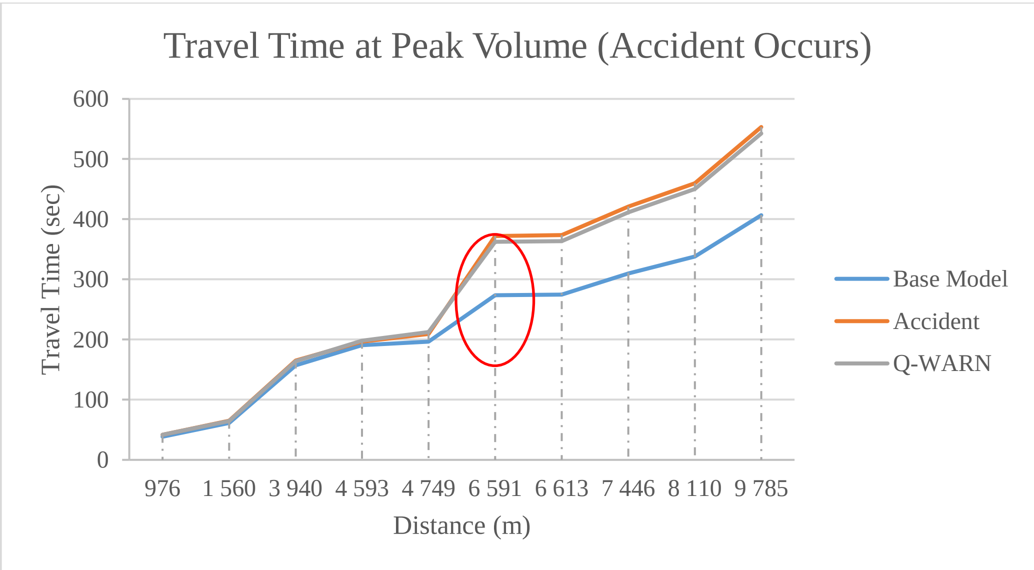

Figure 5.16: Travel Time Comparison of Queue-Warning to Accident and Base Model along the M5 and N1 at Occurrence of Accident

At the occurrence of the accident, the vehicles in the Queue-Warning scenario behave identically to the vehicles in the accident scenario, since no warning has been issued, due to the 5-minute delay implemented. This correlation arises due to the latency (5 min lapse), i.e. the information was sent after a time-delay once detection of the incident was established. Once the incident was detected, the information would be processed by the traffic operating agencies (for Cape Town, the TMC would detect the information using the FMS). This information would then be evaluated by ATMS and then distributed by ATIS. This transfer and confirmation of information would result in some delay of users obtaining the information (which was exaggerated to 5 minutes for this study). Figure 5.17 indicates the final simulation period, the effect of the crash on travel time along the N1 and the effect that the Queue Warning scenario produced:

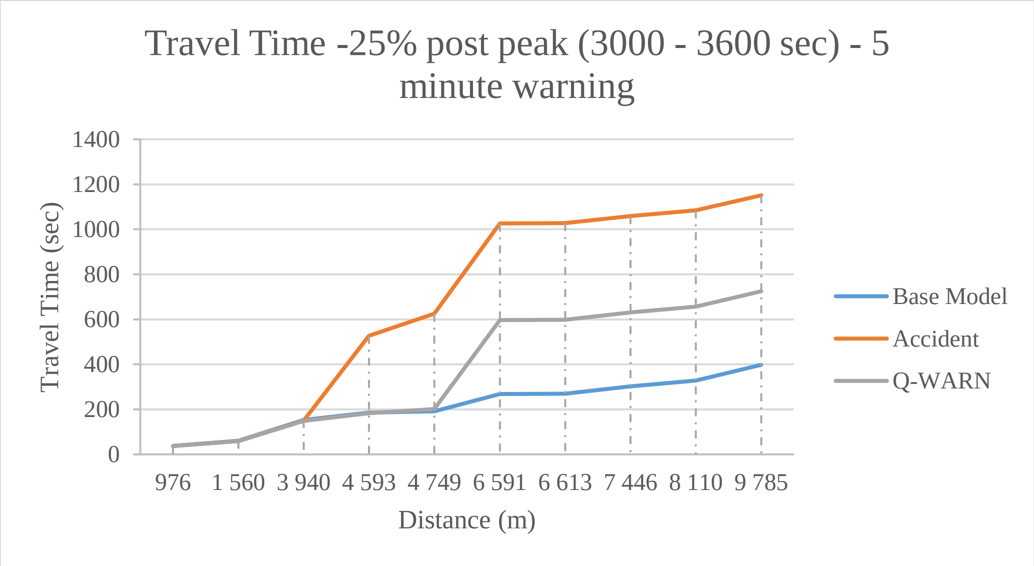

Figure 5.17:Travel Time Comparison of Queue-Warning to Accident and Base Model along the M5 and N1 after Occurrence of Accident (During Final Period)

After 5 minutes, vehicles in the Queue-Warning model received the information and adjusted the route to avoid the incident. Figure 5.17 illustrates the improvement that may be achieved as a result of drivers executing the correct evasive action, that is, taking an available alternative route to reduce travel time. Five minutes after the occurrence of the incident, vehicles are warned and directed along an alternative route, in this case, vehicles initially intending to use the N1 to Central Cape Town remain on the N2 instead of taking the off-ramp to the N1. Figure 5.18. shows the difference in the simulated model between the Accident scenario and the Queue-Warning application:

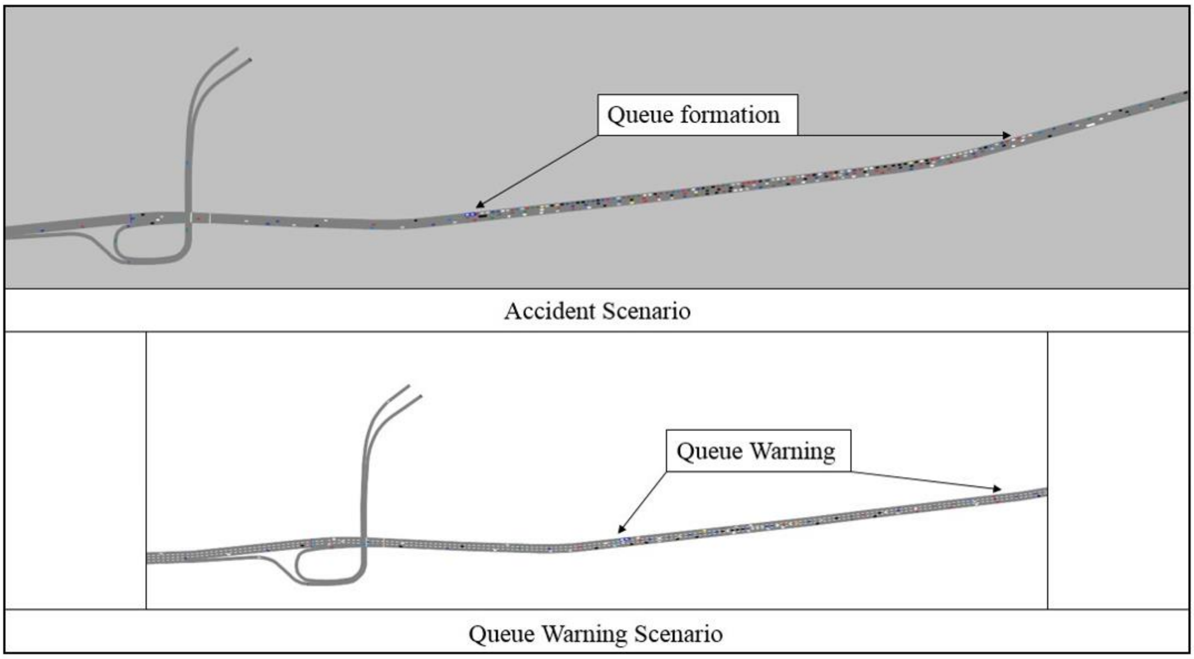

Figure 5.18: Queue-Warning Scenario versus Accident Scenario Traffic Flow

As an illustration, the travel time along the N2 was compared to its base condition to identify a possible increase in travel time based on the increased throughput of vehicles. Figure 5.19 indicates the increase in vehicles along the N2 while Figure 5.20 illustrates the travel time of the base condition versus the Queue-Warning scenario.

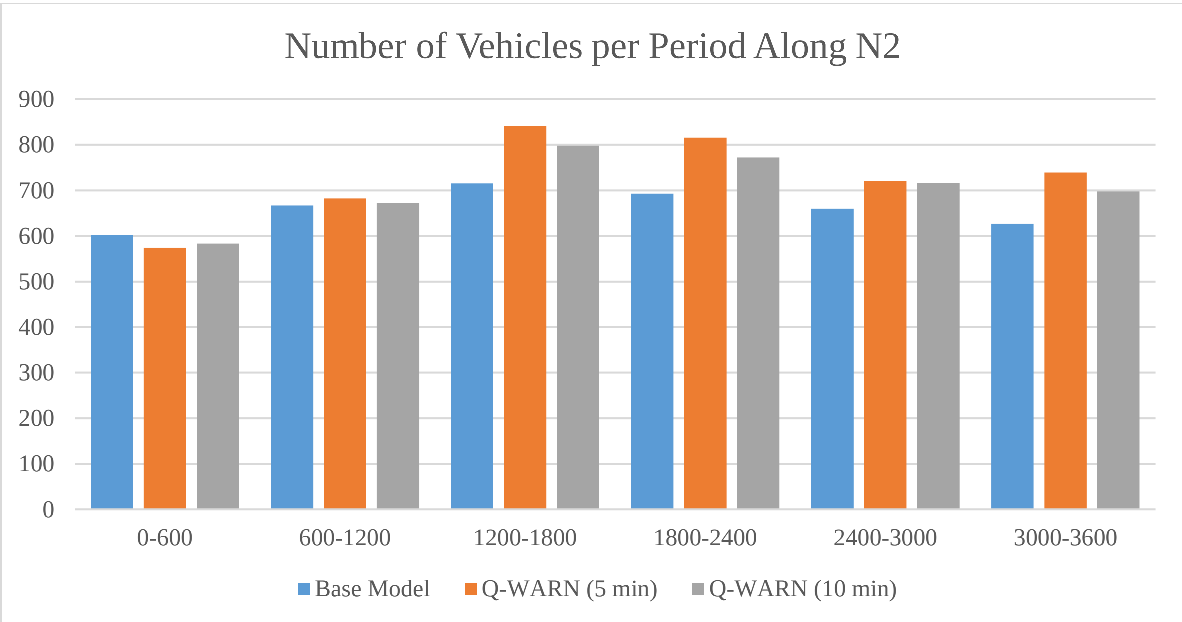

Figure 5.19: Throughput of Vehicles for Queue-Warning Applications versus Base Model Throughput

Figure 5.19 indicates that an increase in the number of vehicles travelling along the alternative route was evident. This was to be expected since the alternative route was suggested as a more appealing route with regards to travel time. Vehicles on the M5 and N1 Route were therefore able to complete the trip at a reduced travel time (in comparison to the accident model), and vehicles travelling along the N2 Route achieve a reduced travel time as well, once again in comparison to the accident model. Figure 5.20 (page 5.13) indicates the travel time along the N2 for the Base and Queue Warning models during the period of the accident.

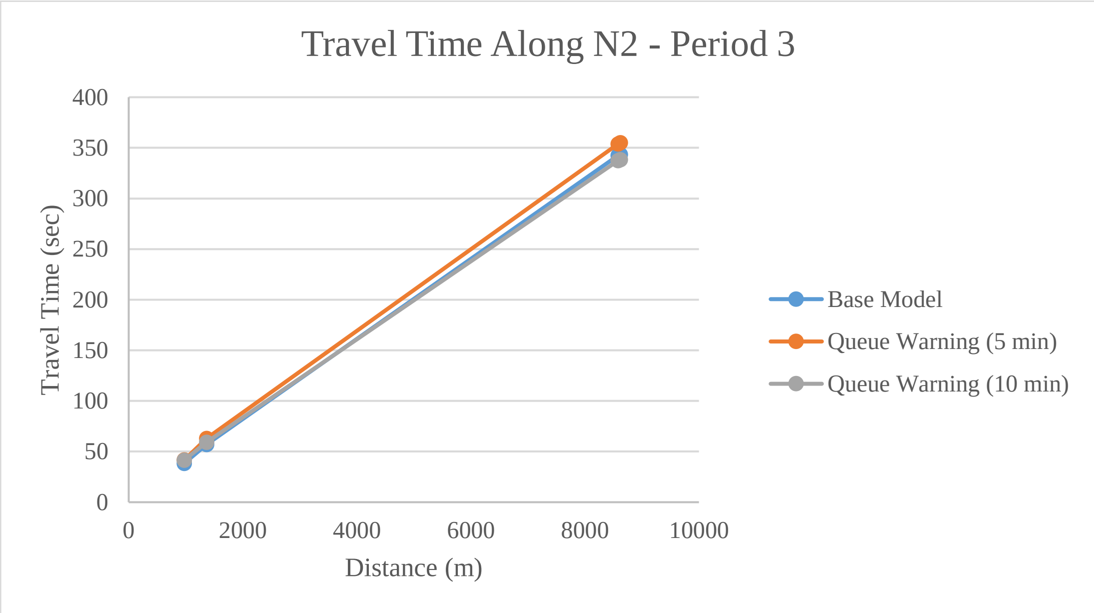

Figure 5.20: Travel Time along N2 at Occurrence of Accident

Figure 5.20 describes the difference in travel times for the Queue-Warning scenario. Although the number of vehicles travelling along the N2 is increased for the Queue-Warning (10 min) model, the travel time was identical to the travel time of the Base Model. The Queue-Warning (5 min) was subjected to a greater number of vehicles and as a result has a slightly higher total travel time, but only exceeds the base condition by 12 seconds.

5.5 CELLULAR VERSUS DSRC-ENABLED CONNECTIVITY

The effects of the applications were presented, a comparison between Cellular and DSRC-equipped connected technology may thus be drawn. Chapter 4 provided a detailed description of the manner in which the following scenarios were modelled. A brief description follows to ensure clarity of the distinctions made between the alternative communication options.

5.5.1 CELLULAR CONNECTIVITY

Cellular connectivity incorporates the use of a nomadic device (i.e. Smartphone) that may provide information to the vehicle user through wireless communication with the cloud (refer to Chapter 2, *Section 2.7*). The external device may be an On-Board Unit (OBU) or, for this study, a Smartphone. A constant internet connection would be necessary to sustain the V2I communication. This type of connectivity was simulated through physical changes in the conditions of the simulation and implementing assisting infrastructure to allow vehicles to behave according to the requirements of the applications. To simulate the applications Queue-Warning and Speed Harmonisation, an accident was modelled to enable Queue Warning, while a Variable Message Sign – Smartphone (VMS-SP) and detectors were modelled in VisVap to display a recommended speed based on the traffic-flow capacity. Changing the modelled environment enabled the simulation to produce results that may be anticipated if users were to abide by the information provided by their on-board devices. In reality, these results would be dependent on the users and the information may be ignored by the driver, if the users indeed utilised the capabilities of the potential Smartphone application or have an uninterrupted broadband connection.

5.5.2 DSRC-ENABLED CONNECTED VEHICLES

Connected Vehicles were modelled with the use of VISSIM's COM functionality (refer to Chapter 4, *Section 4.3.2*), in which the behaviour of vehicles may be coded with any programming language (such as Python, Visual Basic, Java, etc.) to allow the vehicles to react in a manner specific to the requirements of a particular scenario, in this case, to display the behaviour of Connected Vehicles. To achieve the desired behaviour from Queue Warning and Speed Harmonization applications, the vehicles were to be provided with warning messages upon occurrence of the accident. For CV functionality to be implemented, the crash was to occur with a CV to ensure that the message could be sent to other CVs along the route and in the network. It should be noted that this is an example of Vehicle-to-Vehicle (V2V) communication, while Vehicle-to-Infrastructure (V2I) communication could not visually be modelled to assist the vehicles travelling along the route in this case. Additionally, V2I would allow information to be transferred regardless of the nature of the vehicle (Connected versus non-Connected). V2I was however modelled in that vehicles were rerouted at the occurrence of the accident.

Both Cellular and DSRC-enabled environments were modelled to allow the vehicles in the network to perform similarly for a comparison in functionality. The following section discusses the results obtained for these models.

5.5.3 MODEL PERFORMANCE: TRAVEL TIME

Figure 5.21 demonstrates the travel times of the Tethered and Integrated/Embedded CV models against the Base and Accident models. These models perform similarly in the beginning, prior to the occurrence of the accident. The Integrated/Embedded CV model was simulated with an increasing percentage of CVs in the road network to determine the effect of a larger number of CVs on the total travel time, emissions and fuel consumption.

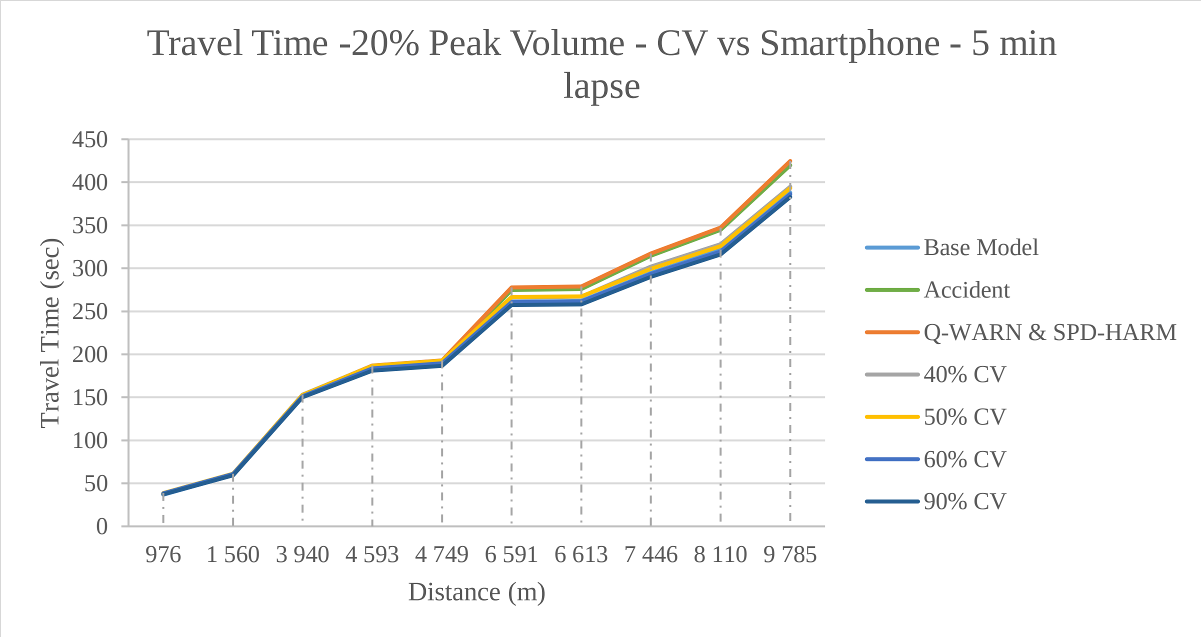

Figure 5.21: Integrated/Embedded CVs versus Tethered CVs Travel Time at Start of Simulation

Figure 5.21 indicates that the vehicles experience similar travel times in all scenarios simulated; any of the scenarios simulated is therefore sufficient to provide results of the travel times experienced by the vehicles based on the altered model environments. Figure 5.22 indicates the change in travel time at the occurrence of the accident (20-minute mark).

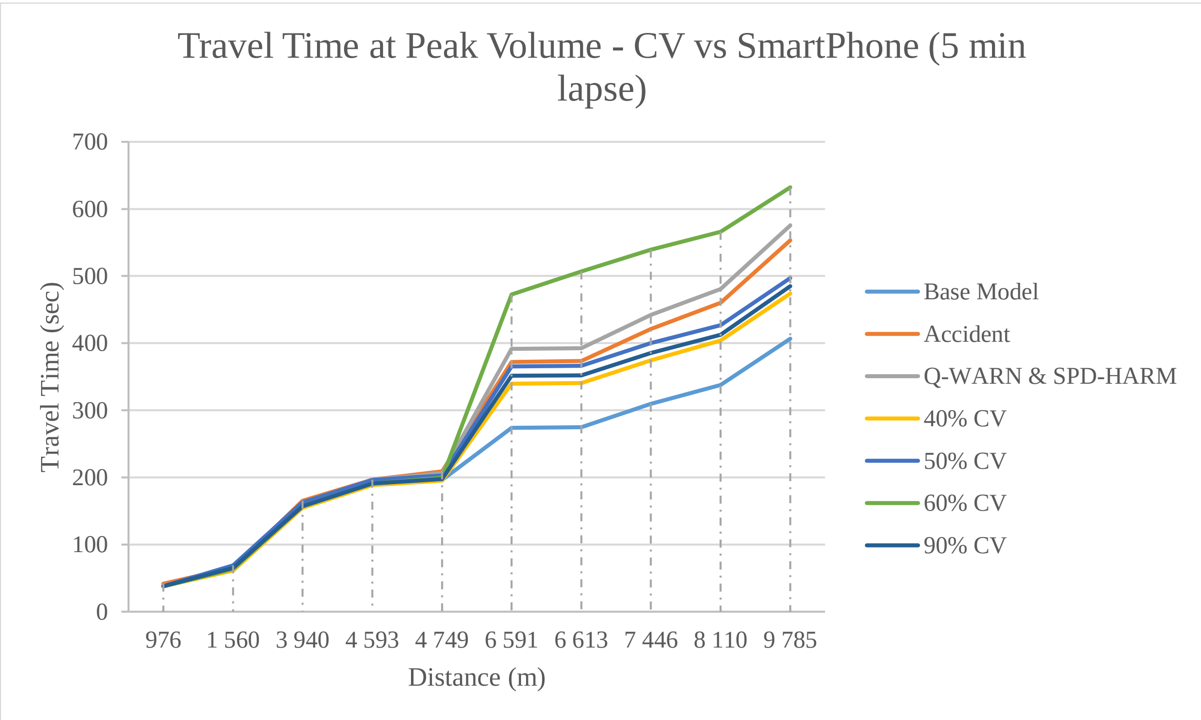

Figure 5.22: Integrated/Embedded CVs versus Tethered CVs Travel Time at Occurrence of Accident

Based on the travel time results indicated in Figure 5.22, it can be seen that all scenarios considered perform more efficiently than the accident scenario. Furthermore, the Cellular-equipped CV model appears to have performed more favourably than the 40% CV-penetration and 50% CV-penetration scenarios. Figure 5.22 highlights a crucial point in the simulation. The DSRC-equipped CVs are expected to reduce travelling speed (average speed of 80 km/h) along the freeway (M5 and N1), while the surrounding (non-equipped) vehicles were not programmed to adjust their speed. This resulted in all non-CVs experiencing a sudden reduction in speed since the message is sent out immediately. The result was an unexpected but logical increase in travel time. The reduction in speed affected the vehicles entering from the merge and affect vehicles intending to pass the slowing vehicles. This behaviour can be shown in the Speed-Acceleration diagram for the 60% CV model in Figure 5.23. The outliers below acceleration of -6 m/s^2 indicate vehicles that experienced unrealistic braking from a higher initial acceleration and speed – this occurs as a result of the sudden change in conditions once the CVs were provided with the message and responded to the information immediately. The areas in Figure 5.23 highlighted as red indicate the average speed at which the vehicles in the simulated network travel.

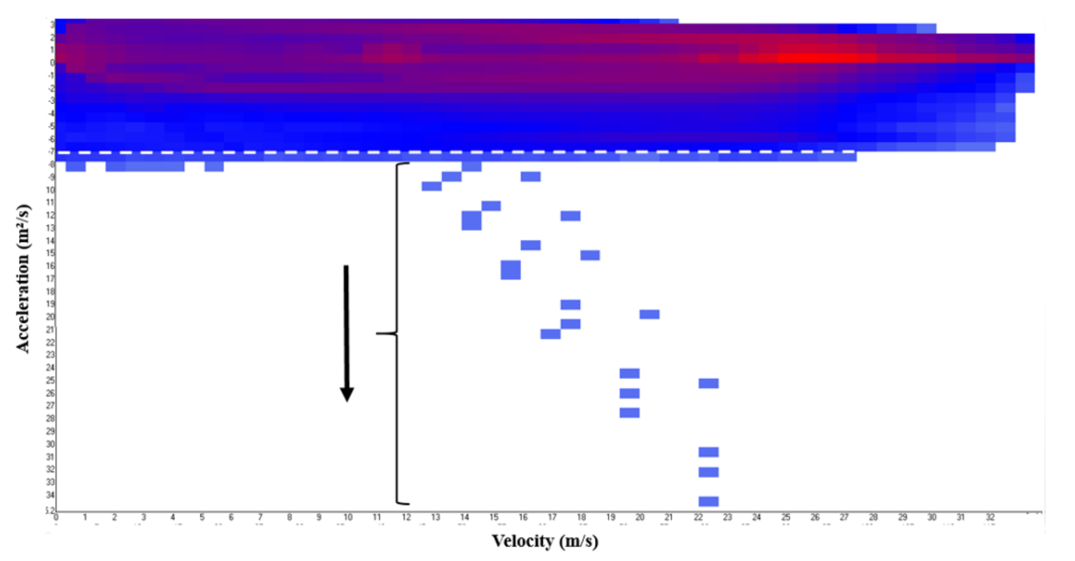

Figure 5.23: Speed-Acceleration Profile of Connected Vehicles

Although the behaviour exhibited by the CVs was correct according to the requirements, the resulting effects did not reflect the anticipated benefits that DSRC-equipped CVs were claimed to provide. The intention was to allow vehicles to slow down and, upon passing the incident, the speed of the network resumed, essentially resulting in a reduction in speed for a partial length of the route, while the Cellular-equipped scenario changes the speed for the duration of the traversed route for all vehicles. This behaviour was also correct since there would be a time-delay for Cellular-equipped CVs receiving information based on the previous discussion of latency. The complication presented by the DSRC-equipped Connected Vehicles affects the travel time of surrounding vehicles with an increasing percentage of Connected Vehicles. Additionally, the application of Queue-Warning and Speed-

Harmonization simultaneously may have only been tested in urban areas, where vehicles were able to slow to reasonable speeds without affecting large numbers of vehicles.

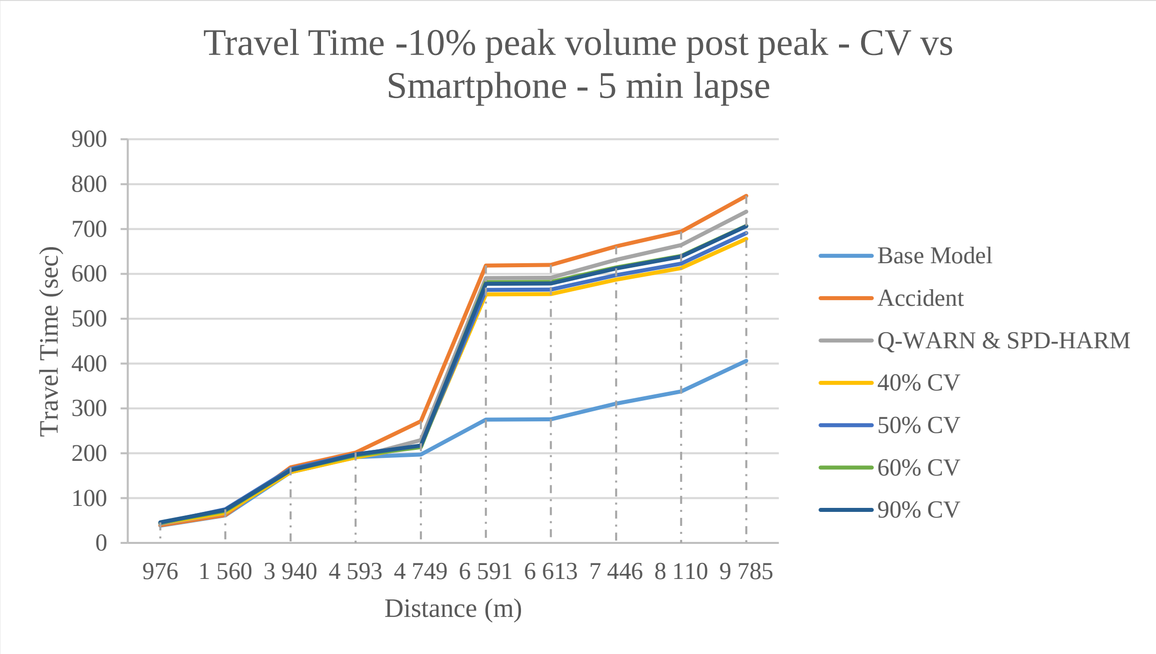

Figure 5.24: Integrated/Embedded CVs versus Tethered CVs Travel Time for Period after Accident

Once the crash occurred and the vehicles were provided with the information about the accident (location and lane position), the travel time began to stabilize as indicated in Figure 5.24. The figure indicates that the travel time for vehicles with 40% CVs in the network performs the most efficiently at this instant, since fewer vehicles were slowed down along the route. DSRC-equipped CVs may also perform more efficiently than Cellular-equipped CVs since the speed of the CVs is adjusted to normal conditions once the incident was passed. Figure 5.25 indicates the travel times of DSRC-equipped and Cellular-equipped CVs in the final simulation period:

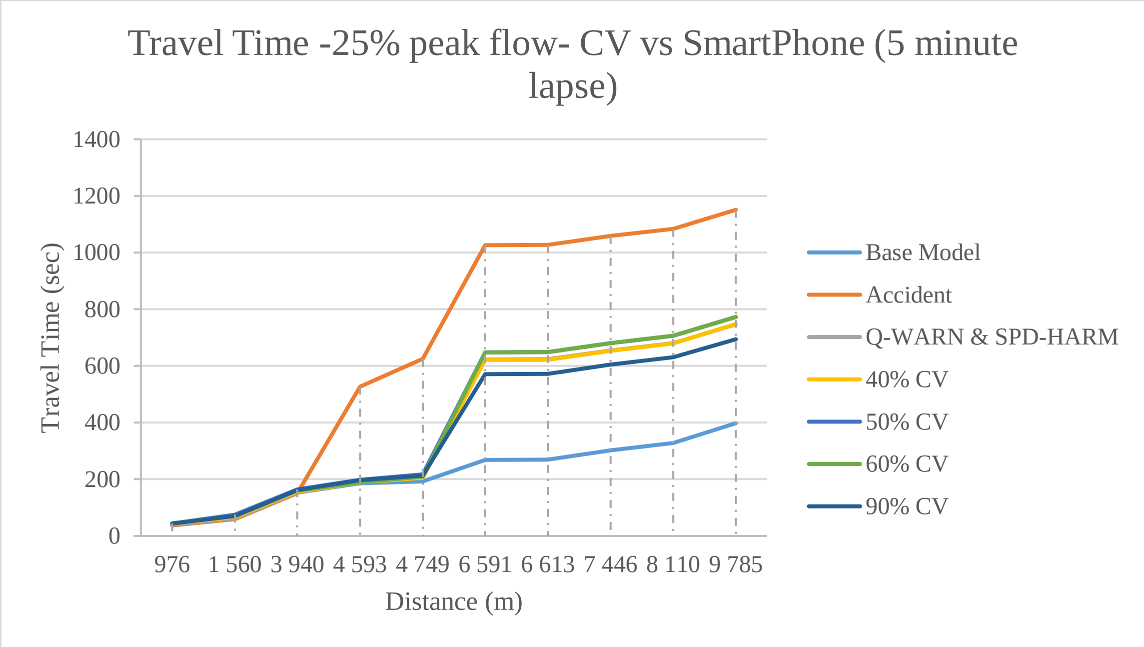

Figure 5.25: Integrated/Embedded CVs versus Tethered CVs Travel Time during Final Simulation Period

In the final period of the simulation, the travel times were similar for all of the models (Cellular-equipped and DSRC-equipped CVs) as the traffic volume was reduced at this interval to more stable conditions (Figure 5.25), reducing the necessity for incorporating Speed-Harmonisation for the Cellular-equipped CVs. The approximate improvement in travel time as a result of these applications was 6 minutes, during the last period, with an average improvement of 4 minutes after the accident occurred. The table below provides the changes in travel time for the duration of the simulation:

Table 5.4: Travel Times per Period for Tethered and Integrated/Embedded CVs

Model	**Travel Time per Period (min)**						
	0 600	**600 1200**	**1200 1800**	**1800 2400**	**2400 3000**	**3000 3600**	**Ave**
Accident	7.00	8.00	9.22	12.90	17.24	19.18	12.26
Q-WARN & SPD-HARM (5 min)	7.08	7.68	9.59	12.31	12.59	12.44	10.28
Q-WARN & SPD-HARM (10 min)	7.08	7.68	9.59	13.43	14.46	14.52	11.13
40% CVs	6.58	6.71	7.90	11.30	12.17	12.46	9.52
50% CVs	6.55	6.75	8.28	11.51	12.95	12.88	9.82
60% CVs	6.44	6.72	10.54	11.78	12.87	12.88	10.20
90% CVs	6.38	6.62	8.08	11.77	12.59	11.57	9.50

Table 5.4 indicates the effect of the applications and the differences in travel times based on the variation of the models. Although the Cellular and DSRC-equipped CVs achieve travel times within the 12-minute period, the Tethered application appears to perform more efficiently than the Integrated/Embedded CVs. This may be attributed to the adjustment in speed of all the vehicles along the M5 and N1 route (Tethered CVs), as opposed to a specific percentage of Integrated/Embedded CVs, affecting the non-CVs. Figure 5.26 and Figure 5.27 illustrate this point:

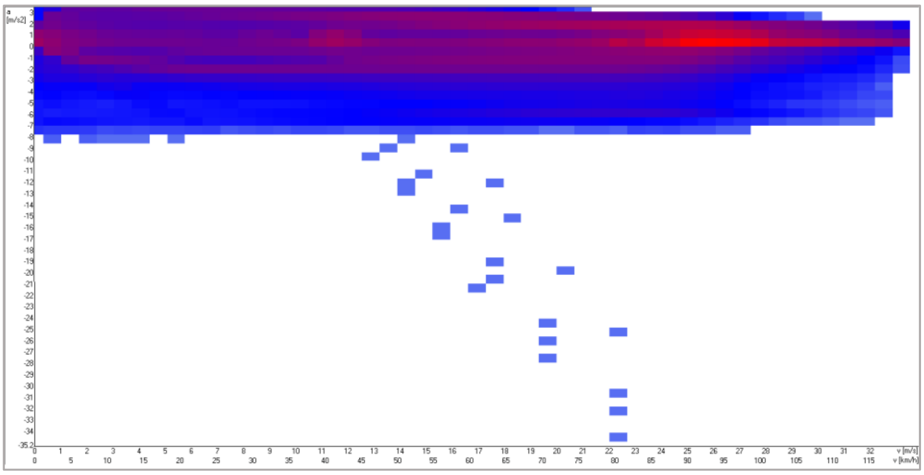

Figure 5.26: Speed-Acceleration Profile of Integrated/Embedded CVs

For the Tethered CVs with a 5-minute delay of receiving the message:

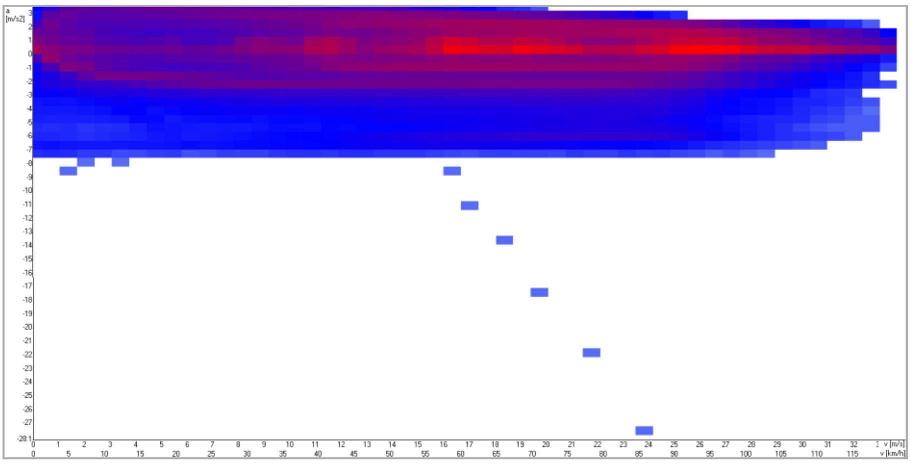

Figure 5.27: Speed-Acceleration Profile of Tethered CVs (5-min lapse)

The Speed-Acceleration profile obtained for the Cellular-equipped CVs with a 10-minute delay was identical to the Cellular-equipped CVs with a 5-minute delay and was therefore not displayed in this section. Appendix E provides the Speed-Acceleration profiles for all scenarios tested.

Comparing the Speed-Acceleration plots, the Cellular-enabled CVs were required to suddenly reduce travel speed in comparison to the DSRC-equipped alternatives. This may be seen as motivation for the improved results attained from Cellular-enabled CVs, creating a false impression that the vehicles are able to travel more efficiently. This should be considered when observing the results obtained for the Cellular-enabled vehicles in comparison to DSRC-equipped vehicles.

The Cellular-equipped connected vehicles produce an improved travel time in comparison to the accident but has the longest travel time (in comparison to the CV, Queue-Warning and Speed-Harmonization scenarios) due to the delay of the message sent to vehicles in the network. Overall however, the average travel time produced for a network consisting of 90% CVs produced the most efficient results. The following tables show the improvements in fuel consumption and reductions in carbon emissions determined from the simulations. Additionally, the delays caused by the increased penetration of CVs in the network was provided as confirmation of the speculated increased travel time.

Table 5.5: Emissions output of Tethered and Integrated/Embedded CVs compared to Accident and Base Models

Application	CO2_g_km	NOx_g_km	PM10_g_km	Fuel Consumption
Base Model	159.70	0.4918	0.0273	6.88
Accident	157.00	0.4796	0.0271	6.77
Q-WARN & SPD-HARM (5 min)	155.50	0.5029	0.0266	6.70
Q-WARN & SPD-HARM (10 min)	155.50	0.5029	0.0266	6.70
40% CVs	155.00	0.4659	0.0271	6.68
50% CVs	155.70	0.4655	0.0272	6.71
60% CVs	154.30	0.4600	0.0271	6.65

Comparing the Accident scenario to the Base condition, it may be seen that an improvement in fuel consumption and Greenhouse Gas (GHG) emissions was prevalent. This may not be the expected outcome, however, vehicles in the Base Model are able to travel at maximum speed which in some cases exceed the speed limit of the road; this resulted in the greater amount of carbon emissions per vehicle as well as increased fuel consumption. More vehicles would be stagnant still in the event of the accident, which produced the falsely improved fuel consumption figure. Additionally, the entire design area was considered and the results presented reflect the conditions experienced for all vehicles. The Cellular and DSRC-equipped connected alternatives produced improved output figures for fuel consumption and a reduction in carbon emissions. Furthermore, the table indicates that the scenario with 60% CV-penetration rate performs the most efficiently, producing reductions in carbon emissions and fuel consumption. The following table indicates the performance of the vehicles along the specific route of the accident (N1, refer to Chapter 4, *Section 4.4.1*).

Table 5.6: Emissions output of Tethered and Integrated/Embedded CVs compared to Accident and Base Models along the N1 (Accident route)

Application	CO2_g_km	NOx_g_km	PM10_g_km	Fuel Consumption
Base Model	147.90	0.4666	0.026	6.37
Accident	150.10	0.469	0.027	6.47
Q-WARN & SPD-HARM (5 min)	146.20	0.5282	0.025	6.30
Q-WARN & SPD-HARM (10 min)	146.10	0.5279	0.025	6.30
40% CVs	148.10	0.4559	0.027	6.38
50% CVs	150.50	0.4617	0.027	6.49
60% CVs	148.50	0.4532	0.027	6.40

Table 5.6 indicates that, along the N1 route (refer to Figure 5.1), the vehicles with Cellular-equipped connectivity perform more efficiently than the DSRC-equipped CVs. Based on observation of the simulation, this appeared to be true since the vehicles with Cellular-equipped technology were expected to conform to the speed limit beyond the location of the incident, while the DSRC-equipped CVs adjust their speed from travelling at a safe speed to comply with the standard speed limit once the incident is passed.

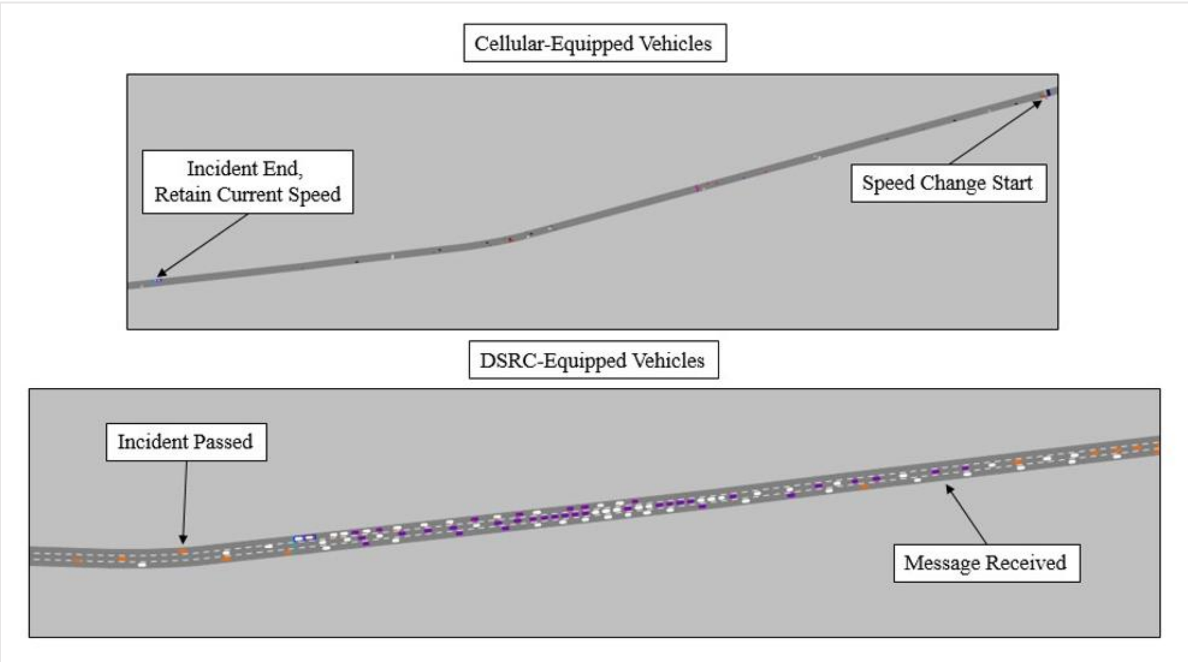

Figure 5.28: Speed Application difference between Cellular and DSRC-enabled Connected Vehicles

In comparison, DSRC-equipped CVs should perform more efficiently than Cellular-equipped CVs. When considered individually, DSRC-equipped vehicles were expected to perform favourably in comparison to the Cellular-equipped alternative, especially in consideration of the difference in technological capability and performance in terms of reacting to changing conditions in traffic interaction (i.e. DSRC connectivity, as discussed in Chapter 2 is more powerful than Cellular connectivity). This added performance to DSRC-equipped CVs was not reflected in this investigation within the simulations, since improvements in efficiency was the focus of this study.

5.6 CONCLUSION

This chapter discussed the results of the Connected Vehicle applications that may enhance efficiency in the South African road network. This was presented by first illustrating the effect of introducing each application individually within a confined area, subjecting the vehicles in the network to multiple scenarios. These scenarios began with the Base Condition and was followed by the Accident, Speed-Harmonization, Queue-Warning and Connected Vehicle scenarios. Cellular and DSRC-equipped CVs were compared to determine the effect that may be achieved with these applications on the traffic network. Although it was anticipated that DSRC-equipped CVs would perform more efficiently than Cellular-equipped CVs, the surrounding environment (freeways) introduced aspects that allowed the scenarios to behave similarly, such as the influence of CVs reducing their speed and affecting the behaviour of non-equipped vehicles. The particular aspects focused on in this case were improvements in travel time, fuel consumption and carbon emission reductions. It may be concluded that, in the event of a crash, the applications prove to be successful in providing improvements in traffic efficiency. Additional applications may be considered in future to possibly influence further enhancement over the efficiency and mobility within the South African traffic network. Since the applications and technology are currently in phases of development and testing, superior options and opportunities may arise in the near future.

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CHAPTER 6 : COST-BENEFIT ANALYSIS

This section is intended to address the costs involved with the construction of an environment that would enhance the capabilities of Connected Vehicles (CVs). In order to establish grounds for comparison, existing equipment and current payments hereof within the design area for the FMS was analysed. The aim of consideration of these elements was to provide an indication of the possible effect that CV technology may have on the environment, while accounting for the current needs of users and to establish an efficient and effective improvement in the traffic network.

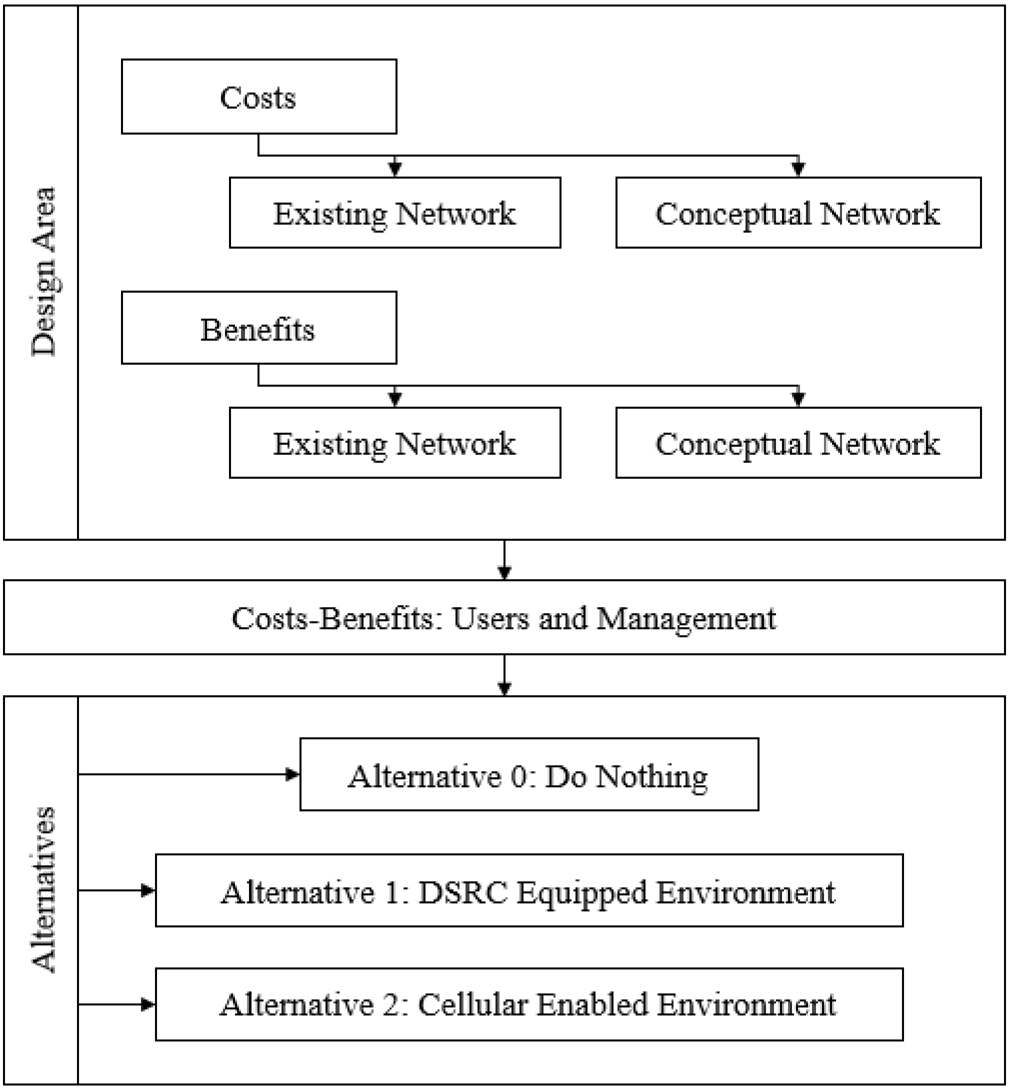
The Cost Benefit analysis was completed by discussing the costs associated with existing FMS infrastructure. The calculations (in some cases) were restricted to the network considered, i.e. the existing FMS network in the Western Cape consists of 52 VMSs while the network analysed contained only 3 VMSs, this Cost-Benefit Analysis therefore only considered the 3 VMSs in the design area. The conceptual environment was therefore similarly restricted to the area selected for analysis.

The proceeding sections consider the costs associated with the construction of a new communications backhaul to enable the transmission and acquisition of data between Connected Vehicles and Infrastructure. The communications infrastructure would be used to assist with DSRC transmissions for vehicles (V2V) and infrastructure (V2I). Thereafter, the benefits that the CV environment may produce are discussed, based on the results obtained in Chapter 5.

Thereafter, Alternative approaches for traffic management are discussed. These include the Null Alternative, an Alternative in which DSRC Communication is implemented and an Alternative that considers the use of Cellular Communication in vehicles. A comparison between these alternatives was then completed for consideration of the most suitable approach.

The format for this Cost-Benefit Analysis was to present the costs associated with all of the options considered, including the up-front costs, monthly and annual payments. Therefore the benefits were considered for both operational management agencies, as well as the users of the system. Thereafter the alternatives were presented and compared through an analysis of the results.

In consideration of the information and results presented, a conclusion will be drawn discussing the viability of implementing new technology with regards to the current means of monitoring the transport network. The following diagram illustrates the format and flow of this chapter:



In this chapter, the Design Area refers to the area chosen for the analysis and simulation as described in Chapter 4 and Chapter 5. The Existing Network refers to the ITS Infrastructure currently installed and operated in the Design Area and the Conceptual Network refers to the potential equipment that may be deployed to support a Connected Vehicles environment. Throughout this chapter, the terms *design area* and *study area* are used interchangeably and should be understood as a reference to the Design Area.

6.1 APPROACH TO COSTS

The approach to completing the cost benefit analysis for this investigation was simplistic and was not designed in conformance to any existing Cost-Benefit format for a large network. The intention was to provide the main areas of consideration with regards to the cost factors. This is simply due to the fact that a detailed cost-benefit analysis of large area is an intricately detailed endeavour. While it was necessary to remain as accurate as possible, a detailed cost-benefit analysis considers multiple factors that cannot be controlled and changes the results substantially in certain aspects. To provide an example, the following aspects may affect the costs of equipment deployed for use on site:

- Transportation:
  - May be affected by weight of equipment transported.
  - May be affected by number of vehicles used to complete delivery (if multiple items are delivered).
- Economy:
  - Affected by inflation.
  - Availability of equipment.
- Miscellaneous
  - Ease of manufacture of equipment.
  - Developer mark-up.
  - Accessible expertise for installation and set-up of special equipment.

These only include a few aspects that were not specifically considered in the cost investigation. Certain items may account for these costs as “inclusive”, but the percentage of inclusion was not specifically provided. A suitable approach then, was to account for the costs to the traffic management agencies and road users. The sections that follow will address the various cost factors involved in the deployment of field devices used for monitoring and communicating with the traffic network. The costs, within each subsection, will be broken down as follows:

- Capital Costs – Monetary value assigned to the tangible objects within the system
- Launch and Implementation Costs – The costs related to changing the design from conceptual to physical.
- Operation and Maintenance Costs – Running costs are inherent to ensuring sustainability of the system and will need to be managed in order to function continuously.
- Backhaul Communications – Infrastructure required to retrieve and provide information of the real-time operation of the network.

These were the main components for discussion between the Existing network and the Connected Vehicle (CV) network. Additional sections were however included in the CV network costs, since the network constructed would be newly development.

Once these costs are identified, a total cost for either approach will be calculated. The costs will compare the price structure of expanding the network and implementing DSRC connectivity.

The cost information with regards to existing ITS infrastructure used in the FMS given by Sanral was approximated (for reasons undisclosed), and should be borne in mind when comparing the systems discussed in this study. Additionally, the devices considered for the Connected Vehicle environment is not currently used or available in South Africa. The technology is still in development and testing stages. The costs were only available for the North American market (based on the test pilots in place). The costs may therefore differ when the technology is made available to South Africa.

The available cost information for the existing network was obtained for the year of 2015, while the cost information for the Connected Vehicle environment was converted to the equivalent Rand value against the US Dollar for 2015, using the average exchange rate between US dollars and the South African Rand. This rate was determined to be R12.77 in 2015 to the US dollar (X-rates.com, 2016).

6.1.1 COSTS: EXISTING NETWORK

The proposed strategy that Sanral intends to execute, is the extension of the existing VMS and CCTV network to include a greater portion of the freeway into the traffic management of the Western Cape region. This extension may currently be a cost effective solution, and most affordable and suitable, given the resources available and success of the existing systems.

The Cost Benefit Analysis of this existing network will therefore be simple due to the nature of the implementation. An extension of the existing network is proposed and will extend beyond the current limits of the infrastructure network used to monitor traffic. Furthermore, the communications backhaul currently exists and will simply be extended to include the areas in which the extensions are intended to take place.

Factors affecting the expansion of the network will be included for the total cost of implementation and, where necessary, will make assumptions of existing expenses to provide a feasible cost structure, and to provide a comparable model to the implementation of DSRC devices.

For the purposes of a fair comparison, the existing network will be compared to the deployment of a new communications backhaul. It is therefore anticipated that the costs associated with the Connected Vehicle environment may be excessive. However, the benefits associated with this system may outweigh initial costs. For overall savings in injuries and accidents, travel time, congestion and carbon emissions, the inherent benefit of the system may be sufficient for the comparison conducted in this study.

6.1.1.1 CAPITAL COSTS

Capital costs are associated with the hardware deployed to specific sites. The following devices are used to monitor the road network, as well as retrieve and provide information specific to traffic management. These items constitute the infrastructure that is deployed in the network, indicating the current use of technology for the operation of the transport network. Approximate costs were provided, which was sufficient for the purposes of this study. The information was obtained from Sanral and is shown in Table 6.1.

Table 6.1: Approximate Cost of Field Equipment (Sanral, 2015)

Equipment	Approximate Unit Cost (R)
Mast with Camera	280 000
Camera (Connected to Existing Mast)	30 000
Security Camera (Connected to Existing Mast)	18 000
Thermal Camera	220 000
Vehicle Detection System (VDS)	82 000
Variable Message System (VMS)	600 000
Environmental System Sensor (ESS)	220 000

The following should be noted with the above mentioned information:

- Mast with Camera: This cost includes a communications connection (not more than 100 meters for fibre), construction for the mast (such as trenches and material costs) as well the camera (PTZ Camera – Pan, Tilt and Zoom).
- Camera (Connected to Existing Mast): Installation of a single camera to an existing mast. Additional cameras are installed on existing mast for accessing visual information in the opposing direction, usually in the case of monitoring larger areas.
- Security Camera: These cameras are static in movement (unable to pan and tilt). Additionally, the zoom function is achieved digitally – this results in an image of suboptimal quality.
- Thermal Camera: Used in areas with constricting visibility due to minimal levels of light (particularly in the evening). The price excludes a mast and must be attached to an existing mast structure.
- Vehicle Detection System (VDS): Detects the number of vehicles and vehicle speeds.
- Variable Message System (VMS): Displays traveller information.
- Environmental System Sensor (ESS):Supports with weather forecasting to assist with provision of traveller information

The cameras described may be installed individually at a single site (single camera at a site), may not be capable of extensive functionality (Security camera) or may require the functionality of each of the cameras specified (Thermal, Security and PTZ cameras) based on the lighting availability at a particular site. Focussing on the design area, the existing number of items is shown in Table 6.2. It was assumed that 50% of the CCTV cameras were installed with masts while the remaining 50% was installed on existing masts. Furthermore, it was assumed that no Security and Thermal cameras were located in the design area. The number of ESSs, VDSs and VMSs in the design area were obtained from layout plans obtained from Sanral (refer to Appendix F). The total approximate cost of the existing ITS infrastructure within the design area is shown in Table 6.2:

Table 6.2: Approximate Total Cost of Hardware Deployed and Installed in Design Area (Source: Sanral, 2015)

Equipment	**Approximate Unit Cost (R)**	**Quantity in Design Area**	**Total Cost (R)**
Mast with Camera	280 000	24	6 720 000
Camera (Connected to Existing Mast)	30 000	23	690 000
Vehicle Detection System (VDS)	82 000	14 (excl. Inrix VDSs)	1 148 000
Variable Message System (VMS)	600 000	4	2 400 000
Total Cost for Hardware			10 958 000

Table 6.2 provides the total cost of hardware existing in the design are, with the total cost of approximately R10 958 000.

6.1.1.2 LAUNCH AND IMPLEMENTATION COSTS

The cost of deployment of infrastructure, along with the costs of labour for installation, planning and design of the layout are provided in Table 6.3.

Table 6.3: Estimated Cost of Launch and Installation of Equipment

Item	**Approximate Cost (R)**
Hardware	10 958 000
Installation Labour	45 334/site
Design and Planning	84 921/site

In this case, the cost of planning and design was considered necessary as the layout of each site varies significantly depending on the traffic conditions and site location. Each site was therefore designed differently with a specific plan for the execution of deployment and installation at that location.

The operation of the Freeway Management Systems are conducted in-house, at the Traffic Management Centre (TMC) in Cape Town. A single operator is required to monitor traffic behaviour by observing the feed of 40 CCTV cameras and, to ensure that the network is monitored continuously, four operators are assigned to a single workstation. The costs associated with the set-up of a single work station is shown in Table 6.4:

Table 6.4: Approximate Cost per Workstation (Sanral, 2015)

Item	Unit	Approximate Cost (R)	Approximate Total Cost (R) per Workstation
Personnel (Wages)	Per Employee/Month	12 000	144 000
	All Employees/Month	48 000	576 000
Software	Per Station	18 000	18 000
Workstation	Single	22 000	22 000

Table 6.4 describes the capital costs associated with the operation of the ITS equipment along the freeways, indicating the approximate cost per workstation. These values are not additive since the Wages are annual costs, while the Software and Workstation costs are based on a useful life basis i.e. the software may be updated when required (a specific interval for regular updating of system software was not provided – updates were assumed to correlate to workstation hardware replacement). Furthermore, for the costs provided for the Software and Workstation:

- Software: Includes cost of annual license repayments and software updates – distribution of costs between these factors was not disclosed.
- Workstation: Includes cost of hardware and office equipment (desk, office chair, miscellaneous office supplies etc.).

6.1.1.3 OPERATION AND MAINTENANCE COSTS

Furthermore, the infrastructure requires maintenance on a recurring basis, along with replacement of certain components that may exceed the operational design life. A license for the maintenance agreement would also be updated in proportion to the maintenance periods of the field devices, along with certificates related to the approval of monitoring and managing these apparatus. The licenses however are continuous and are purchased upfront as part of the Software purchase (Table 6.4). Table 6.5 provides the estimated cost of the remaining items for the operation of the FMS:

Table 6.5: Approximate costs of Operation and Maintenance Aspects (Sanral, 2015)

Item	Cost of Device per year (R)
Power (dependent on device – e.g. VMS) 1 -> for less than 350 kWh (R0.9612/kwh) 2 -> R2.33/kWh	25 000
Traditional Maintenance	380 000/month
License Maintenance Agreements	Included in Software cost (Table 6.4)
Certificate License	Included in Workstation cost (Table 6.4)
Annualised Replacement Cost (every five to ten years)	16 643 - 33 286

6.1.1.4 BACKHAUL COMMUNICATIONS

The costs associated with establishing a communications backhaul for the existing environment were not necessary for consideration since the technology and field devices are currently in place. Additionally, costs associated with planning, design and inspections have been completed and would therefore have no effect on determining the total cost of the existing network in comparison to the conceptual network, as the nature of these costs were non-recurring. However, costs of expanding the communications backhaul were required for consideration due to the expanded network that would be added to the communications network. For this reason, the cost of backhaul and system licenses necessary are provided in Table 6.6:

Table 6.6: Approximate Cost of Backhaul Communications Equipment (Source: Sanral, 2015)

Item	**Average Cost (R)**
Backhaul Cost (for every 1km up to 10km)	265 200
Backhaul Cost (at every 10km an additional cost for an outstation)	204 000
System Integration and License	0
Traffic Control	0

The infrastructure would entail replacement and upgrade costs depending on the extent of the existing equipment on a particular site. For example, the ITS infrastructure may be integrated with an existing backhaul communications network i.e. cellular backhaul network. In most cases however, the backhaul was required to be newly erected.

6.1.2 COSTS: CONCEPTUAL NETWORK

As previously mentioned, the CV environment is under constant development and enhancement, resulting in continually updated and adjusted information. The cost of equipment was therefore obtained from three different sources of the North American market, specifically obtained from a report completed by Write et al.(2014) under the USDOT (*National Connected Vehicle Field Infrastructure Footprint Analysis: Final Report*, 2014), as the infrastructure and equipment discussed was not available in South Africa. The data was therefore obtained from existing Test Beds (areas testing the operations of Connected Vehicles in a real-world environment). The Test Beds in the United States from which the report obtained cost information for the cost of Connected Vehicle equipment are:

- Southeast Michigan Test Bed: This site was developed in phases, consisting of 50 DSRC RSUs deployed along arterial and freeway roads in 2014.
- Arizona: Data generated from a deployment plan that was developed for a region-wide installation.
- Virginia: The Test Bed in Northern Virginia consists of 55 DSRC Roadside Units, covering approximately 10.36 square kilometres of an urban region.

- Turner Fairbank Highway Research Centre (TFHRC) – Intelligent Intersection that was equipped with new infrastructure to support the deployment of DSRC equipment (Write et al., 2014)

As a result, the costs vary for equipment depending on the region, cost of equipment according to the date purchased and costs according to the volume of equipment purchased. For example, the cost of a DSRC RSU (Roadside Unit) in Michigan was R31 925 ($2 500) while in Arizona, the cost of the same device was R12 770 ($1 000). This occurred due to the difference in volume of devices contained within the Test Bed areas – Michigan required 50 RSUs while Arizona made use of 2 680 RSUs. Based on these costs (as well as additional Test Beds in Arizona and THFRC), a relationship was determined between the price and volume of these DSRC Roadside Units. This was necessary to determine the costs based on the volume of DSRC RSUs that may be applicable to the conceptual design in this investigation. Figure 6.1 illustrates this relationship:

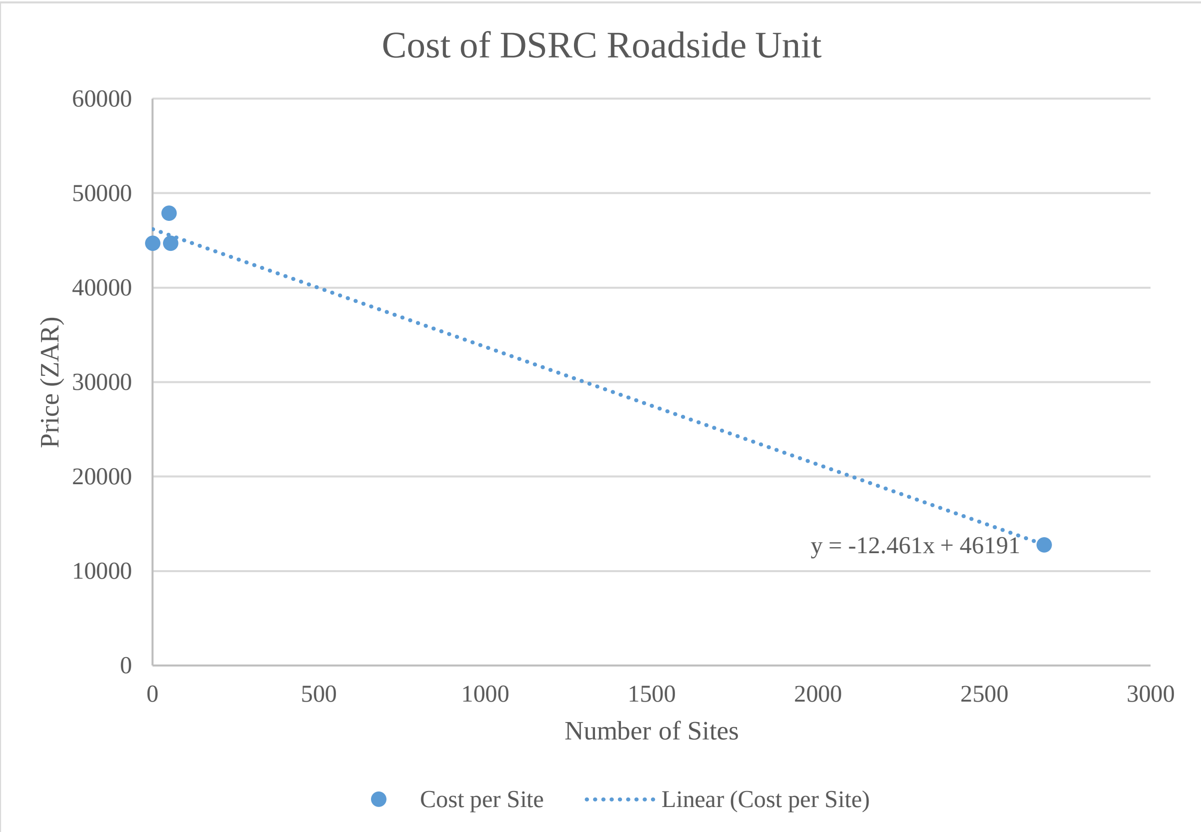


Figure 6.1: Relationship between volume and cost of DSRC devices based on Test Bed prices (Write et al., 2014)

With a cost versus volume relationship obtained (Figure 6.1), the conceptual design would determine the total cost of DSRC Roadside Units based on the number of devices located in the design area. The cost of a single DSRC Roadside Unit (for this investigation) was determined to be R42 179. The full list of prices compiled by USDOT (2014) is attached in Appendix F, indicating all of the areas considered to determine the potential cost of the conceptual environment. The costs discussed for the DSRC communications environment follow the procedure highlighted in *Section 6.1*, and includes:

- Signal Controller Replacement Costs,
- DSRC Deployment Costs,
- Software, Personnel and Infrastructure Components and,
- Additional Cost Information

6.1.2.1 CAPITAL COSTS

The costs associated with capital costs include cost of the devices used and cost of installation. These items are shown in Table 6.7 and Table 6.8. The costs involved were taken from existing pilot test beds and were averaged across the range. The Test-Beds from which cost information was obtained include Michigan, Arizona, Virginia and the Turner Fairbank Highway Research Centre (TFHRC) in the United States. The costs given in Table 6.7 were the average costs of equipment used on the sites:

Table 6.7: Average Cost of Equipment per DSRC site (Source: USDOT/AASHTO 2014, cite by FHWA (2014))

Equipment	**Average Cost (R)**
DSRC RSU	42 179
RSU Incidentals	13 154
Communication Connected Equipment	14 367
Power Connection Equipment	4 151
Additional Installation Equipment	25 540
Total Cost for Hardware	95 137

The following costs relate to installation of the devices:

Table 6.8: Average Cost of Installation per site (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	**Average Cost (R)**
Total Cost for Installation Labour	31 606
Construction Inspection (15% of Hardware Cost)	13 728
Total Installation Cost	45 334

The total capital committed to a single site would therefore be R140 471.

6.1.2.2 LAUNCH AND IMPLEMENTATION COSTS

According to Write et al. (2014), the following cost information was related to planning, design and installation of the connected equipment. It was further assumed that the installations were conducted in areas consisting of existing equipment regarding power supply and mounting facilities (lamp posts, masts or poles). The planning, design and construction inspection costs were determined as percentages of the total implementation cost – these percentages were derived from costs associated with "typical ITS deployment" projects as stated by Write et al. (2014).

Table 6.9: Planning and Design Cost per site (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	**Average Cost (R)**
Radio Survey per site	12 770
Map / GID Generation	12 770
Planning	7 024
Design	20 432
System Integration and License	19 155
Traffic Control	12 770
Total Implementation Cost	84 921

The Federal Highway Administration (2014) describes each of these items to provide an indication of the factors affecting the distribution of a new communications network. The description provided by the FHWA is repeated below:

- **Radio survey**: R12 770 per site – based on the Test Pilots investigated, this was the average cost involved with identifying radio interference at a single site to determine a suitable location in which the DSRC radio and antenna equipment would be installed to optimise the use of its communication range.
- **Map/GID generation**: R12 770 per site – while this is more applicable to the rural environment, it was the average cost for a single site to obtain precise mapping of the intersections. This would provide assistance with the design phase of the projects.
- **Planning**: According to the Write et al. (2014), the amount allocated to planning was 5% of implementation cost (more specifically related to the costing for hardware and installation labour).
- **Design**: The design costs was determined to be 20% of implementation cost (Write et al., 2014).
- **Construction Inspection**: Used as 15% of the implementation cost – The construction inspection included activities such as overseeing of site construction and testing the completed work to ensure conformance to project specifications.
- **System Integration and License**: R19 155 per site – This includes the cost for licenses of the radios (this cost would be allocated to the completion of paper work, DSRC operates on an unlicensed bandwidth and would therefore not require license payments), set-up of radios within the test areas and the cost associated with adding the site to the central system.
- **Traffic Control**: R12 770 per site – This was the costs associated basic traffic control during deployment of site infrastructure, such as switching off the power of electronic equipment along the roadway during installation of DSRC RSUs (Write et al., 2014).

Table 6.10 provides the total average costs involved in attaining an operational system.

Table 6.10: Total Direct Costs of DSRC Installation per site (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	Average Cost (R)
Connected Vehicle DSRC Hardware	95 137
Installation Labour	45 334
Design and Planning	84 282
Total Direct Connected Vehicle Costs	224 753

The total cost for launch and implementation of the necessary equipment per site is R224 753.

6.1.2.3 BACKHAUL COMMUNICATIONS: FREEWAY INSTALLATION

According to the Federal Highway Administration (2014); for the communications infrastructure to be operational, the complete construction of a communications backhaul would be required. Connectivity to back end servers and TMCs establish communication with the field devices. The installation hereof would need additional planning, design and deployment strategies. These will vary according to the jurisdiction and aims of the relevant agencies (Sanral, PGWC and CoCT). Additionally, these are separate tasks for the deployment of RSU and supporting site infrastructure.

The USDOT and AASHTO assembled the costs involved with establishing a communications backhaul based on the deployments and installations at the investigated Test Beds (Table 6.11).

Table 6.11: Costs Associated with Backhaul Installation (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	Average Cost (R)
Reported Backhaul Cost	171 118
Planning	25 540
Design	34 479
Construction inspection	26 817
System Integration and License	19 155
Traffic Control	0
Total Implementation Cost	277 109

The cost of items in Table 12 were completed with the following assumptions, as stated by the FHWA (2014):

- **Planning**: Assumed as 15% of the implementation cost – For development of a communications plan.
- **Design**: 20% of implementation cost.
- **Construction inspection**: 15% of reported backhaul cost - The construction inspection included activities such as overseeing of site construction and testing the completed work to ensure conformance to project specifications.
- **System Integration and License** – R19 155 per site – Based on the Test Bed investigations, this would include the cost for licenses of the backhaul radios (refer to Chapter 2, *Section 2.4*),

set-up of radios within the system and the cost associated with adding a newly constructed site to an existing backhaul system.

- **Traffic Control**: Would not be necessary if installation of backhaul equipment was completed in conjunction with the installation of DSRC RSUs.

While there was no identifiable distinction in the separation of freeway and arterial design, installation and upgrade of roadside equipment in the report compiled by the FHWA (2014), this distinction is indeed evident in the South African context. The following section was therefore separated from the backhaul costs provided above to ensure that the focus of this investigation remains consistent with the freeway operations. Information regarding arterial installation costs was provided to relay the reach of Connected Vehicle technology into the local road network and to provide context of further avenues that may be explored for improvement of traffic operation.

6.1.2.4 BACKHAUL COMMUNICATIONS: ARTERIAL INSTALLATION

The costs compiled by the FHWA (2014) were dependent on results attained from existing and non-existing infrastructure. In this case, not only does the infrastructure not currently exist in South Africa, planning, design and strategic operations have not been considered or established for the deployment of a DSRC communications backhaul. On this basis, it would be necessary to consider the maximum costs involved with the construction of this network as the environment created would be original to South Africa and the Western Cape. Furthermore, the costs were subject to additional variability given the option selected, which may include operational expenses. For example, the communications may be established with leased lines or fibre optic communications. Leased line communications involve an initial low capital cost and ongoing operational costs due to subscription contracts and fees, while fibre optic communication requires a high initial cost (FHWA, 2014). Therefore, the costs determined for initial deployment of backhaul communications range from R38 310 to over R510 800 per site. These costs include planning, design, hardware and labour necessary for establishing the network. The variation presented is the result of the sites investigated housing existing equipment and therefore were not in need of extensive upgrades – this information may therefore be used to gauge the progress and stages of projects executed. Specific assumptions were made by the FHWA when compiling the cost information obtained from AASHTO with for the purpose of generating total costs of upgrading the backhaul communications for traffic signals, which may be found in the report compiled by the FHWA (Write et al., 2014: p.102). In South Africa however, the backhaul communications to the traffic signals do not communicate via DSRC Radios, and the assumption in this case would be that 100% of traffic signals along arterials and freeway would require extensive upgrades, and may cost around R510 800 per signalised intersection (based on the assumptions made by the FHWA (Write et al., 2014: p.102)

Table 6.12: Estimated Backhaul Upgrade Costs (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Backhaul Upgrade Categories	**Estimated Cost (R)**
Integration of Existing Equipment	38 310
Simple Upgrade	280 940
Extensive Upgrade	518 800
Installation of New Backhaul	518 800

As previously mentioned, these assumptions are not applicable in the South African context, but was provided however for possible future reference. In the case of establishing specific levels of backhaul communications, the approximate price may vary according to the backhaul infrastructure deployed; Table 6.12 would therefore be relevant for gauging the cost commitments that may be necessary. Additional software would also need to be included in the current freeway management system, with costs associated for management, operation and running costs (installation and recurring subscriptions). Since a new backhaul installation would most-likely be applicable locally, the costs thereof would be R518 800.

6.1.2.5 SIGNAL CONTROLLER REPLACEMENT ESTIMATES: ARTERIAL INSTALLATION

Although connected signal controllers were not modelled in this study, the costs were included to provide context to the extent of the connected environment, especially in light of including arterial management to the FMS within a connected environment. This information was included based on the Cost-Benefit Analysis in which it is required that signal controllers contain DSRC equipment to address the Red Light Violation application. This application is related to enhancements in safety, which is not the aim of this investigation – this section was therefore only included to provide a “clear picture” of the extent of the environment and additional areas in which research may be extended to determine the benefits of expanding the connected ITS environment.

Table 6.13: Total Cost of Upgrading Signal Controllers (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	**Cost (R)**
New Controller Equipment	28 094
Labour to Install/Program Controller	12 770
Total Cost Per Controller	40 864

According to the FHWA (2014), the costs for maintenance, electronics and related construction work for traffic signals was not considered in this case. The costs indicated simply reflect the extent of the upgrade needed to achieve the desired effect, i.e. communicating with CVs and existing TMCs.

6.1.2.6 TOTAL DSRC DEPLOYMENT COSTS

The approximate total cost of deploying DSRC connectivity and communication is summarised in Table 6.14. The cost structure for installing new equipment and infrastructure was used to determine the total cost of deployment per site.

Table 6.14: Total Potential DSRC Site Costs of Connected Vehicle Infrastructure Deployment (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	**Estimated Cost (R) (Signalised Intersection)**	**Estimated Cost (R) (Non-signalised Intersection)**
(DSRC) Equipment and Site Deployment	224 753	224 753
Backhaul Installation	393 316	393 316
Traffic Signal Controller Upgrade	40 864	
Total Potential Site/Unit Cost (Excl. Traffic Signal Upgrades)	658 933	618 069

The total cost for deploying DSRC equipment and deploying the backhaul communications network to support DSRC connectivity for a freeway would therefore approximately cost 618 069 per site.

6.1.2.7 ADDITIONAL COSTS

The costs discussed in this section will address operations and maintenance of the systems in use, as well as related costs of using the equipment.

OPERATIONS COSTS

The cost in this case was the operation (power and communication) of an additional device at the site, specifically the DSRC equipment. According to Write et al. (2014), the power is not anticipated to consume more power than a typical Wi-Fi router. The cost was therefore determined from operating a 110 Watt device at an average rate of R1.53/kWh (Yelland, 2015), operating for 24 hours and seven days a week, the annual cost was determined to be approximately R1 477 per device.

MAINTENANCE COSTS

The costs involved with maintaining the system may be understood as regular maintenance in which the systems are checked on site on a contractual basis to ensure that the systems are in operational conditions are adhered to(device being damaged by weather or external conditions). The estimated cost of this level of maintenance was given as R6 807 (Write et al., 2014). Additionally, the license for use of device software would require an annual payment, resulting in a cost of R3 050. Finally, the software would be updated on a regular basis to ensure that security is constantly improved and updated, leading to an average cost of R640 per device.

REPLACEMENT COSTS

The replacement of the device may be expected to take place every five to ten years depending on the level of operation and effect of external conditions (FHWA, 2014). The total cost for this would be R136 346 every five to ten years (FHWA, 2014):

Table 6.15: Estimated Annual DSRC Site Operations, Maintenance and Replacement Costs (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Item	Cost of Device per year (R)
Power	1 477
Traditional Maintenance	6 807
License Maintenance Agreements	3 050
*Security Credentials Management System (SCMS) Certificate License	640
Annualised Replacement Cost (every five to ten years)	13 635 – 27 269
Total	25 609 – 39 243

** System that ensures information transferred between mobile devices and roadside devices is established only from authorised access (iteris.com, 2016). Refer to Chapter 2, Section 2.6*

6.1.2.8 COST ESTMATES ASSOCIATED WITH THE BACKEND SYSTEM

This system may be used by traffic management agencies to collect and store raw data from vehicles and road side infrastructure. The information is then distributed back to the vehicles through On-Board Units (OBUs) or cell phones (Smartphones) in terms of useful information to the road users. The following items address the costs involved with ensuring a functional backend system.

6.1.2.8.1 SOFTWARE

According to Write et al. (2014), the following components should be addressed to ensure that connected vehicle back end software solution is attained with regards to the software components:

- **Validate Data**: Ensure that the data is obtained from a valid source containing the correct data points. This will prevent the possibility of security breaches.
- **Route Data**: Once the data is obtained, it should be routed to the appropriate location, such as the traffic management agency or traffic signal operators etc.
- **Process Data**: Once the information is routed, the decision should be made to determine the nature of the content – whether or not the information should be sent to the road users or other facilities and the manner in which the information should appear (via applications as information or requests).
- **Distribute Information**: Once the information is processed, the correct distribution should be executed.
- **Store Data**: The data should be stored for future analysis to improve upon any of the systems implemented (Write et al., 2014).

With this system in place, the connected vehicle environment may be anticipated to constantly improve. This may lead to further enhancements in travel time, safety, mobility and carbon emission reduction.

6.1.2.8.2 PERSONNEL

The following points address the daily responsibilities of the personnel operating the systems:

- System Monitoring: This is necessary to assess the daily system operations, responding to possible cyber-security attacks and related issues.
- System Upgrades and Enhancements: to ensure consistent operational functionality and optimised use.

The network would require consistent monitoring to provide beneficial user experience and trust.

6.1.2.8.3 INFRASTRUCTURE

The infrastructure components may be the following:

- Computer Hardware: The system on which all of the software components run.
- Physical Facilities for Hardware: This is the physical centre housing the computers and servers.
- Facilities for Personnel: The desks, office space and equipment required by personnel to perform the necessary tasks for monitoring the systems.

This would ensure that the operators would be fully equipped to work efficiently in monitoring the network to determine possible improvements to the existing network.

6.1.2.9 IN-VEHICLE DSRC EQUIPMENT

The costs within this section relate to the physical components that need to be installed in vehicles to enable connectivity to the environment, that is, Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication. These costs are therefore an indication of the financial commitment that road users would be expected to pay to acquire the connected technology in their personal vehicles. These costs are described in Table 6.16:

Table 6.16: Unit Costs for DSRC-based Data Collection Equipment (Source: USDOT/AASHTO 2014, cited by FHWA (2014))

Equipment	**Unit Cost (R)**
DSRC Radio	12 770
Installation Tools	1 916
Labour	38 310*
Video Collection System (Optional)	64 489
Total Cost Per Vehicle (Without Video)	52 996
Total Cost Per Vehicle (With Video)	117 485

** Cost based on USDOT Information*

The costs compiled by the USDOT and AASHTO in Table 6.16 were dependent on the in-vehicle systems used. In Michigan, the data was collected from an Android[3] based Smartphone (FHWA, 2014). The cost of installation however may be extensive for local consideration and was adjusted for the cost benefit analysis to range between R5 000 to R10 000 (depending on the service provided) based on the installation of a tracking device (Wheels24, 2007). Based on the increasing rate of penetration of Smartphones and mobile broadband connectivity (refer to Chapter 2, *Section 2.4.3.3*), the use of Smartphones for traveller information would eliminate a significant proportion of the cost for road users; the remaining aspect would be the provision of access to traveller information from the database to road users. The requirements for this type of in-vehicle setup (as described in the FHWA 2014 report compiled by Write et al.) involves the use of a Smartphone, a mounting device on the dashboard for the phone and a power cable with a cigarette lighter adapter (Write et al., 2014). Additionally, the user would be required to install an application providing the necessary information. This application would preferably be designed and developed by and for an existing TMC for use in FMS operations (refer o Chapter 2, *Section 2.5*).

Furthermore, a later study completed by Harding, J., Powell, G., R., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., Lukuc, M., Simons, J., & Wang, J. (2014) considered three further options for installation of CV equipment. These were separated in terms of configuration and requirements of the user and were titled Retrofit, Self-contained and Vehicle Awareness Device. The description for these options is as follows (Harding et al., 2014):

- Retrofit: Connected to the vehicle's data bus (A subsystem of a computer that transfers data between devices), sends and receives Basic Safety Message (BSM) and provides warnings
- Self-contained: Does not connect to the vehicle's data bus and only uses a wire to get power from the vehicle, sends and received BSM and provides warnings
- Vehicle Awareness Device (VAD): Uses a wire to get power from the vehicle, sends out but does not receive BSM and does not provide warnings.

The estimated costs for these devices, according to Harding et al. (2014) were obtained through consultation with confidential companies and is shown below for the provision of alternative costs for users to enable CV technology.

Table 6.17: Cost of Equipment for CV Technology (Excluding Installation Costs) (Harding et al., 2014)

Component	**Unit Costs (R)**		
	Retrofit	**Self-Contained**	**VAD**
DSRC Transmitter/Receiver	1 838.88 (2)	1 470.97 (2)	670.43
DSRC Antenna	191.55 (2)	191.55 (2)	95.78
Electronic Control Unit	861.98	861.98	-

[3] Android is an Operating System (OS) providing functionality to electronic devices (Smartphones, Tablets, etc.) as well as an identifiable User Interface (UI)

GPS	268.17	268.17	219.15
GPS Antenna	76.62	76.62	54.95
Wiring	191.55	153.24	-
Displays	287.33	134.10	-
Total	3 716	3 142	1 035

The installation costs (for the abovementioned items) were not considered, since the costs may be dependent on the amount of time the vehicle is remains at the workshop, the aftermarket installer's rate and possible improvements that may be necessary before the installation of the equipment mentioned thus far may be installed. A range of R5 000 to R10 000 for installation was therefore used in the cost estimation of these devices.

A third cost estimation study for direct vehicle costs was conducted by the Michigan Department of Transport (MDOT, 2012) where the costs were determined for both vehicles being manufactured with the devices as standard, and the vehicle owner installing the equipment as aftermarket fitments. The approximate costs were identified (MDOT, 2012):

- Manufacturer Costs: DSRC and CV Equipment: R7 943.30
- Aftermarket Equipment: R3 026.00

The vehicles in the network may use a combination of DSRC and Wi-Fi connectivity, as well as connections to existing cell phone towers. In the case of using cell phones for connectivity, a data plan to allow vehicles to constantly be connected to the internet (with the use of data). The following rates were obtained from different network providers in South Africa:

Table 6.18: Example Cellular Data Plan Rates

Source and Service	**Monthly Rate (R)**
Vodacom consumer price (www.vodacom.co.za) 10GB + 2GB G-Connect Wi-Fi + 10GB Night Owl	579
Vodacom consumer price (www.vodacom.co.za) 5GB (12 month)	289
MTN Consumer price (www.mtninternet.co.za) 9GB (24 month)	524
MTN Consumer price (www.mtninternet.co.za) 5GB (24 month)	314
Cell C Consumer price (www.cellc.co.za) 10GB data, 10GB anytime time and 10GB night time	349
Cell C Consumer price, www.cellc.co.za, 5GB data, 5GB anytime time and 5GB night time	199

The rates indicated in the table above are subject to change depending on the type of connection that may be established in future. Additionally, the rates may only be applicable at the time of completion of this investigation since increasing connections may reduce internet usage costs. A range of R200 to R400 was therefore selected for the monthly internet connection charge.

6.1.3 COSTS: CELLULAR-ENABLED CONNECTIVITY

The Cellular-enabled CV option involves the use of On-Board Units (OBU) for communication with the driver, where an external display is brought in to provide traveller information concerning the route and surrounding environment. The identified benefit of this option is the existence and ease of availability of devices possessing the capability of providing information to drivers. Smart phones provide a simpler alternative to purchasing additional hardware for vehicles and are capable of being voice-activated, eliminating the need for drivers to change focus from the in-vehicle devices to the road. Both applications addressed in this investigation may be employed with cell phones, since Speed-Harmonisation is the presentation of an appropriate travel speed and Queue-Warning alerts the driver of possible dangers along the route and changes in the nearby environment (Construction, Incidents, Weather, etc.).

Additional costs for cellular connectivity are based on the requirements that the user should not handle the device whilst driving, should ensure that the device is fully operational for the journey and should have a constant internet connection. The driver therefore requires a mounting device on the dashboard (to hold the cell phone), a power cable with an adapter (to be plugged into the cigarette lighter holder) and a data plan. While this information is presented in the Cellular-enabled CV alternative, these costs would be applicable to DSRC-enabled CVs using a Nomadic device to provide information to users. The following costs were identified:

Table 6.19: Cost of Equipment for Cellular Connectivity

Item	Price (R)
Suction-Mount	350
In-Vehicle Charger	250
Data plan (Average: Table 12)	200 400
Total	800 1000

The costs assigned to traffic management agencies would be license costs for obtaining information from cellular network providers (apart from existing licenses for probe data information if necessary). This information would be used to provide the traveller information. Additional costs may be assigned for in-house application updates or third-party application development – this cost would be included in the license agreement. The average cost of the license agreement (as mentioned in Table 6.15) was provided as R3 050 per year. The costs for maintenance of the existing infrastructure (that may later be decommissioned) would be a factor until penetration of CV technology has reached an optimal level to the extent that the presence of existing ITS Infrastructure may be reduced. Since this level may not be predicted, the years selected for optimal penetration were selected as 2020, 2025 and 2030. The maintenance costs of the existing network (particularly for VMSs) would be a factor in the Cost-Benefit Analysis until these arbitrary dates of possible decommission of existing VMSs.

6.1.4 EXISTING NETWORK COMPARED TO THE CONCEPTUAL NETWORK

For this investigation, the design area was selected with the intent of housing existing ITS equipment. This area was further chosen based on the requirement of a starting and end point for the simulation model for this investigation. Since the area contains existing ITS equipment, these will not be added to the cost benefit analysis, but provides an indication of the costs associated with the existing equipment in comparison to the potential equipment for a Connected Vehicle environment. This information would be relevant with consideration of the extension of the existing network.

The initial intention of this investigation was to consider an environment in which the existing equipment would be decommissioned in place of a new system that supports Connected Vehicle technology. This approach was considered due to the high cost of maintenance, licensing and replacement costs associated with existing infrastructure which would surely be increased in expanding the existing network. To determine the effect that Connected Vehicle technology may have on the environment, the following comparison should be considered. The capabilities and purpose of existing equipment will be compared to the potential equipment necessary for a connected environment. This comparison will attempt to shed light on the requirements of an intelligent traffic environment and the transportation related aspects that a traffic network should provide:

Existing Network		**Conceptual Network**	
Equipment	Purpose	Equipment	Purpose
CCTV	Surveillance of network operation		
VMS	Displays traveller/incident information	Nomadic Device	Communication directly to user
VDS	Vehicle counts, speed and classification for network operation and	DSRC-Radio/DSRC RSU	Communication between vehicles and roadside units
ESS	Supports weather information	Weather Sensor	Obtains information from the road to support weather data

From the comparison, it may be discerned that the equipment used in a Connected Vehicle environment would provide similar and possibly an improved view of traffic flow in the Western Cape FMS network. The Nomadic Device would provide the traveller information (VMS) and may additionally be used as a probe in conjunction with the DSRC radios and DSRC RSUs (VDS). The Weather Sensor would be capable of providing the functionality of the ESSs. Therefore, with this comparison and suitable market penetration of Connected Vehicles in the Western Cape, it may be possible to reduce the presence of VMSs, VDSs and ESSs. The VDSs are however third party devices (Inrix owns and operates VDSs along the Freeways in the Western Cape) and will not be considered for decommission. Furthermore, the conceptual design does not present an alternative to CCTV cameras, and will thus also not be considered for decommission in the Cost-Benefit Analysis.

6.1.5 CONCLUDING REMARKS

The costs of the existing infrastructure, Integrated/Embedded CV infrastructure and equipment and Cellular-enabled CV equipment were elaborated on in this section. At this point, it is clear that the costs associated with the installation of a new communications backhaul would be extensive, requires significant planning and organisation in terms of conceptualising the design and operation of the systems. A cost comparison between the three avenues indicates that the planning and deployment of Connected Vehicle technology would require the highest capital commitment, while the Cellular Connectivity option provides the lowest financial investment. However, the benefits that may be attained from these options may provide a different perspective of the situation to be considered, and is discussed in the following section.

6.2 BENEFITS

The benefits (for the purposes of this investigation) was based solely on Connected Vehicles under the assumption that the current situation produced no additional benefits. The results obtained from the simulations were used to determine the factors producing improvements in travel conditions. Three general areas of improvement in transportation are described below, while the focus of this investigation is particularly on the enhancement of efficient travel. The increase in travel time efficiency affects the behaviour of a network entirely, however, the extent of technological enhancement deployed may have a greater effect on this anticipated improvement, as well as provide secondary (to this investigation) benefits. These areas may be described as follows:

- **Efficiency**: As previously mentioned, the purpose of this investigation relates to improving the efficiency of travel on the road network. Gaining direct access to the individual vehicles will have a greater effect on the operation of the network, allowing for greater access to management of the road network.
- **Safety**: The rate at which accidents occur is extremely high in South Africa, implying large costs to the economy and increasing congestion on the road. It is therefore imperative that effective preventative action be executed to reduce road accidents. Connected Vehicle technology proposes a solution to this through V2I and V2V communication.
- **Mobility**: Connected Vehicles receive and provide information consistently, allowing for enhanced mobility by way of time, costs (fuel, maintenance) and reliability.

Within transport efficiency, the sectors of improvement identified were therefore reduced travel time (including reductions in stops and delays), reduced fuel consumption and GHG emissions. The sections that follow discuss the improvements determined through the simulation of the Speed-Harmonisation and Queue-Warning applications, and thereafter the adaptations from Smartphones (Cellular connectivity) and Connected Vehicles (Integrated/Embedded Connectivity).

6.2.1 SIMULATION RESULTS

The simulations provided varying results relating to travel time, emissions and fuel consumption. In general, however, an improvement was identified in the applications tested. Table 6.20 provides the improvements determined through the simulated models.

Table 6.20: Improvements in Efficiency Based on Simulated Model

Applications	Affected Area	Free-Flow: Improvement
Speed-Harmonisation	Travel Time Reduction	-17%
	Queue Reduction	18%
	Emissions Reduction	2.6%
	Fuel Savings	2.6%
Queue Warning	Travel Time Reduction	16.18%
	Queue Reduction	5 min delay: 17.2% 10 min delay: 15.7%
	Emissions Reduction	2%
	Fuel Savings	2%
Connected Vehicle (Cellular)	Travel Time Reduction	9.83%
	Queue Reduction	5 min delay: 8.6% 10 min delay: 5%
	Emissions Reduction	2%
	Fuel Savings	2%
Connected Vehicle (Integrated)	Travel Time Reduction	10.71%
	Queue Reduction	40% CVs: 36.6% 50% CVs: 38.3% 60% CVs: 40.9%
	Emissions Reduction	1.3%
	Fuel Savings	1.3%

The Speed-Harmonisation application was modelled in comparison to the Base Condition, only considering the effect of speed variations against fluctuating capacities, while the Queue-Warning application was modelled in comparison to the Accident Model. Considered individually, Speed-Harmonisation displayed an improvement in traffic flow whereas Queue-Warning showed an improvement in travel time. Queue-Warning and Speed-Harmonisation was however modelled simultaneously with Tethered and Integrated CVs. Improvements in safety were not tested in this case as the applications were not focussed on safety enhancement – Queue-Warning and Speed-Harmonisation may provide safety enhancement given the inherent nature of these applications (refer to Chapter 2, *Section 2.2.3*). It can however be confirmed that the efficiency aspects displayed an improvement, while mobility may be improved based on these results.

6.2.2 BENEFITS TO MANAGEMENT AGENCIES

As previously mentioned, the intention of this study was to determine the effects that Connected Vehicle technology, through modelling and testing CV applications, may evoke through CV application testing, with specific focus on efficiency. While travelling efficiency was the focus, an extensive cost analysis was conducted, including the consideration of potential planning, deployment and power usage necessary for multiple possible sites. Furthermore, the key motive for utilising DSRC communication is to improve safety (refer to Chapter 2, *Section 2.4.1)*. For this reason, the potential benefits were extended to include improvements that may be achieved with respect to safety. The inclusion of these safety benefits may substantiate the extensive capital committed to the potential development of a Connected Vehicle environment. The most significant aspect of safety that may be addressed (from a monetary perspective) is the prevention of accidents, specifically on the freeways within the Western Cape, and more so within the design area for this study. Since accident prevention, avoidance and numerous accident scenarios between light vehicles were not investigated to a quantifiable extent, this information was obtained from an existing study conducted by the USDOT in the report *Big Data Implications for Transport Operations: An Exploration* (USDOT, 2014). Clarity was not given on the nature of the vehicles involved (between a CV and a non-CV equipped vehicle, or between two CVs). For a conservative approach, it was assumed that the stated accident prevention rate of 83% would only be possible for the interaction between two CVs.

Sanral was consulted for freeway-related accident data in the Western Cape. The following information was obtained for the year of 2015 (Figure 6.2):

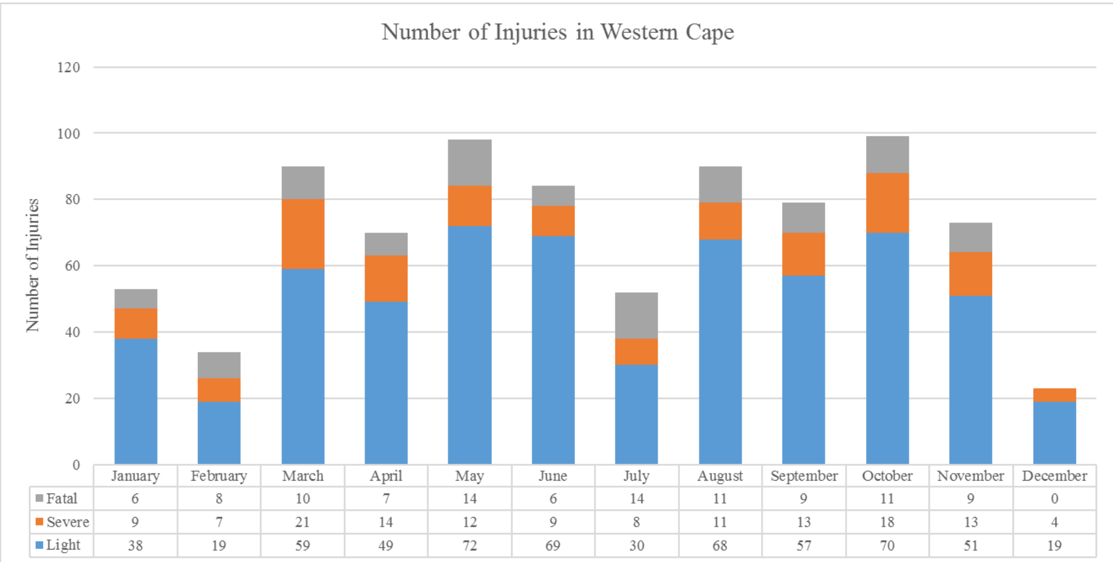


Figure 6.2: Accident Data for 2015 (Source: Sanral)

Figure 6.2 indicates all accidents that occurred along the freeways managed by Sanral in the Western Cape for the entire year of 2015. From this data, the accidents that occurred in the design area were identified and are indicated in Table 6.21:

Table 6.21: Accidents Located in Design Area

Month	Accident Type			Total
	Light	Severe	Fatal	
January	6	1	0	7
February	4	1	2	7
March	4	0	0	4
April	7	3	1	11
May	7	2	0	9
June	10	1	2	13

July	4	0	0	4
August	7	0	0	7
September	17	4	1	22
October	3	0	1	4
November	5	1	0	6
December	7	0	0	7
Total	**81**	**13**	**7**	**101**

With the number of accidents identified for the design area and a usable rate of accident prevention (i.e. 83%), the total cost that may potentially be saved annually is indicated in Table 6.22. The cost per crash type was obtained from a report completed by F. Labuschagne for the Road Traffic Management Corporation (2016), *Cost of Crashes in South Africa: Research and Development Report*. These costs are indicated in Table 6.22 per accident type:

Table 6.22: Average Savings on Accidents with Implementation of Connected Vehicles

Accident Type	Number Involved (Annual)	*Unit Cost (R)	Total Cost (R)	Effect - New Cost (R)	Total Savings (R)
Light	81	152 244	12 331 764	2 096 400	10 235 364
Severe	13	765 664	9 953 632	1 692 118	8 261 514
Fatal	7	5 435 261	38 046 827	6 467 961	31 578 866
Total	**101**	**6 353 169**	**60 332 223**	**10 256 478**	**50 075 745**

**Source: (Labuschagne, 2016)*

The benefits presented in Table 6.25 may only be assumed possible for a CV market penetration rate of 100%. Figure 6.3 therefore illustrates the rate of reduction versus the rate of CV penetration. This rate of CV penetration was included from a study completed by Jan Verlinde (2015) – *Connected Vehicle Prospects for South Africa*, in which several dates for market penetration of Connected Vehicles in the existing vehicle fleet in South Africa was tested. The dates selected for initial penetration was October 2015, October 2020 and October 2025. Since the accidents were detected for 2015, the information for CV penetration beginning in 2015 was selected.

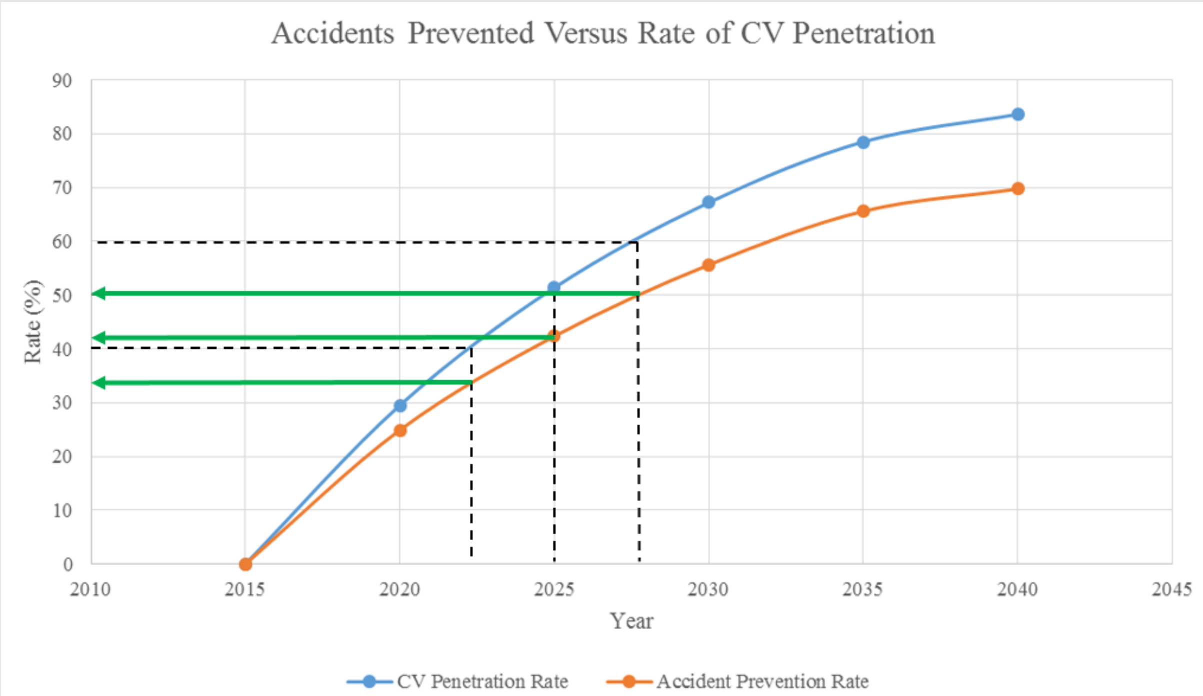


Figure 6.3: Rate of Accident Prevention with Increasing Penetration of Connected Vehicles

Figure 6.3 indicates the anticipated rates of reduction for the penetration rates considered in this study, namely 40%. 50% and 60% CV penetration rates. Therefore, at a CV penetration rate of 40%, the percentage of accidents prevented may be 33%. For penetration rates of 50% and 60% (as discussed in this investigation), the accident prevention rates were determined to be approximately 42% and 50% respectively:

Table 6.23: Accident Prevention Rate based on CV Penetration Rate

CV Penetration Rate (%)	Accident Prevention Rate (%)	Year
40	33.2	2023
50	41.5	2025
60	49.8	2027

This would result in the following present worth savings (within the design area):

Table 6.24: Potential Benefits in Accident Reduction within Design Area

CV Penetration Rate (%)	Accident Prevention Rate (%)	Present Worth Benefits (R)
40	33.2	17 223 903.45
50	41.5	20 732 546.03
60	49.8	23 957 689.22

Figure 6.4 indicates the decrease in accidents versus the rate of CV deployment, with the assumption that the rate of accident occurrences along the freeways remain constant.

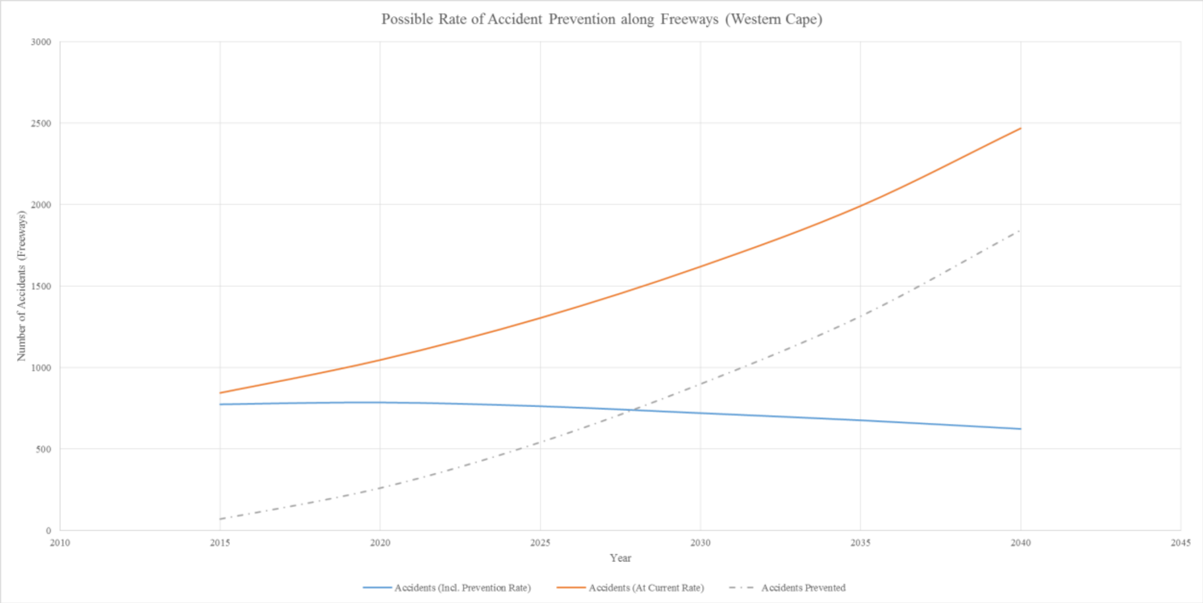


Figure 6.4: Potential Rate of Reduction in Accidents

With the accident prevention rate determined, the benefits of CVs was determined and was summarised in Table 6.22 and Table 6.23. Appendix F contains the full calculation for obtaining the benefits related to Integrated Connected Vehicles.

6.2.3 DIRECT USER BENEFITS

The improvement in travel time and fuel consumption are far reaching advantages not only applicable to commuters, but also to businesses, the political environment and society. Improving the travel time of private vehicles and public transport ensures that employees gain access to work punctually, resulting in a more productive work force (since employees would have a complete work day). Although the effects may only be significant in long term consideration, improving GHG emissions is applicable to both the political sector and society, since the government is expected to produce reduced emissions according to the Department of National Treasury (2010), while the effects on society is the reduction to contribution to climate change.

The models presented the following benefits that may be realised with the implementation of both Cellular-enabled and DSRC-equipped Connected Vehicles (when compared to the Accident Model). A benefit that may be identified by users is savings in fuel consumption. For example, with the use of an alternative route (such as using the N2 instead of the N1, given that the option is both available and possibly feasible) and allowing vehicles along the route to travel at a safer speed, the fuel consumption of the entire network may be reduced or at the very least, would not be unnecessarily consumed through the effects of congestion. The following table indicates the potential fuel savings based on the simulations:

Table 6.25: Savings in Fuel Consumption (R)

Application	Queue-Warning	Connected Vehicles (Tethered)	Connected Vehicles (Integrated)
Average Improvement (R)	8.50	5.70	14.30
(Trip Back and Forth)	17	11.40	28.60
(Working Days: 250)	4 250	2 850	7 150

Values Rounded to nearest Cent

The table indicates that the most effective option would be the Integrated CVs in this case, since it appears to provide the most beneficial fuel-savings for the model considered.

Thereafter, improvements in travel time were identified in comparison to the Accident model. In this case, vehicles may not be subjected to congested traffic and occupants would spend less time in commute, enhancing productivity while reducing operation and maintenance costs to the vehicle. For the savings that may be attained based on the simulations in the design area, the cost of travelling with a private vehicle in the Western Cape was used, based on data provided by Stats South Africa in the *National Household Travel Survey, 2013* (2014). For private vehicles, the average monthly cost of travelling in the Western Cape in 2013 was R1 405 (Statssa.gov.za, 2014). Adjusted to an annual amount and for inflation (based on Consumer Price Index (CPI) for 2015 (Statssa.gov.za, 2016)), the annual cost of travelling for a private vehicle in the Western Cape was used as:

$$Annual\ Cost = Cost_{2013} * 12 * \left(\frac{CPI_{2015}}{CPI_{2013}}\right)$$

Where $Cost_{2013}$ = R1 405

CPI_{2015} = 114.7

CPI_{2013} = 103.4

The average annual cost of travelling was therefore determined to be R18 702.53 for the Western Cape, based on the travellers making use of a private vehicle as transportation. The savings that may be achieved from this amount is indicated in Table 6.26:

Table 6.26: Average Saving in Travel Time per Annum(R)

Application	Queue-Warning	Connected Vehicles (Cellular)	Connected Vehicles (DSRC)
Average Improvement (%)	16.18	9.83	10.71
Total Cost/Annum (Rand)	18 702.53	18 702.53	18 702.53
Benefit (Rand)	4 853.50	2 950.00	3 213.50
Reduced Cost/Annum (Rand)	13 849.03	15 752.53	15 489.03

Savings Rounded to Nearest Cent

Comparing the Connected Vehicle options, it can be seen that the integrated CVs may provide greater savings with travel time. The Queue-Warning application however indicates the highest saving. This may be attributed to the consideration that vehicles modelled in this application were not required to reduce their average speed (only the Cellular-enabled and DSRC-equipped options were tested to comply with the Speed-Harmonisation application).

The final benefit addressed in this investigation was the improvement in vehicle emissions. Although South Africa as a whole is in consideration of implementing carbon emissions, the only tax currently in effect is paid upon purchase of the vehicle. Therefore, the improvements calculated result in no benefit being achieved by the private vehicle owners in Cape Town, and South Africa, since there is no congestion charge in which vehicles are taxed per gram extra CO_2 emitted per kilometre (similar to the congestion charge in London (Matters, 2016)). According to the Department of National Treasury (2010), a proposal for congestion charges involved a payment for emissions above 120 g/km at a rate of R 75 per gram. This would have resulted in the following benefits being achieved, indicated here only for the sake of clarity:

Table 6.27: Savings for Reduced CO_2 Emissions

Application	Queue-Warning	Connected Vehicles (Cellular)	Connected Vehicles (DSRC)
g/km saved	3.2	4	2
R 75 / g/km	240	300	150
Working Days (Trips Back and Forth)	120 000	150 000	75 000

The charge for congestion is a daily charge and was proposed to motivate South Africans to purchase more fuel efficient vehicles. The proposal was however, not implemented under the argument that sufficient alternatives were not available (Booyens, 2013) and should be presented if the congestion charge is to be enforced. These figures were therefore presented as an indication of the possible improvement that Connected Vehicle technology may provide.

6.2.4 CONCLUDING REMARKS

The results presented reflect an improvement in all facets considered for enhancing efficiency of travel. With the use of Speed-Harmonisation and Queue-Warning, two applications of Connected Vehicles, a noticeable improvement was found. The following information was presented in this section for all of the applications and alternative connectivity options:

- Average improvement in Travel Time of 12%
- Improvement in Fuel consumption and CO_2 emissions reduction of 2% per day
- Average reduction in delays of 18%

The benefits that may be achieved by management agencies within the design area was determined to be above R50 million (Table 6.22), while the road user benefits for the design area is summarised in Table 6.28:

Table 6.28: Road User Benefits for Design Area

Application Area	**Annual Savings (Rand)**			
	Fuel	**Travel Time**	**(Potential) Congestion Costs**	**Total**
Queue Warning	4 250	4 853.50	120 000	*9 103.50 129 103.50
Connected Vehicles (Cellular)	2 580	2 950	150 000	*5 530.00 155 530.00
Connected Vehicles (Integrated)	7 150	3 213.50	75 000	*10 363.50 85 363.50

**Excludes potential effect of congestion cost saving*

According to the results obtained, the traffic conditions in Cape Town may therefore be improved with the implementation of Connected Vehicles.

6.3 EVALUATION OF ALTERNATIVES

The costs and benefits associated with each of the three choices were presented. In this section, a discussion of the possible alternatives is presented to compare the opportunities and threats of each of the options. These alternatives are:

- Alternative 0: Do Nothing – the network remains unchanged and continues to be upgraded and maintained according to the current plan in place.
- Alternative 1: Connected Vehicle Network with DSRC – installation of new infrastructure and deployment of equipment.
- Alternative 2: Cellular Connectivity – users incorporate existing equipment to enhance provision of traveller information.

A detailed discussion of each alternative follows with an evaluation of the results to draw a conclusion regarding the optimal choice applicable to South Africa in the Western Cape.

6.3.1 ALTERNATIVE 0: NULL ALTERNATIVE

The Null Alternative discards the suggested proposals, as a plausible alternative may not have been identified. In this case, the alternative entertains the plan currently in effect, and considers the effect of continued implementation i.e. the extension of the existing Freeway Management System Infrastructure would continue to be deployed. For this reason, the approximate singular cost of each item is indicated in Table 6.29, while the following should be taken into account: Although the extension of the network is current in effect, this will not provide a fair comparison for the deployment of a completely new communications backhaul with regards to Alternative 1 (DSRC Communication) as well as an alternative means of providing traveller information in using Alternative 2 (Cellular Communication). The costs used to compare the Null Alternative to the first and second alternative only consider current payments (such as maintenance and licenses) within the design area of this investigation, which is discussed in this section. The cost information of new infrastructure is therefore provided only as a means of clarity, and may be compared to the costs associated with an alternative form of communication (Alternative1).

Table 6.29: Cost of All Hardware Currently Installed in the Western Cape along Freeways (N1, N2, M5) in Design Area

Equipment	Approximate Unit Cost (R)	Quantity in Design Area	Total Cost (R)
Mast with Camera	280 000	24	6 720 000
Camera (Connected to Existing Mast)	30 000	23	690 000
Vehicle Detection System (VDS)	82 000	14 (excl. Inrix VDSs)	1 148 000
Variable Message System (VMS)	600 000	4	2 400 000
Total Cost for Hardware			10 958 000

A site may include any of the items mentioned in Table 6.29 and is dependent on the information required by an existing Traffic Management Centre (TMC) at a particular site, the influence of the environment and the conditions of traffic. This information may therefore serve as a basis for determining the approximate cost of site Infrastructure for the design of a site. The only costs for consideration at this stage however, was the license, maintenance and software updating as the infrastructure was already in place within the design area. The following table provides the potential cost of an existing site (includes price of all hardware):

Table 6.30: Potential Cost of Deployment and Installation of Hardware and Equipment

Item	Estimated Cost (R)
Equipment and Site Deployment (Varies depending on Installation)	1 523 633.5
Backhaul Installation	328 321
Backhaul Upgrades and Deployment	605 200
Total Potential Site/Unit Cost	2 457 154.50

Table 6.31 indicates the costs associated with the license, maintenance and software updating (included in license cost). In this case, based on the view that the use of Nomadic devices (Smartphones, Tablets, etc.) and Weather Sensors in Connected Vehicles may render VMSs and ESSs respectively, only VMSs and ESSs were considered for decommission in this study.

Table 6.31: Total Cost Associated with Existing Equipment in Design Area

Item	Estimated Cost per Annum(R)
Maintenance (Estimated per VMS)	21 923.10
Maintenance (Estimated per ESS)	12 000*
License	3 782.50
Software	Incl. in License
Total Unit Cost	25 705.60

** No ESSs in Design Area*

Since the existing network was established as the Base Condition, the benefits for this alternative were not necessary for calculation. With the use of a 20-year design period, the present worth of the costs for maintaining the current systems was determined to be R1 601 055.02 within the design area. The complete list of costs can be found in Appendix F.

6.3.2 ALTERNATIVE 1: IMPLIMENTING DSRC COMMUNICATIONS

This alternative considers the implementation and deployment of DSRC equipment and infrastructure to assist with V2I and V2V communication in the road network. To gain an understanding of the difference in cost and possible benefit that DSRC may provide, the maintenance costs of equipment for the design area was considered against the deployment of equipment for a new DSRC backhaul. For DSRC equipment and backhaul infrastructure to be deployed and implemented within this network, the design may be illustrated by Figure 6.5:

Figure 6.5: Location of New DSRC devices and DSRC Communications Backhaul Towers

Figure 6.5 shows the approximate design location and frequency of the items that would be necessary to provide communication to vehicles in the road network. The design was shown here for illustrative purposes and was determined based on the frequency range of DSRC RSUs (refer to Chapter 2) and the communications towers was determined from the cost of installing backhaul communication (*Section 6.1.1.4*). It was assumed that, since the installation of communications towers may be 10 kilometres apart, a network of 30 kilometres may require three communications towers. The design indicated in Figure 6.5 is simplistic in nature and shown to indicate the potential quantity of infrastructure that may be required for a DSRC equipped environment. A detailed design for the installation of DSRC units and the design of a communications backhaul layout is beyond the scope of this study and was therefore not pursued further.

The average cost of each device, the planning, maintenance, deployment and staff costs were summarised in Table 6.32 and Table 6.33. The total cost for a 20-year design period was calculated to be R13 928 133.36. The calculation can be found in Appendix F.

Table 6.32: Cost of Implementing DSRC equipment and backhaul

	Item	Amount	Unit Cost	Total Cost	Frequency
DSRC Devices	Hardware	24	95 711.70	2 297 080.77	Five to Ten Years
	Installation	1	45 408.20	45 408.20	Five to Ten Years
	Planning and Design	1	85 119.27	85 119.27	Once-off
DSRC Backhaul Communicat ions	Installation	3	510 800.00	1 532 400.00	Five to Ten Years
	Maintenance	1	17 926.95	17 926.95	Annually
	Planning and Design	1	277 109.00	277 109.00	Once-off

The table below (Table 6.33) indicates the cost of hiring new staff and the alternative options currently available for retro-fitting or incorporating CV technology into an existing vehicle over a 20-year period, starting in 2015:

Table 6.33: Cost of Installation for Vehicles in Network and Hiring New Staff

Item	Amount	Unit Cost (R)	Total Cost (R)
Staff	15	519 915.40	7 798 731.00
DSRC and CV equipment	1	6 704.29	132 725.54
Aftermarket	1	2 554.00	118 234.75
Retro-fitting Cost	1	3 716.07	122 292.12
Self-Contained	1	3 141.42	120 285.72
Vehicle Awareness Device	1	1 034.37	112 928.92
Standard Equipment	1	14 770.32	160 888.24
Standard Equipment With Video Equipment	1	79 295.54	386 179.15

The costs for hiring new staff (Table 6.33) was not considered in the cost benefit analysis and was only indicated for illustrative purposes. Precise costing for staffing is subject to great variability since only wages, equipment and software were included in the pricing. The cost does not account for training, number of days of leave, availability of office space or the costs required for occupying a new building or any costs associated with hardware and software concerns. Additionally, the costs for the installation of equipment for vehicles would be required by the users of the technology – it may be optimistic to assume that road users would commit to R79 296 for installation of technology for their personal vehicles.

The focus of investigating the effect of CVs in this environment was based on the efficiency of travel, however, with the consideration of the benefits associated with the environment, it would be negligent to disregard the overall benefits that may be produced with Connected Vehicles, especially with the incorporation all of the costs, i.e. while the focus was the improvement of efficiency, the benefits include the improvements on safety that may be achieved. With the existing infrastructure being identified as the basis of the analysis, and having reached an optimum level of effect, the possible benefits of implementing the network within the study area may be as follows:

Table 6.34: Approximate Forecasted Benefit of CV Technology within Design Area

Application	Cost (R)	CV Application Benefit	Effect (New Cost) (R)	Saving (R)
Accidents (Light)	152 244	83%[1]	25 881.48	126 362.52
Accidents (Severe)	765 664	83%[1]	130 162.88	635 501.12
Accidents (Fatal)	5 435 261	83%[1]	923 994.37	4 511 266.63
Travel Time	18 702.53	10.71%	16 699.49	2 003.04
Fuel Consumption	7 211.90	1.3%	7 119.30	92.6
Average Emissions	R75/(gCO_2/km)	1.3%[2]	-	75 000

1: used from existing studies not conducted in South Africa and may be subject to variation depending on the network conditions.
2: not currently applicable to South Africa.

The accident data in Table 6.34 involves only the accidents along the Freeways (N1, N2 and M5) within the study area. Furthermore, reductions in travel time, fuel consumption and CO_2 emissions were determined from a vehicle fleet penetration of 50% CVs in the network. Additionally, the user benefits would be related to savings in travel time, fuel consumption and reductions in emissions. The details of the comparison are provided below. Table 6.35 indicates the costs and benefits for road users:

Table 6.35: User Costs and Benefits for Integrated/Embedded CV Equipment Installation

CV Installation Choice	Present Costs (Min.) (R)	Present Costs (Max.) (R)	Present Benefits (R)	Net Benefit (Min) (R)	Net Benefit (Max) (R)
Option 1: Added to Vehicle	132 725.54	242 042.90	182 215	49 489.46	-59 827.90
Option 2: Aftermarket	118 234.75	156 717.36	182 215*	63 980.25	25 497.64
Option 3: Retro-fitted	122 292.12	231 609.48	182 215	59 922.88	-49 394.48
Option 4: Self-Contained	120 285.72	229 603.08	182 215	61 929.28	-47 388.08
Option 5: VAD	112 928.92	222 246.28	182 215*	69 286.08	-40 031.28
Option 6: Standard Equipment (SE)	160 888.24	270 205.60	182 215*	21 326.76	-87 990.60
Option 7: SE with Video	386 179.15	495 496.51	182 215*	-203 964.15	-313 281.51

Table 6.36 indicates the costs and benefits relevant to traffic management agencies:

Table 6.36: Costs and Benefits of Connected Vehicle Network Deployment and Implementation

Penetration Rate	Present Costs (Minimum)	Present Benefits	Net Benefit	Year	Date
40% CV Penetration	-R13.928 mil	R17.22	R3.295	8	2023
50% CV Penetration		R20.73	R6.80	10	2025
60% CV Penetration		R23.96	R10.03	12	2027

The final amounts that were determined in the cost benefit analysis indicate that deploying an entirely new network would be a costly endeavour. A new communications backhaul would have to be deployed, new equipment purchased, delivered and installed at these sites. New offices may be constructed or rented, along with the employment of individuals with experience in communications with DSRC technology; inexperienced staff would require training with the use of the technology, which may lead to unnecessary delays in deployment of equipment and infrastructure. Additionally, the optimised effect of this equipment and infrastructure would only be applicable if utilised. For this to occur, a significant number of vehicles would be required to be connected with DSRC devices. In the first case, these vehicles are not easily accessible (at present), would initially cost more than non-DSRC equipped vehicles to accommodate the additional equipment and would have to be substantial in numbers to provide the necessary benefit to the traffic network. With the current age of vehicles, it is unlikely that connected vehicle capacity necessary for the benefits to be achieved will be attained in the near future. The total cost for implementing this system would therefore be excessive and the deployment of a network of this capability may not be achievable in the foreseeable future. In addition to the excessive costs involved, it would take a considerable amount of time for the effects of this technology to be achieved. It would also take a significant amount of time for vehicles to be connected with CV devices. The benefits would therefore not be applicable before these milestones are reached.

6.3.3 ALTERNATIVE 2: ENABLING CONNECTIVITY WITH CELLPHONES

Alternative 2 considers the use of Cellular connectivity, in which Smartphones are brought-in to provide information to users (as opposed to owning a vehicle with an on-board centre console with a touch screen or purchasing additional equipment, such as On-Board Units). In comparison to Alternative 1, a large number of CV applications would be discarded due to the lack of functionality. However, improved levels of efficiency within the network may still be achieved. Cell phones provide the possibility of implementing applications such as Speed Harmonisation and Queue Warning, and may eliminate the requirement of VMSs in future. The possible costs and benefits of implementing Cellular connectivity was summarised in Table 6.37:

Table 6.37: Costs and Benefits of Cellular-enabled Technology

	Present Cost (R)	**Present Benefit (R)**	**Net Present Benefit (R)**
Maximum	40 099.90 75 554.20	101 324.80	61 224.90 25 770.60
Minimum	40 099.90 75 554.20	158 730.30	118 630.00 83 176.10

Table 6.37 indicates that the benefits of this system will eventually surpass the initial costs committed for implementing the Alternative 2. This does not include all of the costs involved in implementing an alternative of this nature, but provides an overview of the effect that may be experienced as a result of its use.

6.4 COMPARISON

The approach in this section indicates the costs that would be associated with traffic management agencies and the costs that would be applicable to vehicle owners.

COSTS TO TRAFFIC MANAGEMENT AGENCIES

The costs and benefits associated with the management and operation agencies were discussed in detail in the previous sections (*Section 6.1* to *6.3*) and was summarised in Table 6.37 (page 6.39):

Table 6.38: Cost-Benefit Analysis Summary Relevant to Management Agencies

Decision		**Total Present Cost (Design Area)**	**Total Present Benefit**	**Total Net Benefit**
Alternative 0	From 2015	- R1 601 055	-	- R1 601 055
Alternative 1	40%	- R13.928 mil	R17.22 mil	R3.295 mil
	50%		R20.73 mil	R6.80 mil
	60%		R23.96 mil	R10.03 mil
Alternative 2	At 2020	-R430 970	-	-R430 970
	At 2025	-R702 652	-	-R702 652
	At 2030	-R949 875	-	-R949 875

The table shows the present costs associated with the design area investigated in this study and includes a column for the costs associated with the FMS infrastructure in the design area (Cape Town, Western Cape). The second column (Total Present Cost (Design Area)) shows the total costs for each of the alternative approaches which should be understood as follows:

- **Alternative 0**: Costs of maintenance for the VMSs in the design area.
- **Alternative 1**: Costs of implementing and deploying CV equipped environment with immediate decommission of existing infrastructure.
- **Alternative 2**: Cost of implementing Cellular communication between vehicles and infrastructure with phased out decommission of VMSs.

As stated in Chapter 3, the remaining FMS infrastructure (VDSs and CCTV Cameras) were not considered in the cost analysis since these items, according to this investigation, may be crucial for traffic analyses purposes.

The third column (Total Present Benefits) shows that only the DSRC equipped environment would achieve benefits with regards to accident prevention. This corresponds to the description for the inclusion of accident costs provided in *Section 6.2.2*. The complete calculation for the costs and benefits to management agencies may be found in Appendix F.

COSTS TO ROAD USERS

Alternative 0, the null Alternative, considered the costs associated with ITS infrastructure in Cape Town (Western Cape) within the design area, Alternative 1 examined the implementation and deployment of a DSRC equipped environment in support of Connected Vehicle technology, and Alternative 2 explored the use of existing infrastructure and cellular technology to develop communication similar to a DSRC environment. As previously indicated, the alternatives present costs and benefits to both users and management agencies. The costs that would be committed by a single user involves payments for the in-vehicle equipment. This equipment may be improved upon at a later stage (i.e. faster broadband connection), may involve the purchase of a Nomadic device (Smartphone or Table) and would require monthly payments and regular upgrades to the system. Therefore, for each user involved, the singular payments may be considered in the following section. The following costs and benefits relate to the requirements for single Cellular Connected Vehicle:

Table 6.39: Costs and Benefits for a single Cellular-equipped Vehicle

Cellular Communication			
Field	**Item**	**Effect**	**Comment**
Costs	Suction Mount	± R300	(Quality dependent) once-off at a 2 year replacement rate
	Vehicle Charger	± R250	(Quality dependent) once-off at a 2 year replacement rate
	Data Plan	± R400/month	Fluctuates depending on user needs
Benefits	Fuel Savings	Approximately R5.70	per 8 – 10km trip
	Travel Time Savings	Approximately R9.90	per 8 – 10km trip
	Reduced Emissions	Reduction of 4gCO_2/km	Not currently applicable to South African market

In the case of DSRC equipped vehicles, the equipment costs would increase substantially as it includes the cellular communications devices. According to the Write et al. (2014), investigations of the Test-Beds in North America found that the average cost of retro-fitting CV technology may be as indicated in Table 6.40 (USDOT/AASHTO 2014, cited by FHWA, 2014). A second investigation (separate to the investigation completed by the USDOT), conducted by the Michigan Department of Transport (2012), involved consultation with vehicle manufacturers to determine the costs associated with Embedded DSRC and Connected Vehicle technology, as well as the cost of adding DSRC equipment as Aftermarket fitments (MDOT, 2012), is summarised in Table 6.40. Thereafter, the benefits for a single road user with a DSRC equipped vehicle, based on the simulated scenarios, is summarised:

Table 6.40: Costs and Benefits for DSRC-equipped Vehicle

DSRC Communication			
Field	**Item**	**Amount (Rand)**	**Comment**
USDOT *Costs	DSRC After-market Safety Device	± R15 200	DSRC equipment as Aftermarket item
	Cabling Management/Installation Kits	± R2 300	
	Installation Labour	± R45 400	
	Video Data Collection System (Optional)	± R76 450	
MDOT *Costs	Embedded DSRC equipment	R2 647.80	Preinstalled by Vehicle Manufacturers (in 2017)
	Costs added to Vehicles for CV technology	R5 295.50	Equipment Setup (in 2017)
	Adding DSRC Device	R3 026.00	DSRC equipment as Aftermarket item (in 2017)
Benefits	Fuel Savings	Approximately R14.30	per 8 – 10km trip
	Travel Time Savings	Approximately R10.70	per 8 – 10km trip
	Reduced Emissions	Reduction of 2gCO2/km	Not currently applicable to South African market

**Excluding costs indicated in Table 6.41*

The road user benefits was only determined based on the scenarios investigated in this study. The safety benefits that may be applicable to DSRC equipped vehicles was therefore not considered, but should be factored in when considering a suitable alternative (Cellular versus DSRC communication) for deployment in the Western Cape region. The costs and benefits of both Cellular and DSRC equipped vehicles is summarised in Table 6.41:

Table 6.41: Cost-Benefit Analysis Summary for Users

Decision	Option	Total Present Cost (Minimum) (R)	Total Present Cost (Maximum) (R)	Total Present Benefit (R)	Benefit Cost Ratio (Min)	Benefit Cost Ratio (Max)
Alternative 0	-	-	-	-	-	
Alternative 1	Option 1: Added to Vehicle	132 725.54	242 043.90	182 215	1.37	0.75
	Option 2: Aftermarket	118 234.75	156 717.36	182 215*	1.54	1.16
	Option 3: Retro-fitted	122 292.12	231 609.48	182 215	1.49	0.79
	Option 4: Self-Contained	120 285.72	229 603.08	182 215	1.51	0.79
	Option 5: VAD	112 928.92	222 246.28	182 215*	1.61	0.82
	Option 6: Standard Equipment (SE)	160 888.24	270 205.60	182 215*	1.13	0.67
	Option 7: SE with Video	386 179.15	495 496.51	182 215*	0.47	0.37
Alternative 2	1: Min. Delay	40 099.90	75 554.20	158 730.30	3.49	1.77
	2: Max. Delay	40 099.90	75 554.20	101 324.80	2.53	1.34

** Safety Benefits not Assigned Monetary Value for Users*

Refer to Appendix F for the complete calculation of costs and benefits for the road users.

6.5 CONCLUSION

This chapter provided a detailed discussion of cost and benefit factors associated with the deployment of existing ITS infrastructure, deploying new infrastructure in the Western Cape FMS network in Cape Town, for the assistance of Integrated/Embedded CVs and examined the implementation of Cellular-enabled CV technology for existing vehicles.

Based on the analysis of the alternatives, it appears that Alternative 2 (Cellular Connectivity) was the most suitable for the South African (Western Cape) perspective, according to this investigation. To reiterate, Alternative 2 would be the most affordable option for users, appears to be the most realistic in short-term achievement based on the resources available to South Africa and may be more sustainable (by way of reduced costs to management agencies) at this stage. Additionally, Cellular-enabled CVs may provide insight to the avenues that may be explored with Integrated/Embedded CV technology in future development and planning of the Freeway Management System. This option presents the opportunity for achieving benefits within the traffic network; however, further criticism and consideration of the choices may be justified as follows:

Table 6.42: Benefits and Criticism of Alternatives

Benefits	Critical Aspects
Alternative 0: Do Nothing	
Making use of the system in its current existence will ensure that funding is only spent on maintaining the system and expanding the network which has been planned for. The system has provided an improved effect to the traffic network, this effect may be extended to areas further from Central Cape Town along the Freeways	Congestion levels in Cape Town is currently at 30% (Tomtom.com, 2016); neglecting to research alternative methods of alleviating current traffic obstacles (refer to Chapter 1) may lead to increasing congestion levels. The system appears to have reached an optimal level of efficiency (refer to Chapter 1); an extension of the existing network may therefore not improve traffic conditions.
Alternative 1: DSRC Connectivity	
Would enhance road efficiency, traffic mobility, safety and network integration. Would potentially improve management and operation of traffic network	Expensive and not completely developed. Would take a significant amount of time to be planned, implemented and deployed.
Alternative 2: Cellular-enabled Connectivity – Smartphones	

Would be the most affordable and realistic alternative (with regards to existing infrastructure and technology in South Africa).	Would have to be enforced, although it will start out as a suggestion (i.e. phased into the existing operation of traffic).
Would enhance efficiency if utilised correctly	Would require all vehicles to utilise a Smartphone/Tablet

In consideration of the information mentioned above, it can be seen that Alternative 2 presents an advantage over Alternative 0 in that improvement in efficiency may be achieved, and is significantly less cost intensive than Alternative 1. The criticism for either alternative further highlights the appearance that Alternative 2 may present the least hindrance with regards to planning, deployment and execution. In comparison to Alternative 0, it may be more sustainable (monetarily) to implement Alternative 2 than to maintain the existing infrastructure, specifically within the design area. Alternative 2 was therefore selected as the basis for discussing an implementation strategy. This will be elaborated on in Chapter 7.

CHAPTER 7 : IMPLEMENTATION STRATEGY

The implementation strategy for this investigation was developed for the purpose of indicating the communications and information that would be necessary for the effective implementation of a Connected Vehicle strategy. The execution of these phases and the specific design of sectors was not considered in this case as this was dependent on information that exceeds the scope of this investigation. Understanding of the existing environment, the operations of systems architecture and infrastructure, procedural compliance, adherence to jurisdictional boundaries, network development strategies and achieving rapport. The following strategy was developed from the plan set out by the Wyoming Department of Transport (Wyoming DOT Connected Vehicle Pilot Deployment Program, 2015) as it was the plan set up upon deployment of the network investigated in this study, and considered all the necessary factors that may play a role in the execution of the strategy. The strategy presented however is based on a conceptual design and does not involve correspondence with the stakeholders mentioned. The intention is to provide a base from which the stakeholders can develop a working model for executing a connected vehicle infrastructure development and deployment.

7.1 FIRST STEPS

Connected Vehicle technology has not reached maturity and has not been fully implemented in any existing environment. However, the initiation of a connected vehicle project is likely to be similar to the deployment of any ITS infrastructure. In this case however, the optimisation of the technology is dependent on its use by the traffic network, which is out of the control of traffic agencies.

The initial steps to deployment, as briefly discussed in the *National Connected Vehicle Field Infrastructure Footprint Analysis* report (Write et al., 2014), have been addressed in this investigation, covering the following points:

- Development of Needs and Deployment Opportunities: The needs of the systems, with regards to equipment, infrastructure and the analysis of an environment with connected technology was investigated in this report and identified a significant amount of equipment, addressed the needs and discussed multiple opportunities that may be available.
- Development of Institutional Awareness and Support: In this case, Institutional awareness should be addressed in a similar manner to the management of the Traffic Management Operations, in which Sanral is in partnership with local traffic agencies such as the City of Cape Town (CoCT) and the Provincial Government (PGWC). The management of a potential connected environment will most-likely be operated from the Traffic Management Centre; it will therefore be crucial that support is established between all of the agencies involved.

- Consideration of Alternatives to Connected Vehicle Applications: Alternatives approaches were addressed in this investigation and may form the basis of understanding of the necessary facets for consideration with the implementation of connected infrastructure and equipment. The inclusion of further alternatives may be extended with enhancement of available technology, application ease of use, availability of technology and equipment, as well as funding support from traffic and government agencies.
- Consideration of Local Implementation of a Pilot Project: Although the applications considered in this investigation produced positive results and existing pilot studies have proven the effective application of connected vehicles in a real world setting, support for Connected Vehicles can only be achieved with real-life investigations and results. For this reason, applications specific to the requirements of the traffic agencies should be investigated in real-world conditions locally – this approach may provide the necessary motivation for implementing the technology.
- Long Term Planning: This will be necessary to establish a time-line of the intention to deploy. Planning of budgetary costs, management of facilities, identification of funding strategies from local government and possibly third-party partnerships.
- Design and Procurement Standards: For this, the USDOT should be leveraged as the information is available for use and may form the basis for establishment of all Connected Vehicle environments. Thereafter, the standards may be adjusted to tie in with the conditions of the local management and traffic operations.
- Staff Development and Training: Depending on the alternative established, traffic agencies may wish to consider training staff members. This approach however, will require more office space, establishment of new structures, and purchase of additional in-house equipment (additional servers, computers, furniture, etc.). An alternative approach would be to explore third-party partnerships for assistance – this approach may reduce the time lapse between deployment and use (under the assumption that new staff will require training, this would increase the time between deploying the systems and making use of the technology).

The following sections discuss the funding strategies and the procedural phases that may be incorporated for implementation of the necessary environment.

7.2 POSSIBLE AVENUES FOR FUNDING

The benefits and costs of implementing CV equipment and infrastructure were discussed in detail in the previous chapters (Chapter 5 and Chapter 6). It is clear that the equipment involved is related to general ITS equipment. Therefore, deployment funds set for safety systems, infrastructure upgrades and deployment of infrastructure may be appropriate in for this setting. Additionally, South Africa has been investigating routes that can be taken to reduce GHG emissions – this approach from the Western Cape may spark motivation for other provinces to follow suit and funding may be accessed for attempts to reduce emissions. According to Climateactiontracker.com (2015), South Africa submitted a document concerning the intended reduction of GHG emissions (Intended Nationally Determined Contribution (INDC)); given that South Africa is ranked 14th in terms of Carbon Emissions from the consumption of energy (Union of Concerned Scientists, 2011), Connected Vehicle technology may provide an incentive for funding to reduce carbon emissions. Furthermore, Climateactiontracker.com states that South Africa will need to implement additional polices to reach the proposed targets (2015) – connected vehicles may provide an excellent opportunity for an overall CO_2 reduction.

In addition to the costs associated with equipment, infrastructure and deployment, costs will be incurred for daily operations related to staffing, training, maintenance, updates and replacement of equipment when necessary. In this case, it may be necessary for traffic agencies to establish public-private partnerships to reduce costs. For example, companies such as Inrix and TomTom may explore technologies associated with Connected Vehicle infrastructure management and analysis. Costs could therefore be alleviated through a partnership with either firm, and the local traffic management agencies.

7.3 IMPLEMENTATION STRATEGY IN PHASE 1

The following implementation strategy was lifted as an approach based on the USDOT for an approach to implementing a connected vehicle environment (Wyoming DOT Connected Vehicle Pilot Deployment Program, 2015), in this case applied to the western cape, specifically Cape Town.

STRATEGIC FOCUS AREAS

The following points were highlighted by Wyoming DOT (2015) as the main benefactors of establishing the connected environment and would be similar in requirement for application in the Western Cape:

- Ensure traceability between documents – this would ensure that all involved parties are aware of the project status and would allow other developers to leverage the successful tasks.
- Understand and support evaluation needs early in Concept Operations development.
- Develop detailed plan for training needs and requirements of public transport stakeholders and Emergency Response units.
- Inventory and leverage federal research investments as much as possible
- Develop a branding and outreach strategy to support both internal and external marker needs
- Develop and cultivate an active stakeholder group in Cape Town around the potential project
- Collaborate with CV environments from other parts of the world to incorporate alternative approaches to achieve success within the creation of a new environment
- Engage with vendors and cellular-network data providers for alternative analysis

With these factors in place, the necessary base would be set for establishing responsibility amongst stakeholders and vendors to allow for an identifiable time-line in which to deploy the relevant tasks for the network development. Further development would therefore be achieved more conveniently as this Phase would establish the necessary blue-print for expansion. Upon completion of Phase 1, detailed planning for Phase 2 and 3 would be required.

7.4 IMPLEMENTATION STRATEGY IN PHASE 2 AND PHASE 3

The proposed lead agencies would be Sanral, CoCT and PGWC as they are the leading custodians in partnership for managing the freeways and deploying infrastructure within the traffic network. The roles of the stakeholders in Phase 1 should be revisited upon implementation planning, it would therefore be critical to ensure that the traceability of documents is attained. In Phase 2, additional partners (in not currently in place) should be considered for addition to the list of stakeholders for assistance with third-party expertise. Partnerships may include discussions with management in the following areas:

- DSRC Radio Providers
- Cellular Network Providers

In this phase, it would be necessary to establish a strategic focus. To ensure that the work completed conforms to the necessary standards established by the stakeholders, the following should be taken into consideration for instituting:

- Develop robust testing and acceptance plan
- Integrate into existing network before consideration of “deconstructing” certain existing equipment (in consideration of Alternative 1 and Alternative 2, decommission of existing VMS infrastructure)
- Consideration of open source development to enhance options available for consideration and plans to provide improvements over the traffic network wherever possible.

Emphasis should be given to Systems Engineering Management. The development of a Connected Vehicle environment (or any new complex development) would be an extensive commitment. It is therefore crucial that the work process be outlined in extensive detail, the methods and practices used be optimised to increase productivity and that risk management goals are set and adhered to.

Leverage the Connected Vehicle Reference Implementation Architecture (CVRIA) framework for the development of mobile data collected, in-vehicle advisories for wind, speed limits, and parking availability using DSRC and cellular communication for V2V and V2I applications. CVRIA (iteris.com, 2016) provides detailed explanations of Connected Vehicle systems, applications, standards currently in effect. Furthermore, information about the functions that need to be in place, the physical environment that should be established, communications requirements and the equipment necessary for vehicles and infrastructure is provided – with the extensive information available about the environment, focus may be given to logistics, coordinating the stakeholders and provision of responsibilities and thereafter, establishing regular evaluations, testing and maintenance updates of the potential system.

Leverage existing federal research and prototypes: These prototypes consider a particular set of applications that specifically address mobility, safety and environmental concerns. The prototypes in place are therefore set up in the format of a framework for implementation by other departments, regions and countries. This information can therefore be used as the basis for the development of the design and implementation of Connected Vehicle applications. The following prototypes contain information that may be found on the CVRIA framework (iteris.com, 2016):

- INFLO (Intelligent Network Flow Optimisation) – for improving network efficiency.
- R.E.S.C.U.M.E. (Response, Emergency, Staging and Communications, Uniform Management and Evacuation) – for improving access to incidents to return traffic flow to standard conditions.
- MAW (Motorist Advisories and Warnings) – traveller information to assist with network efficiency and safety.

Support Evaluation and Performance Measurement: Performance Measurement Plan and development would occur in the project concept development. This would ensure that the project design focused on outcome benefits and should be prepared to collect the data required. The following approach may be applicable in this case:

- Key performance measures should focus on improving operation of the network to ensure efficient operation.
- Impacts, improvements and milestone achievements of CV Test-Pilots - This would allow for a base model in which testing of a working model may be executed in an attempt to identify any changes that may be implemented or adjusted to compliment the conditions of the Western Cape.
- Further modelling and simulation should be utilised to enhance data analysis and performance measurements in the areas of safety, environmental impact, operation efficiencies, and mobility of the traffic network through the constant provision of information to users of the system. Additionally, real-world testing in the existing traffic network should be established before deployment. The behaviour of the applications and information systems may be different when applied locally.
- Continuous data collection and support to independent evaluation activities – this would ensure that enhancement of the systems is continuous and that other regions (perhaps the Northern Cape, Eastern Cape etc.) would have the necessary aspects in place to develop projects and test-beds.

Stakeholder Involvement will be an essential factor. Ensuring that the necessary stakeholders are in place would reduce the occurrence of any clashing approaches and ideas. Furthermore, involvement of all parties would create a consistent environment, ensuring that all transport related vendors are constantly in agreement and are aware of the status of the network. The list of probable stakeholders included or that should be considered for inclusion:

- MyCiti
- Golden Arrow
- South African Emergency Responders (South African Police Service (SAPS), South African Fire Department (SAFD), Ambulance, Traffic Services)
- Sanral
- TCT
- CoCT
- WCDOT
- PGWC
- South African Weather Service

The involvement of these institutions in Phase 1 would be necessary for the development of user needs, the review of a Concept of Operations model for enhancement, adjustment or elimination of specific sections with regards to Phase 1 development. MyCiti and the Golden Arrow bus service would allow for enhancement in efficiency of public transport with the use of connected technology i.e. allowing public transportation services to communicate with traffic signals (through wireless communication) may enhance travel times and improve the reliability in destination arrival times. South African Emergency Responders would benefit from connected vehicle technology, especially with traffic signal communications. TCT would be responsible for handling the details of upgrades and communications equipment for traffic signals. Sanral, CoCT, WCDOT and PGWC would be responsible for the planning of the layout, determining costs, establishing communications with existing CV sites (abroad) and dividing responsibility amongst stakeholders. The South African Weather Service would be required to sustain their present position of providing accurate weather data for provision of traveller information. Finally, these stakeholders will be necessary for commitment to Phase 2.

CHAPTER 8 : CONCLUSION AND RECOMMENDATIONS

This chapter describes the conclusions drawn from the investigations and provides recommendations for future studies that may branch off the information provided in this study.

8.1 DISCUSSION: THESIS STUDY AND FINDINGS

Connected Vehicle applications were considered for implementation on the traffic network with the investigation of two applications, namely Speed-Harmonisation and Queue-Warning. Developed from these applications followed two alternative forms of deployment in the traffic network, namely Cellular and DSRC-enabled CVs. These alternatives were compared to determine the effect that may be achieved from these applications within the traffic network. It was determined that Integrated/Embedded CVs performed slightly more favourably than Cellular-equipped CVs, but brought to light an aspect that was not previously considered. When the DSRC-equipped CVs slow down to establish a safer driving speed, the non-equipped vehicles reduce their speed unexpectedly as the behaviour was not anticipated by these vehicles.

The focus for this study, was improvements in travel time, fuel consumption and carbon emission reductions. It may be concluded that, in the event of an accident, the applications proved to be successful with regards to efficiency. To gain a greater understanding of the effect that CVs may have on the local network, additional applications should be considered. The applications and technology are in a state of maturity and it may be found that superior options and opportunities arise in the near future.

Thereafter, a detailed discussion of costs and benefits of the existing network and the conceptual CV environment was provided. Alternative 2 appeared to be the most appropriate for local implementation, especially for short-term deployment to gain a deeper understanding of the potential benefits of a connected environment. This alternative would be the most affordable option for South Africans and may be more sustainable at this stage. As mentioned in Chapter 6, the benefits and criticism for each alternative should be considered (Table 8.1).

Finally, Table 8.2 and Table 8.3 indicate the costs and benefits of Connected Vehicle technology. Alternative 2 performs well with the user benefits but still produces negative Total Net Benefits. In comparison to the existing conditions however, it can be seen that savings of R786 362 at least and R4 871 022 may be incurred. Additionally, Alternative 1 is dependent on the users implementing extensive technology in their vehicles, while Alternative 2 presents a more realistic approach since the equipment and technology may be existent.

Table 8.1: Benefits and Criticism of Alternatives

Benefits	Critical Aspects
Alternative 0: Do Nothing	
Making use of the system in its current existence will ensure that funding is only spent on maintaining the system and expanding the network which has been planned for. The system has provided an improved effect to the traffic network, this effect may be extended to areas further from Central Cape Town along the Freeways	Congestion levels in Cape Town is currently at 30% (Tomtom.com, 2016); neglecting to research alternative methods of alleviating current traffic obstacles (refer to Chapter 1) may lead to increasing congestion levels. The system has reached an optimal level of efficiency; an extension of the network may not improve traffic conditions.
Alternative 1: DSRC Connectivity	
Would enhance road efficiency, traffic mobility, safety and network integration.	Expensive Would take a significant amount of time to be planned, implemented, deployed and managed.
Alternative 2: Tethered Connectivity – Smartphones	
Would be the most affordable and realistic solution. Would enhance efficiency if utilised correctly	Will have to be enforced, although it will start out as a suggestion. Will require all vehicles to have a Smartphone

In addition to these points, the Cost-Benefit provided the following information:

Table 8.2: User Benefits of Connected Vehicles to Road Users

User Benefits						
Decision	**Option**	**Total Present Cost (Minimum) (R)**	**Total Present Cost (Maximum) (R)**	**Total Present Benefit (R)**	**Benefit Cost Ratio (Min. Cost)**	**Benefit Cost Ratio (Max. Cost)**
Alternative 0	-	-	-	-	-	
Alternative 1	Option 1: Added to Vehicle	157 254.30	286 774.40	182 215	1.18	0.64
	Option 2: Aftermarket	140 085.50	185 680.00	182 215*	1.30	0.98
	Option 3: Retro-fitted	144 892.70	274 412.80	182 215	1.26	0.66
	Option 4: Self-Contained	142 515.50	272 035.60	182 215	1.28	0.67
	Option 5: VAD	133 799.10	263 319.20	182 215*	1.36	0.69

	Option 6: Standard Equipment (SE)	190 621.70	320 141.80	182 215*	0.96	0.57
	Option 7: SE with Video	457 548.20	587 068.30	182 215*	0.40	0.31
Alternative 2	1: Min. Delay	45 510.70	89 517.20	158 730.30	3.49	1.77
	2: Max. Delay	45 510.70	89 517.20	101 324.80	2.23	1.13

Table 8.3: Costs and Benefits of Connected Vehicles to Traffic Agencies and local Government

Traffic Agency and local Government Benefits					
Decision		**Total Present Cost (Investigated Network)**	**Total Present Cost (Entire Network)**	**Total Present Benefit**	**Total Net Benefit**
Alternative 0	From 2015	- R1 601 055	-	- R1 601 055	-
Alternative 1	40%	- R13.928 mil	R17.22 mil	R3.295 mil	R10.0 mil
	50%		R20.73 mil	R6.80 mil	R7.13 mil
	60%		R23.96 mil	R10.03 mil	R3.90 mil
Alternative 2	At 2020	- R430 970	-	- R430 970	-
	At 2025	- R702 652	-	- R702 652	-
	At 2030	- R949 875	-	- R949 875	-

Based on the discussion (p. 8.1) (in consideration of Table 8.2 and Table 8.3), it was concluded that Alternative 2 may be the most appropriate option for the Western Cape at this stage.

8.2 DRAWBACKS OF THE STUDY

This study was performed through simulations and obtained data from existing sites. The simulations may not be representative of the driving behaviour in the Western Cape and may be criticised as portraying an optimistic environment. This may be addressed with real-world investigations; the issue however, is that the technology and the anticipated environment that may be developed is relatively new (initial proven tests were concluded in 2012 and new test-beds were confirmed for construction as recently as 2015 (its.dot.gov, 2015)). The technology was therefore not in use in South Africa at the time of completing the investigations. For this reason, the Cost-Benefit Analysis was only possible to complete with costing information from existing CV sites in the United States. The costs were obtained from detailed studies but, due to the exchange rate of the Dollar to the Rand, probable importing taxes and differences in salaries, the costs may vary from those identified in the Test-Beds. Once the technology reaches a stage in which the results are confirmed, is available locally and deployment has expanded to use by commuters in the U.S., the Cost-Benefit Analysis should be reconsidered and evaluated.

8.3 CONCLUSION

Alternative 0, the Existing Network brings about a question of sustainability - the continuous costs of maintenance and requirement of the existing technology, specifically the Variable Message Signs. At this stage, it should be clear that leading transportation industries, particularly the United States and most parts of Europe (refer to Chapter 2, Section 2.2.3) appears to be moving towards implementing technology in vehicles that may see the use of VMSs, for example, as redundant. The use of probe data for example, has reduced the requirement for vehicle counters to be installed in the road, as probes are able to determine a close enough approximation of the real information required. Using the same analogy, Connected Vehicle technology may eventually reduce the need for VMS boards and certain information boards as it would be accessible instantaneously, and to all users. Electronic Toll facilities may not be necessary as users may be able to pay for use of the road from their vehicles. These examples present the fact that funding spent on maintenance and updates of existing infrastructure may be utilised more efficiently with the consideration of alternative forms of providing traveller information, i.e. considering the development of a Connected Vehicle environment. At the moment, the following items were deemed requirements for the road network:

- Vehicle Detection Systems (VDSs): These were installed to enhance Probe Data analysis, which is still relevant for traffic calculations and traveller information
- CCTV Surveillance: This is necessary for traffic agencies to have constant footage of the road network.
- Environmental Sensor System (ESS): Retrieves weather data, which enhances traveller information

At present, the VMSs are able to present traveller information to the public, while all travellers may not have access to traffic data from their vehicles, this system will still be necessary in the near future. However, this item is most-likely replaceable, as alternatives forms of accessing traveller information may prove to be more sustainable – the only concern would be penetration into all vehicles. The use of Smartphones or similar technology (On-Board Units) may provide a sustainable alternative as the equipment is easily replaceable and may alleviate large costs from the traffic agencies in terms of maintenance, software updates and license costs.

8.4 RECOMMENDATIONS

At this stage however, the technology is still in a state of maturity and connected vehicle technology has not yet been released to the public in significant capacity. In South Africa, there is no record of a connected vehicle. South Africa does not have the facilities for a vehicle of this nature to thrive at the moment, and a significant amount of connected vehicles would need to be present already for other vehicle to benefit. It is therefore recommended that pilot studies be explored of this nature to determine the real-world benefit that may be achieved. The approach in this case may be to seek assistance from existing pilot sites and connected vehicle investigations. The United States and Europe are currently funding large projects related to connected vehicles, assistance may therefore be provided from the traffic agencies of these areas to expand on global market penetration and the results that may be attained in alternative markets, such as the South African market.

Furthermore, internet connectivity options are evolving and may present favourable alternatives to DSRC connectivity. Internet providers have discussed the release of 4 G LTE Advanced and 5 G technology. The achievements of either of these bandwidths are not fully known yet, but claims to be extremely powerful and may provide a beneficial alternative to the purchase of connected vehicles. For example, the current 4G LTE bandwidth has a maximum download speed of 200 MB/sec, while 4G LTE Advanced and 5G are claimed to have a potential download speed of 8 to 10 GB/sec, a claimed improvement of 12-fold in comparison to 4G (Mundy, 2016). This means that the delay in information transfer may be unnoticeable; with an increased speed in information transfer, multiple applications may be enhanced and considered for implementation, cell phones would then be able to assist with applications such as Curve Warning and Red Light Violation applications. For this reason, it is recommended that further information regarding the possible opportunities presented by this enhancement in information transfer, as well as investigations be considered to determine the associated benefits.

Applications for connected vehicles are constantly improved and updated, especially since the technology is still in development and maturation stages. Additional applications may therefore become more appropriate for investigating, simulating and testing. It is thus recommended that additional applications be considered for use and development in a modelled environment to understand the possible impacts on the local traffic network.

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APPENDICES

APPENDIX A

The following data was provided to indicate the layout and format of the information used. Refer to the folder for Chapter 1 on the attached flash drive for the complete list of data.

31-May-2016 - Live vehicle population as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	2 904 756	954 580	1 201 335	435 783	305 028	404 122	303 747	309 938	124 182	6 943 471	64.96%
Minibuses	117 742	49 852	33 022	22 648	12 343	22 256	18 258	21 683	4 800	302 604	2.83%
Buses, bus trains, midibuses	19 544	7 819	6 618	4 076	2 983	7 691	3 925	5 972	1 670	60 298	0.56%
Motorcycles, quadrucycles, tricycles	147 789	34 465	86 000	23 104	20 469	20 074	14 554	10 138	8 505	365 098	3.42%
LDV's, panel vans, other light load veh's GVM <= 3500kg	794 364	346 675	310 747	194 338	127 315	205 766	145 971	213 744	76 633	2 415 553	22.60%
Trucks (Heavy load vehicles GVM > 3500kg)	136 704	49 297	41 988	22 710	21 967	44 951	18 163	24 237	9 439	369 456	3.46%
Other self-propelled vehicles	35 134	32 112	37 237	15 983	36 903	27 292	22 613	16 575	9 041	232 890	2.18%
Total self-propelled vehicles	4 156 033	1 474 800	1 716 947	718 642	527 008	732 152	527 231	602 287	234 270	10 689 370	
Provincial % of total	39%	14%	16%	7%	5%	7%	5%	6%	2%	100%	% of total tow vehicles
Caravans	40 213	7 582	17 255	5 290	7 833	10 198	6 550	5 604	2 905	103 430	9.10%
Light load trailers GVM <= 3500kg	326 688	81 146	137 710	55 087	62 421	62 885	52 254	40 549	28 005	846 745	74.53%
Heavy load trailers GVM > 3500kg	58 851	23 819	19 307	7 504	17 438	33 972	11 045	8 400	5 646	185 982	16.37%
Total trailers	425 752	112 547	174 272	67 881	87 692	107 055	69 849	54 553	36 556	1 136 157	
Provincial % of total	37%	10%	15%	6%	8%	9%	6%	5%	3%	100%	
All other and unknown vehicles	5 136	3 228	4 551	2 858	4 101	4 096	4 732	2 596	1 392	32 690	
Total number of live vehicles	4 586 921	1 590 575	1 895 770	789 381	618 801	843 303	601 812	659 436	272 218	11 858 217	
Provincial % of total	39%	13%	16%	7%	5%	7%	5%	6%	2%	100%	

30-June-2016 - Live vehicle population as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	2 909 673	956 625	1 204 236	436 348	305 413	404 994	304 445	310 976	124 338	6 957 048	64.96%
Minibuses	117 997	50 094	33 098	22 694	12 325	22 296	18 273	21 727	4 826	303 330	2.83%
Buses, bus trains, midibuses	19 647	7 822	6 682	4 104	2 998	7 729	3 933	6 020	1 664	60 599	0.57%
Motorcycles, quadrucycles, tricycles	147 653	34 396	86 004	23 045	20 409	20 023	14 541	10 119	8 488	364 678	3.41%
LDV's, panel vans, other light load veh's GVM <= 3500kg	796 098	347 403	311 648	194 984	127 511	206 232	146 147	214 392	76 627	2 421 042	22.61%
Trucks (Heavy load vehicles GVM > 3500kg)	136 916	49 224	42 127	22 705	22 009	44 956	18 117	24 534	9 440	370 028	3.46%
Other self-propelled vehicles	35 158	32 136	37 427	16 059	36 794	27 311	22 588	16 550	9 070	233 093	2.18%
Total self-propelled vehicles	4 163 142	1 477 700	1 721 222	719 939	527 459	733 541	528 044	604 318	234 453	10 709 818	
Provincial % of Total	39%	14%	16%	7%	5%	7%	5%	6%	2%	100%	% of total tow vehicles
Caravans	40 175	7 571	17 298	5 272	7 829	10 197	6 547	5 610	2 914	103 413	9.09%
Light load trailers GVM <= 3500kg	327 253	81 142	137 964	55 177	62 442	63 018	52 263	40 685	28 068	848 012	74.52%
Heavy load trailers GVM > 3500kg	58 892	23 735	19 320	7 518	17 593	34 088	11 038	8 662	5 661	186 507	16.39%
Total Trailers	426 320	112 448	174 582	67 967	87 864	107 303	69 848	54 957	36 643	1 137 932	
Total Provioial % of total	37%	10%	15%	6%	8%	9%	6%	5%	3%	100%	
All other and unknown vehicles	5 108	3 211	4 573	2 856	4 096	4 081	4 726	2 601	1 388	32 640	
Total number of live vehicles	4 594 570	1 593 359	1 900 377	790 762	619 419	844 925	602 618	661 876	272 484	11 880 390	
Provincial % of total	39%	13%	16%	7%	5%	7%	5%	6%	2%	100%	

Increase / Decrease in Live Vehicle Population from 31 May 2016 to 30 June 2016

Vehicle Class	Province									Total Inc/Decr	% change
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	4 917	2 045	2 901	565	385	872	698	1 038	156	13 577	0.20%
Minibuses	255	242	76	46	- 18	40	15	44	26	726	0.24%
Buses, bus trains, midibuses	103	3	64	28	15	38	8	48	- 6	301	0.50%
Motorcycles, quadrucycles, tricycles	- 136	- 69	4	- 59	- 60	- 51	- 13	- 19	- 17	-420	-0.12%
LDV's, panel vans, other light load veh's GVM <= 3500kg	1 734	728	901	646	196	466	176	648	- 6	5 489	0.23%
Trucks (Heavy load vehicles GVM > 3500kg)	212	- 73	139	- 5	42	5	- 46	297	1	572	0.15%
Other self-propelled vehicles	24	24	190	76	- 109	19	- 25	- 25	29	203	0.09%
Total inc/decr in self-propelled vehicles	7 109	2 900	4 275	1 297	451	1 389	813	2 031	183	20 448	
% increase/decrease	0.17%	0.20%	0.25%	0.18%	0.09%	0.19%	0.15%	0.34%	0.08%	0.19%	
Caravans	- 38	- 11	43	- 18	- 4	- 1	- 3	6	9	-17	-0.02%
Light load trailers GVM <= 3500kg	565	- 4	254	90	21	133	9	136	63	1 267	0.15%
Heavy load trailers GVM > 3500kg	41	- 84	13	14	155	116	- 7	262	15	525	0.28%
Total inc/decr in trailers	568	- 99	310	86	172	248	-1	404	87	1 775	
% increase/decrease	0.13%	-0.09%	0.18%	0.13%	0.20%	0.23%	0.00%	0.74%	0.24%	0.16%	
All other and unknown vehicles	- 28	- 17	22	- 2	- 5	- 15	- 6	5	- 4	-50	
Total inc/decr	7 649	2 784	4 607	1 381	618	1 622	806	2 440	266	22 173	
% increase/decrease	0.17%	0.18%	0.24%	0.17%	0.10%	0.19%	0.13%	0.37%	0.10%	0.19%	

Figure 8.1: Layout of Live Vehicle Population Data (Source: Enatis.com, 2016)

30 June 2015 - New vehicle registrations as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	15 048	4 585	3 529	2 610	831	1 473	869	1 012	404	30 361	62.20%
Minibuses	392	213	119	117	39	88	74	72	30	1 144	2.34%
Buses, bus trains, midibuses	83	41	73	20	9	30	10	23	6	295	0.60%
Motorcycles, quadrucycles, tricycles	975	178	312	104	74	88	57	38	29	1 855	3.80%
LDV's, panel vans, other light load veh's GVM <= 3500kg	6 151	1 651	1 242	766	491	719	436	602	221	12 279	25.16%
Trucks (Heavy load vehicles GVM > 3500kg)	806	291	221	138	110	204	51	129	49	1 999	4.10%
Other self-propelled vehicles	216	111	128	96	80	86	56	61	46	880	1.80%
Total self-propelled vehicles	23 671	7 070	5 624	3 851	1 634	2 688	1 553	1 937	785	48 813	% of total tow vehicles
Provincial % of Total	48.49%	14.48%	11.52%	7.89%	3.35%	5.51%	3.18%	3.97%	1.61%	100.00%	
Caravans	65	17	21	5	8	13	6	6	4	145	3.92%
Light load trailers GVM <= 3500kg	1 137	282	271	174	156	202	169	178	74	2 643	71.49%
Heavy load trailers GVM > 3500kg	364	82	81	24	82	159	41	40	36	909	24.59%
Total Trailers	1 566	381	373	203	246	374	216	224	114	3 697	
Total Provicial % of total	42.36%	10.31%	10.09%	5.49%	6.65%	10.12%	5.84%	6.06%	3.08%	100.00%	
All other and unknown vehicles	12	3	0	0	0	0	0	3	0	18	
Total number	25 249	7 454	5 997	4 054	1 880	3 062	1 769	2 164	899	52 528	
Provincial % of total	48.07%	14.19%	11.42%	7.72%	3.58%	5.83%	3.37%	4.12%	1.71%	100.00%	

30 June 2016 - New vehicle registrations as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	13 975	4 478	3 427	1 753	636	1 122	708	833	306	27 238	62.19%
Minibuses	863	212	169	109	43	111	67	103	23	1 700	3.88%
Buses, bus trains, midibuses	116	21	49	13	25	52	15	24	5	320	0.73%
Motorcycles, quadrucycles, tricycles	719	131	220	56	52	55	31	35	20	1 319	3.01%
LDV's, panel vans, other light load veh's GVM <= 3500kg	4 271	1 668	1 248	779	484	751	469	679	228	10 577	24.15%
Trucks (Heavy load vehicles GVM > 3500kg)	811	252	235	86	89	250	57	100	29	1 909	4.36%
Other self-propelled vehicles	128	89	113	88	65	90	49	54	59	735	1.68%
Total self-propelled vehicles	20 883	6 851	5 461	2 884	1 394	2 431	1 396	1 828	670	43 798	% of total tow vehicles
Provincial % of Total	47.68%	15.64%	12.47%	6.58%	3.18%	5.55%	3.19%	4.17%	1.53%	100.00%	
Caravans	79	18	18	3	7	16	7	3	4	155	4.31%
Light load trailers GVM <= 3500kg	1 157	289	288	134	152	210	148	152	84	2 614	72.69%
Heavy load trailers GVM > 3500kg	390	73	64	21	88	108	42	35	6	827	23.00%
Total Trailers	1 626	380	370	158	247	334	197	190	94	3 596	
Total Provicial % of total	45.22%	10.57%	10.29%	4.39%	6.87%	9.29%	5.48%	5.28%	2.61%	100.00%	
All other and unknown vehicles	9	3	0	0	1	0	0	0	0	13	
Total number	22 518	7 234	5 831	3 042	1 642	2 765	1 593	2 018	764	47 407	
Provincial % of total	47.50%	15.26%	12.30%	6.42%	3.46%	5.83%	3.36%	4.26%	1.61%	100.00%	

Change in new vehicle registrations between 30 June 2015 and 30 June 2016

Vehicle Class	Province									Total Inc/Decr	% change
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	- 1 073	- 107	- 102	- 857	- 195	- 351	- 161	- 179	- 98	- 3 123	-10.29%
Minibuses	471	- 1	50	- 8	4	23	- 7	31	- 7	556	48.60%
Buses, bus trains, midibuses	33	- 20	- 24	- 7	16	22	5	1	- 1	25	8.47%
Motorcycles, quadrucycles, tricycles	- 256	- 47	- 92	- 48	- 22	- 33	- 26	- 3	- 9	- 536	-28.89%
LDV's, panel vans, other light load veh's GVM <= 3500kg	- 1 880	17	6	13	- 7	32	33	77	7	- 1 702	-13.86%
Trucks (Heavy load vehicles GVM > 3500kg)	5	- 39	14	- 52	- 21	46	6	- 29	- 20	- 90	-4.50%
Other self-propelled vehicles	- 88	- 22	- 15	- 8	- 15	4	- 7	- 7	13	- 145	-16.48%
Total inc/decr in self-propelled vehicles	- 2 788	- 219	- 163	- 967	- 240	- 257	- 157	- 109	- 115	- 5 015	
% Increase/decrease	-11.78%	-3.10%	-2.90%	-25.11%	-14.69%	-9.56%	-10.11%	-5.63%	-14.65%	-10.27%	
Caravans	14	1	- 3	- 2	- 1	3	1	- 3	0	10	6.90%
Light load trailers GVM <= 3500kg	20	7	17	- 40	- 4	8	- 21	- 26	10	- 29	-1.10%
Heavy load trailers GVM > 3500kg	26	- 9	- 17	- 3	6	- 51	1	- 5	- 30	- 82	-9.02%
Total inc/decr in trailers	60	- 1	- 3	- 45	1	- 40	- 19	- 34	- 20	- 101	
% Increase/decrease	3.83%	-0.26%	-0.80%	-22.17%	0.41%	-10.70%	-8.80%	-15.18%	-17.54%	-2.73%	
All other and unknown vehicles	- 3	0	0	0	1	0	0	- 3	0	- 5	
Total inc/decr	- 2 731	- 220	- 166	- 1 012	- 238	- 297	- 176	- 146	- 135	- 5 121	
% Increase/decrease	-10.82%	-2.95%	-2.77%	-24.96%	-12.66%	-9.70%	-9.95%	-6.75%	-15.02%	-9.75%	

Figure 8.2: Layout of New Vehicle Registration Data (Source: Enatis.com, 2016)

31 July 2015 - Used vehicle registrations as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	43 300	13 354	14 721	5 782	4 071	5 829	4 353	4 149	1 474	97 033	69.40%
Minibuses	1 796	861	428	310	230	307	317	375	44	4 668	3.34%
Buses, bus trains, midibuses	227	62	41	80	45	102	65	74	16	712	0.51%
Motorcycles, quadrucycles, tricycles	1 755	485	813	223	234	254	152	108	91	4 115	2.95%
LDV's, panel vans, other light load veh's GVM <= 3500kg	9 863	4 177	3 001	1 984	1 402	2 527	1 752	2 322	687	27 715	19.85%
Trucks (Heavy load vehicles GVM > 3500kg)	1 554	600	323	227	238	769	197	357	86	4 351	3.12%
Other self-propelled vehicles	211	176	89	72	153	112	59	127	51	1 050	0.75%
Total self-propelled vehicles	58 706	19 716	19 416	8 678	6 373	9 900	6 895	7 512	2 449	139 644	% of total tow vehicles
Provincial % of Total	42.04%	14.12%	13.90%	6.21%	4.56%	7.09%	4.94%	5.38%	1.75%	100.00%	
Caravans	406	69	117	42	72	113	55	47	18	939	16.11%
Light load trailers GVM <= 3500kg	1 085	240	416	181	186	252	187	156	82	2 785	47.77%
Heavy load trailers GVM > 3500kg	735	258	183	50	159	445	101	97	78	2 106	36.12%
Total Trailers	2 226	567	716	273	417	810	343	300	178	5 830	
Total Provicial % of total	38.18%	9.73%	12.28%	4.68%	7.15%	13.89%	5.88%	5.15%	3.05%	100.00%	
All other and unknown vehicles	12	17	9	12	6	7	9	7	5	84	
Total number	60 944	20 299	20 141	8 963	6 796	10 717	7 247	7 819	2 632	145 558	
Provincial % of total	41.87%	13.95%	13.84%	6.16%	4.67%	7.36%	4.98%	5.37%	1.81%	100.00%	

31 July 2016 - Used vehicle registrations as per the National Traffic Information System - eNaTIS

Vehicle Class	Province									Total	% of total self-propelled
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	40 614	12 231	13 955	5 352	3 825	5 319	4 075	3 322	1 441	90 134	68.89%
Minibuses	1 856	899	390	315	227	303	300	309	74	4 673	3.57%
Buses, bus trains, midibuses	243	78	46	52	38	100	143	75	19	794	0.61%
Motorcycles, quadrucycles, tricycles	1 663	383	803	261	233	201	176	77	74	3 871	2.96%
LDV's, panel vans, other light load veh's GVM <= 3500kg	9 762	4 008	3 003	1 878	1 283	2 298	1 680	1 848	733	26 493	20.25%
Trucks (Heavy load vehicles GVM > 3500kg)	1 343	583	292	194	178	678	189	256	57	3 770	2.88%
Other self-propelled vehicles	239	185	121	67	144	153	97	59	40	1 105	0.84%
Total self-propelled vehicles	55 720	18 367	18 610	8 119	5 928	9 052	6 660	5 946	2 438	130 840	% of total tow vehicles
Provincial % of Total	42.59%	14.04%	14.22%	6.21%	4.53%	6.92%	5.09%	4.54%	1.86%	100.00%	
Caravans	367	54	116	38	66	108	70	55	24	898	16.32%
Light load trailers GVM <= 3500kg	977	251	414	187	180	253	199	118	114	2 693	48.95%
Heavy load trailers GVM > 3500kg	710	217	166	49	158	418	81	65	46	1 910	34.72%
Total Trailers	2 054	522	696	274	404	779	350	238	184	5 501	
Total Provicial % of total	37.34%	9.49%	12.65%	4.98%	7.34%	14.16%	6.36%	4.33%	3.34%	100.00%	
All other and unknown vehicles	17	14	12	30	8	13	19	8	4	125	
Total number	57 791	18 903	19 318	8 423	6 340	9 844	7 029	6 192	2 626	136 466	
Provincial % of total	42.35%	13.85%	14.16%	6.17%	4.65%	7.21%	5.15%	4.54%	1.92%	100.00%	

Change in used vehicle registrations between 31 July 2015 and 31 July 2016

Vehicle Class	Province									Total Inc/Decr	% change
	GP	KZ	WC	EC	FS	MP	NW	L	NC		
Motor cars and station wagons	- 2 686	- 1 123	- 766	- 430	- 246	- 510	- 278	- 827	- 33	- 6 899	-7.11%
Minibuses	60	38	- 38	5	- 3	- 4	- 17	- 66	30	5	0.11%
Buses, bus trains, midibuses	16	16	5	- 28	- 7	- 2	78	1	3	82	11.52%
Motorcycles, quadrucycles, tricycles	- 92	- 102	- 10	38	- 1	- 53	24	- 31	- 17	- 244	-5.93%
LDV's, panel vans, other light load veh's GVM <= 3500kg	- 101	- 169	2	- 106	- 119	- 229	- 72	- 474	46	- 1 222	-4.41%
Trucks (Heavy load vehicles GVM > 3500kg)	- 211	- 17	- 31	- 33	- 60	- 91	- 8	- 101	- 29	- 581	-13.35%
Other self-propelled vehicles	28	9	32	- 5	- 9	41	38	- 68	- 11	55	5.24%
Total inc/decr in self-propelled vehicles	- 2 986	- 1 348	- 806	- 559	- 445	- 848	- 235	- 1 566	- 11	- 8 804	
% Increase/decrease	-5.09%	-6.84%	-4.15%	-6.44%	-6.98%	-8.57%	-3.41%	-20.85%	-0.45%	-6.30%	
Caravans	- 39	- 15	- 1	- 4	- 6	- 5	15	8	6	- 41	-4.37%
Light load trailers GVM <= 3500kg	- 108	11	- 2	6	- 6	1	12	- 38	32	- 92	-3.30%
Heavy load trailers GVM > 3500kg	- 25	- 41	- 17	- 1	- 1	- 27	- 20	- 32	- 32	- 196	-9.31%
Total inc/decr in trailers	- 172	- 45	- 20	1	- 13	- 31	7	- 62	6	- 329	
% Increase/decrease	-7.73%	-7.94%	-2.79%	0.37%	-3.12%	-3.83%	2.04%	-20.67%	3.37%	-5.64%	
All other and unknown vehicles	5	- 3	3	18	2	6	10	1	- 1	41	
Total inc/decr	- 3 153	- 1 396	- 823	- 540	- 456	- 873	- 218	- 1 627	- 6	- 9 092	
% Increase/decrease	-5.17%	-6.88%	-4.09%	-6.02%	-6.71%	-8.15%	-3.01%	-20.81%	-0.23%	-6.25%	

Figure 8.3: Layout of Used Vehicle Data (Source: Enatis.com, 2016)

NetworkId	EventID	CreatedLOcalDateTime	CreatedLocalDate	Type	Details	VehicleTyp	LicensePlat	Color
WC	35764	2015/01/01 01:59	2015/01/01 01:59	Accident		Car		Other
WC	35765	2015/01/01 04:17	2015/01/01 04:17	Accident	BMW	Car		Silver
WC	35766	2015/01/01 05:26	2015/01/01 05:26	Accident	Toyota	LDV		Black
WC	35769	2015/01/01 07:44	2015/01/01 07:44	Accident		Car		Blue
WC	35770	2015/01/01 07:49	2015/01/01 07:49	Accident	Hyundai	Car		Other
WC	35770	2015/01/01 07:49	2015/01/01 07:49	Accident		Minibus		Other
WC	35772	2015/01/01 08:37	2015/01/01 08:37	Accident		Motorcycle		Other
WC	35772	2015/01/01 08:37	2015/01/01 08:37	Accident		Car		Beige
WC	35775	2015/01/01 13:04	2015/01/01 13:04	Accident	B M W	Car		Black
WC	35777	2015/01/01 14:06	2015/01/01 14:06	Accident	Toyota Tazz	Car		White
WC	35779	2015/01/01 17:23	2015/01/01 17:23	Accident	TOYOTA	Car		Red
WC	35779	2015/01/01 17:23	2015/01/01 17:23	Accident	GOLF	Car		White
WC	35825	2015/01/03 04:10	2015/01/03 04:10	Accident	VW Golf	Car	CF 197191	Red
WC	35837	2015/01/03 17:34	2015/01/03 17:34	Accident	opel Kadett	Car	CA 957 320	Other
WC	35837	2015/01/03 17:34	2015/01/03 17:34	Accident	nissan bakkie	LDV	CA 30467	Other
WC	35838	2015/01/03 18:13	2015/01/03 18:13	Accident	Unknown	Minibus		White
WC	35841	2015/01/03 19:17	2015/01/03 19:17	Accident	opel corse	Car	CAM 1370(	White
WC	35862	2015/01/04 14:11	2015/01/04 14:11	Accident	Ford Bantum	LDV		White
WC	35873	2015/01/05 07:14	2015/01/05 07:14	Accident	Reanualt	Car	CY 712426	White
WC	35898	2015/01/06 06:52	2015/01/06 06:52	Accident	Audi A4	Car	CA 590755	Silver
WC	35898	2015/01/06 06:52	2015/01/06 06:52	Accident	Chev	LDV	CS 63VL GP	White
WC	35898	2015/01/06 06:52	2015/01/06 06:52	Accident	BMW	Car	CA 856285	White
WC	35899	2015/01/06 07:20	2015/01/06 07:20	Accident	OPEL	Car		Silver
WC	35900	2015/01/06 07:20	2015/01/06 07:20	Accident	HYUNDI	Car	CA 619423	Blue
WC	35900	2015/01/06 07:20	2015/01/06 07:20	Accident	FORD	Car	CEY 61484	Silver
WC	35900	2015/01/06 07:20	2015/01/06 07:20	Accident	VW POLO	Car	CA 25165	White
WC	35921	2015/01/06 12:13	2015/01/06 12:13	Accident	VW CAREVELLE	Minibus	HDV 045 E(	Silver
WC	35921	2015/01/06 12:13	2015/01/06 12:13	Accident	HYUNDAI	LDV		White
WC	35924	2015/01/06 13:54	2015/01/06 13:54	Accident	Toyota Quantum	Minibus		White
WC	35929	2015/01/06 15:39	2015/01/06 15:39	Accident		Car		Red
WC	35931	2015/01/06 16:38	2015/01/06 16:38	Accident	Mercedes Benz	Car		Other
WC	35931	2015/01/06 16:38	2015/01/06 16:38	Accident	Volkswagen	Car		White
WC	35931	2015/01/06 16:38	2015/01/06 16:38	Accident	Unknown	Car		Red
WC	35963	2015/01/07 12:17	2015/01/07 12:17	Accident	Opel	Car	CA 81056	White
WC	36005	2015/01/08 08:33	2015/01/08 08:33	Accident		LDV		Green
WC	36005	2015/01/08 08:33	2015/01/08 08:33	Accident	VW Golf	Car		Yellow
WC	36041	2015/01/08 19:22	2015/01/08 19:22	Accident	VW	Minibus		White
WC	36042	2015/01/08 19:30	2015/01/08 19:30	Accident	renault	Car	ca162171	Silver
WC	36047	2015/01/08 23:05	2015/01/08 23:05	Accident		Car		Other
WC	36060	2015/01/09 07:44	2015/01/09 07:44	Accident	VW	Car	CY 63775	Black
WC	36060	2015/01/09 07:44	2015/01/09 07:44	Accident	VW	Car	CA 785-344	Silver
WC	36069	2015/01/09 11:04	2015/01/09 11:04	Accident	TOYOTA	Car	CY 248948	Beige
WC	36071	2015/01/09 12:53	2015/01/09 12:53	Accident		Car		Black
WC	36089	2015/01/10 01:52	2015/01/10 01:52	Accident		Car		Black
WC	36090	2015/01/10 03:19	2015/01/10 03:19	Accident	Tow Truck	LDV		White
WC	36090	2015/01/10 03:19	2015/01/10 03:19	Accident		Car		Black
WC	36092	2015/01/10 04:35	2015/01/10 04:35	Accident		Car		Other
WC	36102	2015/01/10 10:38	2015/01/10 10:38	Accident	GOLF	Car	CA693-323	White
WC	36102	2015/01/10 10:38	2015/01/10 10:38	Accident	Truck	Truck	CF195-647	Other
WC	36105	2015/01/10 12:42	2015/01/10 12:42	Accident	toyota	LDV	FVD 979EC	Other
WC	36108	2015/01/10 14:39	2015/01/10 14:39	Accident	Range rover	Car		White
WC	36117	2015/01/11 07:02	2015/01/11 07:02	Accident	VW Golf	Car	CA 615 326	Silver
WC	36117	2015/01/11 07:02	2015/01/11 07:02	Accident	Golden Arrow	Bus	CA 565 367	Beige
WC	36121	2015/01/11 08:53	2015/01/11 08:53	Accident	Mazda	Car	CCD12512	White
WC	36126	2015/01/11 16:13	2015/01/11 16:13	Accident	Toyota	LDV	FVD 979EC	White
WC	36126	2015/01/11 16:13	2015/01/11 16:13	Accident	Opel	Car	CFM 70364	White
WC	36132	2015/01/12 01:02	2015/01/12 01:02	Accident		Taxi	CA 933326	Other
WC	36132	2015/01/12 01:02	2015/01/12 01:02	Accident		Taxi	CA 43147	Other
WC	36135	2015/01/12 07:37	2015/01/12 07:37	Accident		Car		White
WC	36135	2015/01/12 07:37	2015/01/12 07:37	Accident		Car		Red
WC	36160	2015/01/12 11:22	2015/01/12 11:22	Accident		LDV		White
WC	36160	2015/01/12 11:22	2015/01/12 11:22	Accident		Car		Silver
WC	36161	2015/01/12 11:31	2015/01/12 11:31	Accident	Toyota	LDV	CA 28844	Black
WC	36161	2015/01/12 11:31	2015/01/12 11:31	Accident	VW	Minibus	CA 746220	Green
WC	36163	2015/01/12 12:01	2015/01/12 12:01	Accident	Truck	Truck		White
WC	36163	2015/01/12 12:01	2015/01/12 12:01	Accident	Mercedes Benz	Bus		White
WC	36181	2015/01/12 16:25	2015/01/12 16:25	Accident	isuzu	LDV		Silver
WC	36181	2015/01/12 16:25	2015/01/12 16:25	Accident	verso	Car		White

Figure 8.4: Layout of Accident Data for January 2015

Refer to *Sanral Accident Data* folder on attached flash disk for entire data set.

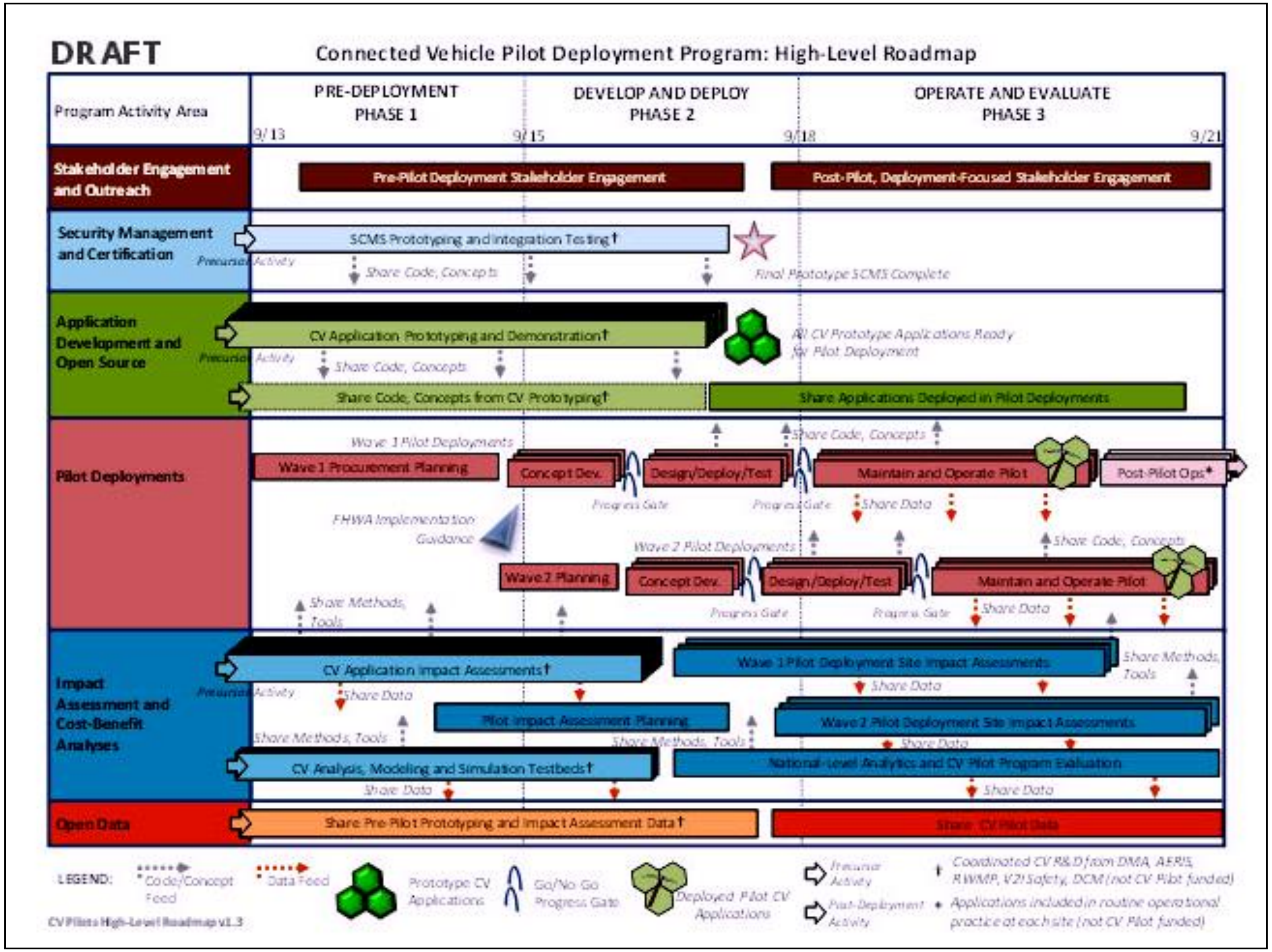


Figure 8.5: USDOT Connected Vehicle Deployment Plan (Source: Its.dot.gov, 2016)

APPENDIX B

Table 8.4: Vehicle Sensors (Model/Options/Year dependent) (Chambers, 2015)

Crankshaft Angle Sensor	Fuel Vapour Pressure Sensor	Vehicle Speed Sensor	Door Ajar Sensors
Camshaft Angle Sensor	Fuel Temperature Sensor	Drive Shaft Rotation Sensor	Air conditioning pressure Sensor
Mass Airflow Sensor	Engine Coolant Temperature Sensor	Transmission Oil Temperature Sensor	Heater & AC Temperature Sensor
Exhaust Oxygen Sensor (+/- 6)	Engine Temperature Sensor	Anti-Lock Brake Sensor	Outside Air Temperature Sensor
Exhaust Gas Recirculation Valve Position Sensor	Engine Compartment Temperature Sensor	Seat Belt Sensor	Steering Angle Sensor
Spark Knock Sensor	Manifold Air Temperature Sensor	Windshield Cracked Sensor	Steering Wheel Sensor
	Mass Air Flow (MAF)		Crash Sensors (3 or more)
Throttle Position	Accelerator Pedal Position	Wheel Speed Sensor	Intake/Ambient Air Temperature

ADDITIONAL VEHICLE SENSORS

- **Air flow meter**
- **Air–fuel ratio meter**
- **Blind spot monitor**
- **Crankshaft position sensor**: Monitors the rotational speed of the crankshaft.
- **Curb feeler**: Warns a driver that the wheels are approaching a curb.
- **Defect detector**: Detects axle and signal problems.
- **Engine coolant temperature sensor**: Measures engine temperature.
- **Hall Effect sensor**: Times the speed of wheels and shafts.
- **Knock sensor**: Detects detonation of engine (ignition)
- **Manifold Absolute Pressure (MAP) sensor**: Used to regulate fuel metering.
- **Mass flow/Mass airflow (MAF) sensor**: Tells the ECU the mass of air entering the engine.
- **Oxygen sensor:** Monitors the amount of oxygen in the exhaust.
- **Parking sensors**: Alerts the driver of obstacles that may not be visible to the driver during parking.
- **Radar gun**: Detects speed of other objects.
- **Throttle position sensor**: Monitors the position of the throttle.
- **Tire-pressure monitoring sensor**: Monitors air pressure in the tires.
- **Torque sensor**: A torque transducer measures the torque of a rotating system.
- **Transmission fluid temperature sensor**: Measures the temperature of the transmission fluid.
- **Turbine speed sensor (TSS):** Measures the rotational speed of the input shaft or torque converter.

- **Variable reluctance sensor**: Measures position and speed of moving metal components.
- **Vehicle speed sensor (VSS)**: Measures the speed of the vehicle.
- **Water sensor:** Indicates the presence of water in fuel.
- **Wheel speed sensor:** Reads the speed of a vehicle's wheel rotation.

DSRC BASIC SAFETY MESSAGE

Table 8.5: Basic Safety Message Content

BSM Part 1	BSM Part 2
Timestamp	Recent Braking
Position (Longitude, Latitude, Elevation)	Path Prediction
Speed	Throttle Position
Heading	Vehicle Mass
Acceleration	Trailer Weight
Brake System Status	Vehicle Type
Vehicle Size	Vehicle Description
Steering Wheel Angle	ABS, Traction Status
Positional Accuracy	Stability Control
	Differential GPS
	Lights Status
	Wiper Status
	Brake Level
	Coefficient of Friction
	Rain Type
	Air Temperature
	Air Pressure
	Vehicle Identification
	Cargo Weight
	GPS Status

Table 8.6: Standardised Messages Sent by DSRC SAE J2735 (CAMP, 2012:3)

ID	Message	Description	Typical Use
0	Reserved		N/A
1	MSG_A_la_Carte		V2X
2	MSG_BasicSafetyMessage (BSM)		V2V
3	MSG_CommonSafetyRequest		V2?
4	MSG_EmergencyVehicleAlert		
5	MSG_IntersectionCollisionAvoidance		V2X
6	MSG_MapData		I2V
7	MSG_NMEA_Corrections		I2V
8	MSG_ProbeDataManagement		I2V
9	MSG_ProbeVehicleData		V2I
10	MSG_RoadSideAlert		
11	MSG_RTCM_Corrections		I2V
12	MSG_SignalPhasingAndTiming		I2V
13	MSG_SignalRequestMessage		V2I
14	MSG_SignalStatusMessage		I2V
15	MSG_TravellerInformationMessage		I2V

Table 8.7: Extension of Information transmitted via DSRC (CAMP, 2012:5)

Data Item	Detail
DF_SafetyExtention	EventFlag
	PathHistory
	PathPrediction
	RTCMPackage
DF_VehicleStatus	ExteriorLight
	WipperStatus
	ThrottlePosition
	VehicleData (VehicleHeight, BumperHeaights, VehicleMass, VehicleType…)

Table 8.8: Mobile Data Field Descriptions (Adapted from Booz, Allen, Hamilton, 2012:14)

Heading	Description
Subsid	Encrypted subscriber identification number to uniquely define the mobile device
Epoch*	Epoch time (Unix time) of the sighting. Ephoch time is the number of seconds that have elapsed since January 1970
Time	Date and time of sighting converted from the epoch time
X coord	Latitude of the sighting location
Y coord	Longitude of the sighting location
Duration	Time between this sighting and the following one in seconds
Distance	Straight-line distance between this sighting and the consecutive one based on latitude and longitude in meters
Speed	Calculated speed (distance/duration) in kilometres per hour

Parameter Identification Data (PID).PID is the codes that are used to request data from a vehicle. This information is provided to an On-Board Diagnostics (OBD) unit through a vehicle's OBD-II port. The following table indicates, as far as possible, the PIDs applicable to vehicles:

Table 8.9: PID List for Light Vehicles (Wikipedia, 2016)

PID 00 – PIDs supported by the ECU	**PID 0A** – Fuel Pressure (Gauge)	**PID 10** – Air Flow Rate from Mass Airflow Sensor (MAF)	**PID 1A** – Oxygen Sensor 3 Bank 2	**PID 21** – Distance Travelled While MIL is Activated	**PID 2C** – Commander EGR	**PID 30** – Number of Warm-ups Since DTCs Cleared	**PID 3C** – Catalyst Temperature Bank 1 Sensor 1
PID 01 – DTCs, MIL status and monitor status	**PID 0B** – Intake Manifold Absolute Pressure	**PID 11** – Absolute Throttle Position	**PID 1B** – Oxygen Sensor 4 Bank 2	**PID 22** – Fuel Rail Pressure Relative to Vacuum	**PID 2D** – EGR Error	**PID 31** – Distance Since DTCs Cleared	**PID 3D** – Catalyst Temperature Bank 2 Sensor 1
PID 03 – Fuel System Status	**PID 0C** – Engine RPM	**PID 12** – Commanded Secondary Air Status	**PID 1C** – OBD2 Support Requirements	**PID 23** – Fuel Rail Pressure	**PID 2E** – Commanded Evaporative Purge	**PID 32** – EVAP System Vapour Pressure	**PID 3E** – Catalyst Temperature Bank 1 Sensor 2
PID 04 – Calculated Load Value	**PID 0D** – Vehicle Speed Sensor	**PID 13** – Oxygen Sensor Location	**PID 1E** – Power Take Off (PTO) Status		**PID 2F** – Fuel Level Input	**PID 33** – Barometric Pressure	**PID 3F** – Catalyst Temperature Bank 2 Sensor 2
PID 05 – Engine Coolant Temperature	**PID 0E** – Ignition Timing Advance for #1 Cylinder	**PID 14** – Oxygen Sensor 1 Bank 1	**PID 1F** – Time Since Engine Start				
PID 06 – STFT Bank 1, Bank 3	**PID 0F** – Intake Air Temperature	**PID 15** – Oxygen Sensor 2 Bank 1					
PID 07 – LTFT Bank 1, Bank 3		**PID 16** – Oxygen Sensor 3 Bank 1					
PID 08 – LTFT Bank 2, Bank 4		**PID 17** – Oxygen Sensor 4 Bank 1					

PID 09 – LTFT Bank 2, Bank 4		**PID 18 –** Oxygen Sensor 1 Bank 2					
		PID 19 – Oxygen Sensor 2 Bank 2					
PID 41 – Monitor Status this Driving Cycle	**PID 44 –** Commanded Equivalence Ratio	**PID 49 –** Accelerator Pedal Position D		**PID 4A –** Accelerator Pedal Position E	**PID 4D –** Minutes Run by the Engine While MIL Activated		
PID 42 – Control Module Voltage	**PID 45 –** Relative Throttle Position			**PID 4B –** Accelerator Pedal Position F	**PID 4E –** Time Since DTCs Cleared		
PID 43 – Absolute Load Value	**PID 46 –** Ambient Air Temperature			**PID 4C –** Command Throttle Actuator Control			

By Continent

Continent	Projects
Asia	85
Europe	159
North America	149
Oceania	7
Grand Total	400

By Country

Country	Projects
China	9
India	1
Israel	6
Japan	44
Singapore	1
South Korea	17
Taiwan	6
Turkey	1
Austria	2
Belgium	10
Finland	2
France	14
Germany	43
Greece	2
Italy	12
Netherlands	21
Norway	2
Portugal	1
Romania	1
Spain	6
Sweden	15
United Kingdom	9
Europe-Wide	19
Canada	5
USA	144
Australia	6
New Zealand	1
Grand Total	400

By U.S. State

State	Projects
Arizona	3
California	28
Colorado	2
District of Columbia	4
Florida	6
Georgia	1
Idaho	1
Illinois	2
Indiana	1
Maryland	3
Massachusetts	2
Michigan	30
Minnesota	7
Missouri	1
Montana	10
Nevada	1
New Jersey	2
New York	6
North Carolina	1
Ohio	1
South Carolina	1
Texas	5
Virginia	8
US-Wide	18
Grand Total	144

Figure 8.6: Geographical Summary of Projects (Source: MDOT & CAR, 2013)

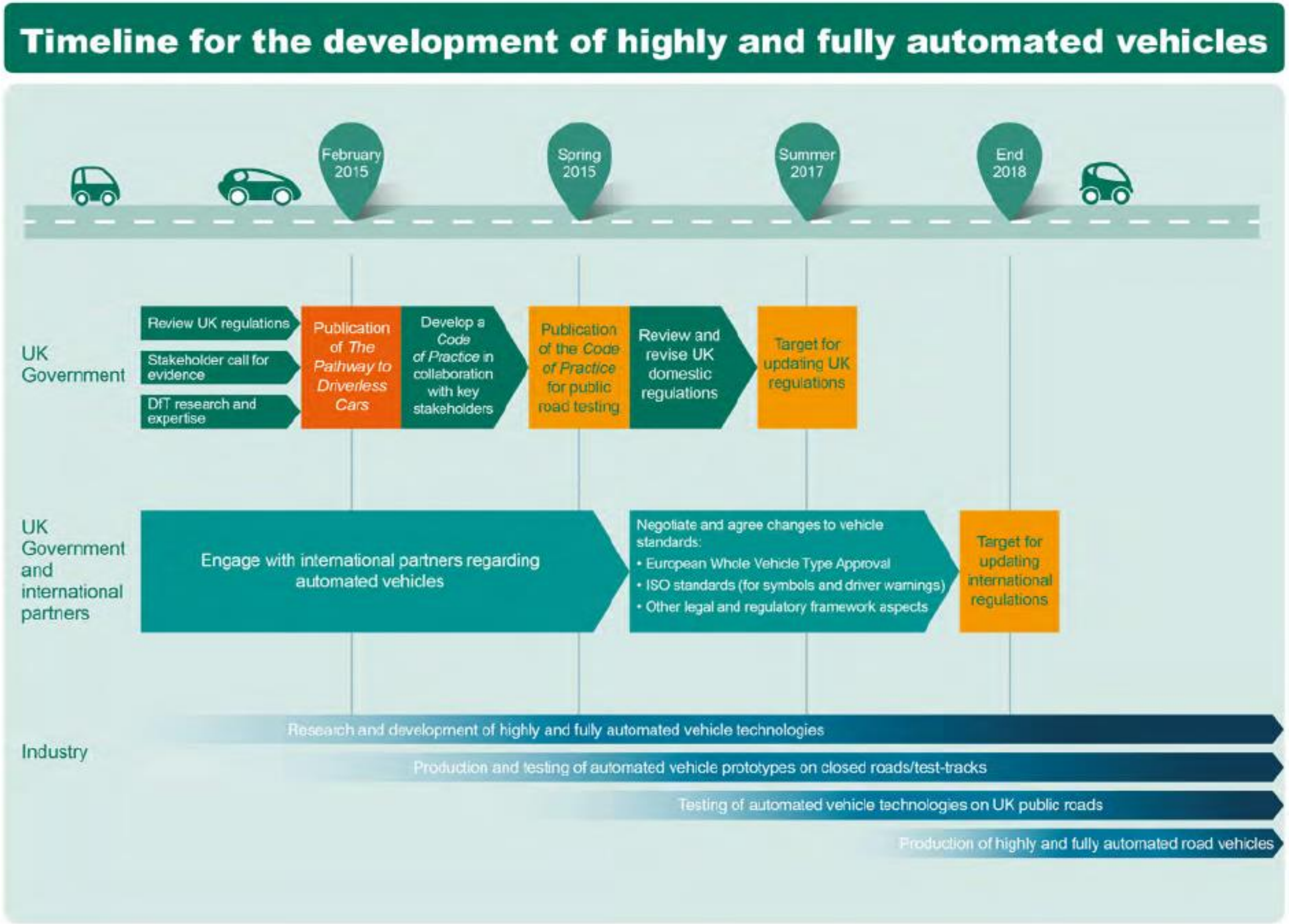
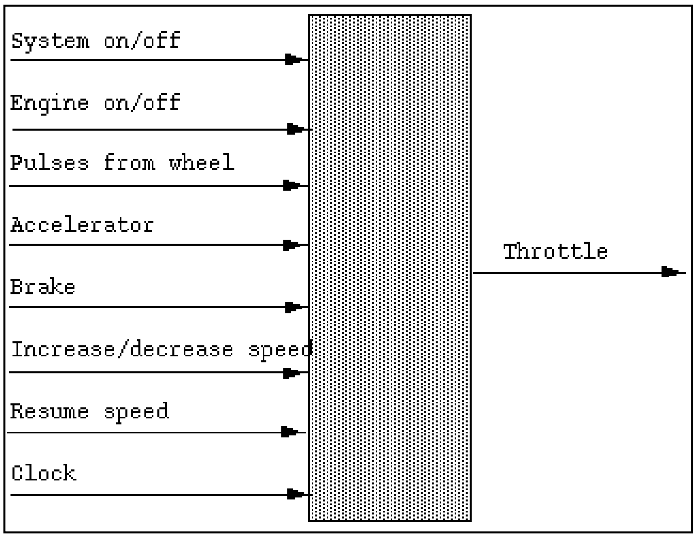


Figure 8.7: Timeline for Automated Vehicles Development (Source: Department for Transport, 2015)

APPENDIX C

CACC uses a forward-looking radar to detect the speed and distance of the vehicle ahead of it (Nice, K., 2001). CACC automatically adjusts speed to maintain specific distance from the vehicle ahead. By comparison, conventional Cruise Control is only able to maintain a certain speed. Maintaining a safe following distance is achieved through a radar headway sensor, digital signal processor and longitudinal controller (Nice, K., 2001). The following diagram shows the Cruise Control block diagram and the inputs required to produce the desired output (maintain speed).



According to Shaw, M. (n.d.), the inputs may be described as follows:

System on/off: If on, the cruise control system should maintain the vehicle speed

Engine on/off: If on, the engine is turned on; cruise control is only active if the engine is on.

Pulses from wheel: a pulse is sent for every revolution of the wheel

Accelerator: indicator of how far the acceleration pedal has been suppressed

Brake: On when the brake is pressed; cruise-control system temporarily reverts to manual control if the brake is pressed.

Increase/Decrease Speed: increase or decrease the maintained speed. Applicable if cruise control is active

Resume: Resume last maintained speed

Clock: Timing pulse every millisecond

Throttle: digital value for engineer throttle setting

APPENDIX D

FORMAT OF VDS DATA

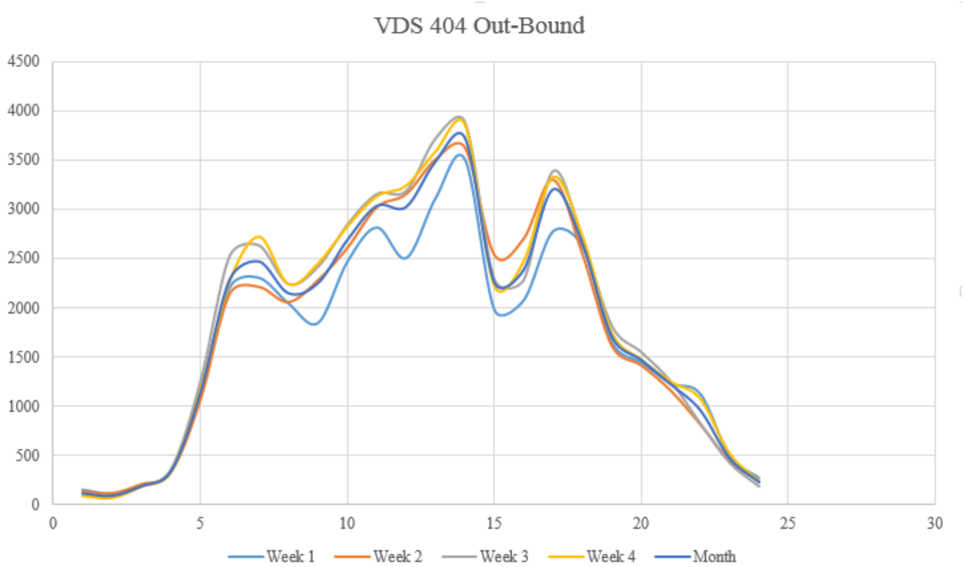
The following table provides an indication of the format of the VDS data obtained for the freeway routes modelled in this study

Region	VDS	Date	Time	Class 1	Class 2	Class 3	Speed
WC	DS VDS 101 OB	2016/05/01	05:00:00	99	2	1	103
WC	DS VDS 101 OB	2016/05/01	05:01:00	132	1	0	99
WC	DS VDS 101 OB	2016/05/01	05:02:00	139	5	2	100
WC	DS VDS 101 OB	2016/05/01	05:03:00	143	0	2	99
WC	DS VDS 101 OB	2016/05/01	05:04:00	166	5	1	99
WC	DS VDS 101 OB	2016/05/01	05:05:00	210	5	1	103
WC	DS VDS 101 OB	2016/05/01	06:00:00	187	2	2	99
WC	DS VDS 101 OB	2016/05/01	06:01:00	211	9	3	100
WC	DS VDS 101 OB	2016/05/01	06:02:00	232	3	1	101
WC	DS VDS 101 OB	2016/05/01	06:03:00	243	5	1	101
WC	DS VDS 101 OB	2016/05/01	06:04:00	268	4	1	99
WC	DS VDS 101 OB	2016/05/01	06:05:00	349	6	1	101
WC	DS VDS 101 OB	2016/05/01	07:00:00	319	6	0	101
WC	DS VDS 101 OB	2016/05/01	07:01:00	369	3	2	100
WC	DS VDS 101 OB	2016/05/01	07:02:00	370	8	2	100
WC	DS VDS 101 OB	2016/05/01	07:03:00	386	6	3	99
WC	DS VDS 101 OB	2016/05/01	07:04:00	399	5	2	101
WC	DS VDS 101 OB	2016/05/01	07:05:00	443	7	1	99
WC	DS VDS 101 OB	2016/05/01	08:00:00	422	6	2	100
WC	DS VDS 101 OB	2016/05/01	08:01:00	480	4	4	98
WC	DS VDS 101 OB	2016/05/01	08:02:00	460	8	5	99
WC	DS VDS 101 OB	2016/05/01	08:03:00	487	7	2	98
WC	DS VDS 101 OB	2016/05/01	08:04:00	505	5	1	98
WC	DS VDS 101 OB	2016/05/01	08:05:00	517	9	1	99
WC	DS VDS 101 OB	2016/05/01	09:00:00	519	7	7	96
WC	DS VDS 101 OB	2016/05/01	09:01:00	555	10	2	98
WC	DS VDS 101 OB	2016/05/01	09:02:00	616	6	1	96
WC	DS VDS 101 OB	2016/05/01	09:03:00	615	15	3	98
WC	DS VDS 101 OB	2016/05/01	09:04:00	597	6	2	97
WC	DS VDS 101 OB	2016/05/01	09:05:00	615	8	1	98
WC	DS VDS 101 OB	2016/05/01	10:00:00	665	6	5	98
WC	DS VDS 101 OB	2016/05/01	10:01:00	652	6	0	99
WC	DS VDS 101 OB	2016/05/01	10:02:00	661	6	1	98
WC	DS VDS 101 OB	2016/05/01	10:03:00	597	9	1	98
WC	DS VDS 101 OB	2016/05/01	10:04:00	594	6	6	99
WC	DS VDS 101 OB	2016/05/01	10:05:00	639	8	0	99
WC	DS VDS 101 OB	2016/05/01	11:00:00	565	8	1	100
WC	DS VDS 101 OB	2016/05/01	11:01:00	571	6	1	99
WC	DS VDS 101 OB	2016/05/01	11:02:00	636	14	0	98
WC	DS VDS 101 OB	2016/05/01	11:03:00	594	10	2	101
WC	DS VDS 101 OB	2016/05/01	11:04:00	587	6	1	98
WC	DS VDS 101 OB	2016/05/01	11:05:00	610	9	4	97
WC	DS VDS 101 OB	2016/05/01	12:00:00	567	8	3	98
WC	DS VDS 101 OB	2016/05/01	12:01:00	594	7	3	98
WC	DS VDS 101 OB	2016/05/01	12:02:00	595	6	3	98
WC	DS VDS 101 OB	2016/05/01	12:03:00	593	11	1	97
WC	DS VDS 101 OB	2016/05/01	12:04:00	604	8	3	99
WC	DS VDS 101 OB	2016/05/01	12:05:00	573	11	0	97
WC	DS VDS 101 OB	2016/05/01	13:00:00	620	7	4	98
WC	DS VDS 101 OB	2016/05/01	13:01:00	662	6	3	98
WC	DS VDS 101 OB	2016/05/01	13:02:00	599	12	4	100
WC	DS VDS 101 OB	2016/05/01	13:03:00	592	6	5	99
WC	DS VDS 101 OB	2016/05/01	13:04:00	601	3	0	99
WC	DS VDS 101 OB	2016/05/01	13:05:00	592	10	2	98
WC	DS VDS 101 OB	2016/05/01	14:00:00	656	9	1	96
WC	DS VDS 101 OB	2016/05/01	14:01:00	576	3	2	97
WC	DS VDS 101 OB	2016/05/01	14:02:00	600	6	4	97
WC	DS VDS 101 OB	2016/05/01	14:03:00	622	7	1	98
WC	DS VDS 101 OB	2016/05/01	14:04:00	598	7	2	98
WC	DS VDS 101 OB	2016/05/01	14:05:00	620	8	0	98
WC	DS VDS 101 OB	2016/05/01	15:00:00	572	9	2	99
WC	DS VDS 101 OB	2016/05/01	15:01:00	606	7	5	97
WC	DS VDS 101 OB	2016/05/01	15:02:00	689	9	5	95
WC	DS VDS 101 OB	2016/05/01	15:03:00	640	8	9	95
WC	DS VDS 101 OB	2016/05/01	15:04:00	640	3	4	93
WC	DS VDS 101 OB	2016/05/01	15:05:00	603	7	1	94
WC	DS VDS 101 OB	2016/05/01	16:00:00	651	6	3	96
WC	DS VDS 101 OB	2016/05/01	16:01:00	602	9	3	96
WC	DS VDS 101 OB	2016/05/01	16:02:00	623	7	1	93
WC	DS VDS 101 OB	2016/05/01	16:03:00	585	9	2	93

The following table shows the data aggregated into weekly flow volumes for a single month (August, 2016)

Time	Week 1	Week 2	Week 3	Week 4	Month
12 AM	150	133	104	92	120
01 AM	109	112	84	70	94
02 AM	184	203	191	187	191
03 AM	345	324	358	331	339
04 AM	1074	1057	1244	1160	1134
05 AM	2205	2142	2526	2266	2285
06 AM	2303	2210	2632	2721	2467
07 AM	2043	2057	2242	2240	2145
08 AM	1844	2278	2415	2449	2247
09 AM	2466	2607	2842	2824	2685
10 AM	2815	3021	3154	3130	3030
11 AM	2504	3155	3184	3239	3021
12 PM	3112	3509	3717	3585	3481
01 PM	3505	3627	3884	3858	3719
02 PM	1979	2536	2285	2219	2255
03 PM	2077	2704	2284	2474	2385
04 PM	2778	3301	3388	3329	3199
05 PM	2620	2537	2692	2720	2642
06 PM	1643	1606	1811	1740	1700
07 PM	1441	1411	1549	1473	1469
08 PM	1231	1154	1252	1250	1222
09 PM	1124	813	829	1077	961
10 PM	497	442	428	520	472
11 PM	267	231	189	240	232

The figure below provides a graphical description of the above data



Refer to the *VDS Data* file available on the attached flash disk.

FORMAT OF LOCAL DATA

The following figure illustrates the format of the data provided for the local routes modelled in this study.

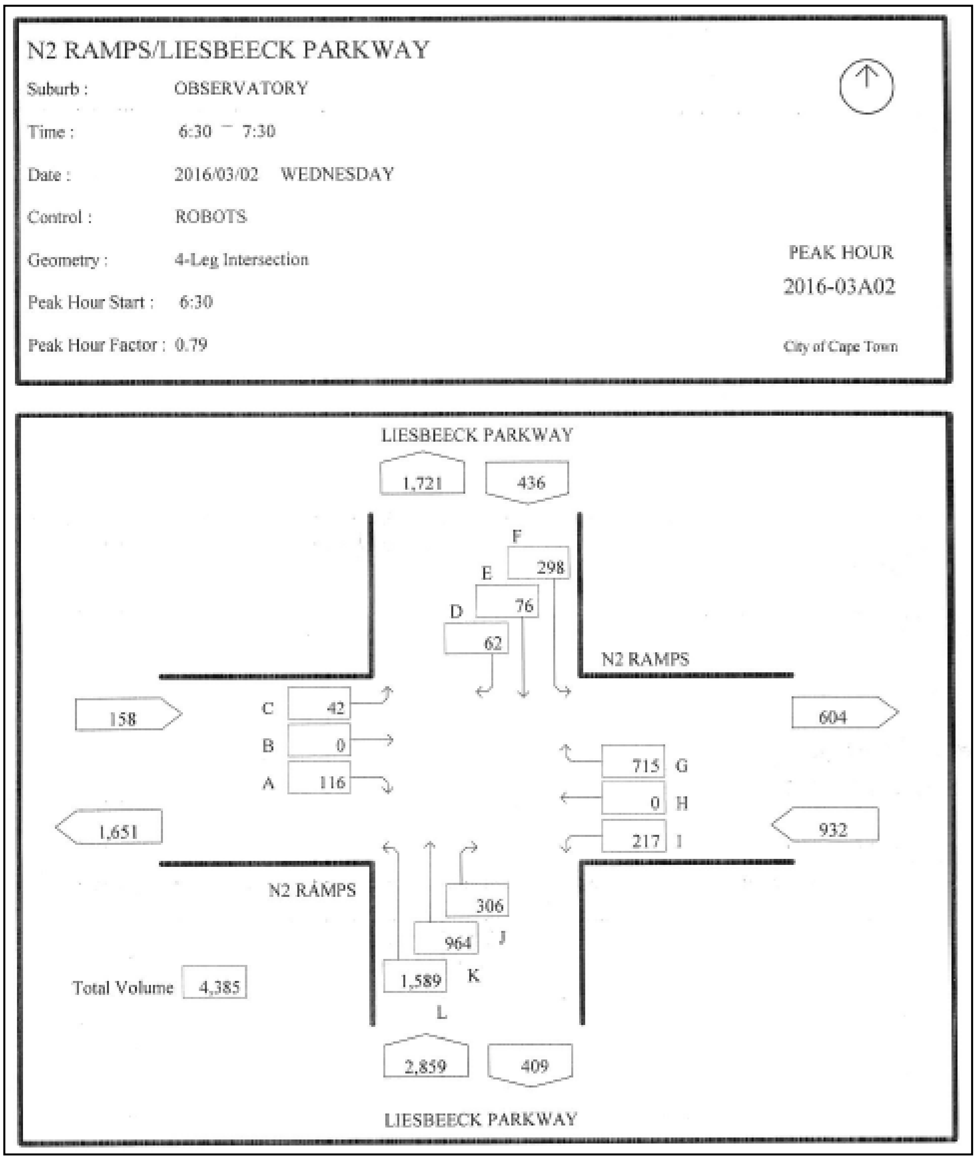


Figure 8.8: Intersection Volume Distribution for Arterial Route (Source: CoCT)

This information is further divided into vehicle classes in 15-minute intervals as illustrated in the following figure:

N2 RAMPS/LIESBEECK PARKWAY

Suburb : OBSERVATORY

Time : 6:30 – 7:30

Date : 2016/03/02 WEDNESDAY

Control : ROBOTS

Geometry : 4-Leg Intersection

Peak Hour Start : 6:30

Peak Hour Factor : 0.79

PEAK HOUR

2016-03A02

City of Cape Town

	A	B	C	D	E	F	G	H	I	J	K	L
6:30	24	0	5	6	11	37	204	0	38	109	354	548
6:45	37	0	5	16	18	58	142	0	33	93	295	403
7:00	28	0	21	19	15	83	181	0	42	45	160	276
7:15	26	0	10	20	29	99	150	0	69	54	136	349
Light	115	0	41	61	73	277	677	0	182	301	945	1,576
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	0	0	0	0	1	3	0	1	0	12	0
6:45	1	0	1	0	1	3	2	0	0	0	2	0
7:00	0	0	0	1	0	0	2	0	0	0	2	0
7:15	0	0	0	0	1	3	3	0	0	0	3	0
Heavy	1	0	1	1	2	7	10	0	1	0	19	0
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	0	0	0	0	1	8	0	9	0	0	4
6:45	0	0	0	0	1	2	11	0	9	0	0	3
7:00	0	0	0	0	0	2	5	0	11	1	0	3
7:15	0	0	0	0	0	0	1	0	5	0	0	0
Taxis	0	0	0	0	1	5	25	0	34	1	0	10
	A	B	C	D	E	F	G	H	I	J	K	L
6:30	0	0	0	0	0	2	2	0	0	0	0	1
6:45	0	0	0	0	0	2	1	0	0	3	0	0
7:00	0	0	0	0	0	4	0	0	0	1	0	2
7:15	0	0	0	0	0	1	0	0	0	0	0	0
Busses	0	0	0	0	0	9	3	0	0	4	0	3

Figure 8.9: Volume Distribution and Classification for Arterial Route (Source: CoCT)

Refer to the *Local Data* file available on the attached flash disk.

CCTV FOOTAGE

The number of vehicles exiting from off-ramps and entering the freeway via on-ramps was counted in 15 minute intervals. This data may be obtained from Sanral.

FORMAT OF TRAFFIC SIGNAL PHASING AND TIMING DATA

The table below shows the daily program for a single intersection:

Daily signal program list		
Name:	Daily signal program list 1000	
No:	1000	
Time	**Name**	**Cycle time**
06:00:00	AM Peak	63
09:00:00	Interpeak	51
16:00:00	PM Peak	73
19:00:00	Off Peak	42

Signal control		
	Controller frequency: 1	
Signal groups		
	A	
	F	
	B	
Intergreen matrices		
	AM Peak	
	Interpeak	
	PM Peak	
	Off Peak	
Signal programs		
	AM Peak	
	Interpeak	
	PM Peak	
	Off Peak	
Daily signal program lists		
	Daily signal program list 1000	

Figure 8.10: Traffic Signal Program for N2-Liesbeek Ramps

Signal groups		
No	**Name**	**Notes**
1	A	Liesbeek
2	F	On-ramp to N2
3	B	Exiting N2

Signal group	
Name:	A
No:	1
Signal state	**Duration**
Red	2 (minimum duration)
Green	7 (minimum duration)
Amber	3 (Duration)

Signal group	
Name:	F
No:	2
Signal state	**Duration**
Red	1 (minimum duration)
Green	4 (minimum duration)
Amber	3 (Duration)

Signal group	
Name:	B
No:	3
Signal state	**Duration**
Red	2 (minimum duration)
Green	7 (minimum duration)
Amber	3 (Duration)

Signal program											
Name:	AM Peak										
No:	1										
Intergreen matrix:	AM Peak										
Cycle time:	63										
Offset:	0										
Switch point:	0										
No	**Signal group**	**Signal state sequence**	**Red (red) (End)**	**Green (green) (End)**	**Red (red) (End) 2**	**Green (green) (End) 2**	**Red/Amber (red) (fixed duration)**	**Amber (red) (fixed duration)**	**Flashing Red (red) (fixed duration)**	**Flashing green (green) (fixed duration)**
1	A	Red-green-amber	63	20	–	--	–	3	--	--
2	F	Red-green-amber	23	30	–	--	–	3	--	--
3	B	Red-green-amber	33	60	–	--	–	3	--	--

Signal program										
Name:	Interpeak									
No:	2									
Cycle time:	51									
Offset:	0									
Switch point:	0									

No	Signal group	Signal state sequence	Red (red) (End)	Green (green) (End)	Red (red) (End) 2	Green (green) (End) 2	Red/Amber (red) (fixed duration)	Amber (red) (fixed duration)	Flashing Red (red) (fixed duration)	Flashing green (green) (fixed duration)
1	A	Red-green-amber	51	18	–	--	–	3	--	--
2	F	Red-green-amber	21	26	–	--	–	3	--	--
3	B	Red-green-amber	29	48	–	--	–	3	--	--

Signal program										
Name:	PM Peak									
No:	3									
Cycle time:	73									
Offset:	0									
Switch point:	0									
No	**Signal group**	**Signal state sequence**	**Red (red) (End)**	**Green (green) (End)**	**Red (red) (End) 2**	**Green (green) (End) 2**	**Red/Amber (red) (fixed duration)**	**Amber (red) (fixed duration)**	**Flashing Red (red) (fixed duration)**	**Flashing green (green) (fixed duration)**
1	A	Red-green-amber	73	16	–	--	–	3	--	--
2	F	Red-green-amber	19	32	–	--	–	3	--	--
3	B	Red-green-amber	35	70	–	--	–	3	--	--

Signal program										
Name:	Off Peak									
No:	4									
Cycle time:	42									
Offset:	0									
Switch point:	0									
No	**Signal group**	**Signal state sequence**	**Red (red) (End)**	**Green (green) (End)**	**Red (red) (End) 2**	**Green (green) (End) 2**	**Red/Amber (red) (fixed duration)**	**Amber (red) (fixed duration)**	**Flashing Red (red) (fixed duration)**	**Flashing green (green) (fixed duration)**
1	A	Red-green-amber	42	20	–	--	–	3	--	--
2	F	Red-green-amber	23	27	–	--	–	3	--	--
3	B	Red-green-amber	30	39	–	--	–	3	--	--

Refer to the *Local Data* file available on the attached flash disk.

VISSIM INPUT VOLUMES

The following table provides the input data used to simulate free flow conditions:

0	600	1200	1800	2400	3000
-20%	**-10%**	**0**	**-10%**	**-20%**	**-25%**
3200	3600	4000	3600	3200	3000
1456	1638	1820	1638	1456	1365
1469	1652	1836	1652	1469	1377
2944	3312	3680	3312	2944	2760
138	156	173	156	138	130
264	297	330	297	264	248
50	56	62	56	50	47
474	533	592	533	474	444
3840	4320	4800	4320	3840	3600
45	50	56	50	45	42
146	164	182	164	146	137
157	176	196	176	157	147
1830	2058	2287	2058	1830	1715
640	720	800	720	640	600
1055	1187	1319	1187	1055	989
1600	1800	2000	1800	1600	1500
768	864	960	864	768	720
320	360	400	360	320	300
45	50	56	50	45	42
19	22	24	22	19	18
45	50	56	50	45	42
45	50	56	50	45	42
19	22	24	22	19	18
19	22	24	22	19	18
64	72	80	72	64	60
19	22	24	22	19	18
160	180	200	180	160	150
32	36	40	36	32	30
13	14	16	14	13	12
64	72	80	72	64	60
1600	1800	2000	1800	1600	1500

.

The table below indicates the input values used to simulate traffic flow for a full day

					Warm-Up	Morning Peak			Interpeak							Evening Peak			Off-Peak	
Data Input Ref.	Type	Zone	Link	Location	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
VDS	Freeway	1	176	Settlers Way	500	1748	2011	2981	3166	3187	3015	3000	2951	2940	3087	3073	2564	1661	1290	1196
CoCT Int	Local	2	130	Raapenburg	1000	2230	2274	2393	2568	2781	3011	3239	3446	3612	3718	3744	3671	3479	3150	2663
CoCT Int	Local	3	2	Raapenburg	1000	2249	2295	2253	2156	2030	1897	1774	1670	1591	1536	1499	1469	1429	1356	1222
VDS	Freeway	4	134	M5 (NB)	1500	2284	2750	4213	4466	4147	3856	4050	4049	4157	4375	4091	3512	2810	3511	4433
CoCT Int	Local	5	169	Lower Main Rd	100	232	221	228	250	283	322	364	405	440	467	481	478	454	425	400
CoCT Int	Local	6	111	Station Rd	100	434	413	476	602	771	965	1163	1344	1490	1581	1596	1516	1400	1325	1300
CoCT Int	Local	7	114	Observatory Rd	50	82	78	83	95	113	132	152	171	186	194	195	185	173	161	150
CoCT Int	Local	8	85	Koeberg Rd	200	703	740	735	705	664	621	586	563	555	561	579	602	623	628	606
VDS	Freeway	9	87	N1 Start	3086	3332	2925	2944	2883	2868	2692	2494	2383	2260	2152	2194	1506	946	757	96
CCTV	Local	10	89	Marine Dr	1505	1686	1770	1484	1349	1133	935	780	685	657	691	772	878	972	1005	940
CoCT Int	Local	11	161	Salt River	640	809	956	974	691	619	587	604	643	689	729	751	771	770	782	839
CoCT Int	Local	12	162	Durham Rd	640	807	947	964	695	608	559	558	581	616	650	676	710	737	791	878
CoCT Int	Local	13	166	M57 Start (Liesbeek)	1825	2716	2859	2812	2618	2320	1961	1584	1233	950	778	762	943	1150	1275	1350
CoCT Int	Local	14	43	Berkley Rd	500	1189	1213	1231	1248	1266	1289	1317	1348	1379	1406	1422	1421	1393	1326	1209
CoCT Int	Local	15	165	Voortrekker	1040	2116	2309	2276	1895	1615	1362	1176	1051	987	977	1007	1080	1161	1255	1329
VDS	Freeway	16	13	De Waal Dr start (N2)	500	783	2172	2154	2127	2090	2045	1990	1926	1853	1770	1679	1578	1468	2163	2108
VDS	Freeway	17	144	N2 to De Waal Dr (SB)	2285	2467	2145	2247	2685	3030	3021	3481	3719	2255	2385	3199	2642	1700	1469	1222
VDS	Freeway	18	143	From N2 to Liesbeek Bridge (SB)	3509	3494	2999	3314	3574	3933	4010	4450	4036	3657	3931	4040	2714	1747	1608	222
CCTV	Freeway	19	141	Exit Bridge onto N2 (SB)	200	317	445	449	392	322	279	289	365	513	723	974	1236	1464	1604	1588
CCTV	Local	20	21	Hospital Bend Input	106	128	129	119	104	89	81	80	90	111	140	176	214	249	275	283
CCTV	Local	21	149	Ritchie Str	220	263	266	244	209	174	145	128	126	230	380	454	528	577	571	475
CCTV	Local	22	148	Ritchie Str	512	614	620	568	489	406	339	299	293	230	163	195	226	247	245	203
CCTV	Local	23	151	Lever Str	64	77	78	71	61	51	42	37	37	29	20	24	28	31	31	25
CCTV	Local	24	152	Upper Adelaide	46	55	55	51	44	36	30	27	26	29	34	41	47	51	51	42
CCTV	Local	25	154	Searle	59	87	99	100	93	81	67	53	39	28	20	15	13	13	14	14
Est.	Local	26	83	Beach Rd	2	3	5	7	9	12	15	17	20	23	28	37	57	77	65	22
Est.	Local	27	97	Albert Entrance	121	387	495	500	451	386	337	324	360	450	587	758	940	1101	1200	1188
Est.	Local	28	81	M176 (Lower Curch)	353	385	386	366	333	295	258	226	202	188	184	188	199	212	217	205
Est.	Local	29	101	Malta Exit	3	5	8	11	14	18	23	26	30	35	42	56	86	116	98	33
Est.	Local	30	104	Fir Str	0	12	23	30	40	49	59	75	95	121	164	250	375	225	105	0
VDS	Freeway	31	126	M5 (SB)	3750	3876	3893	3680	3905	4063	3878	4287	4830	3621	3118	3878	2794	1847	1579	1111

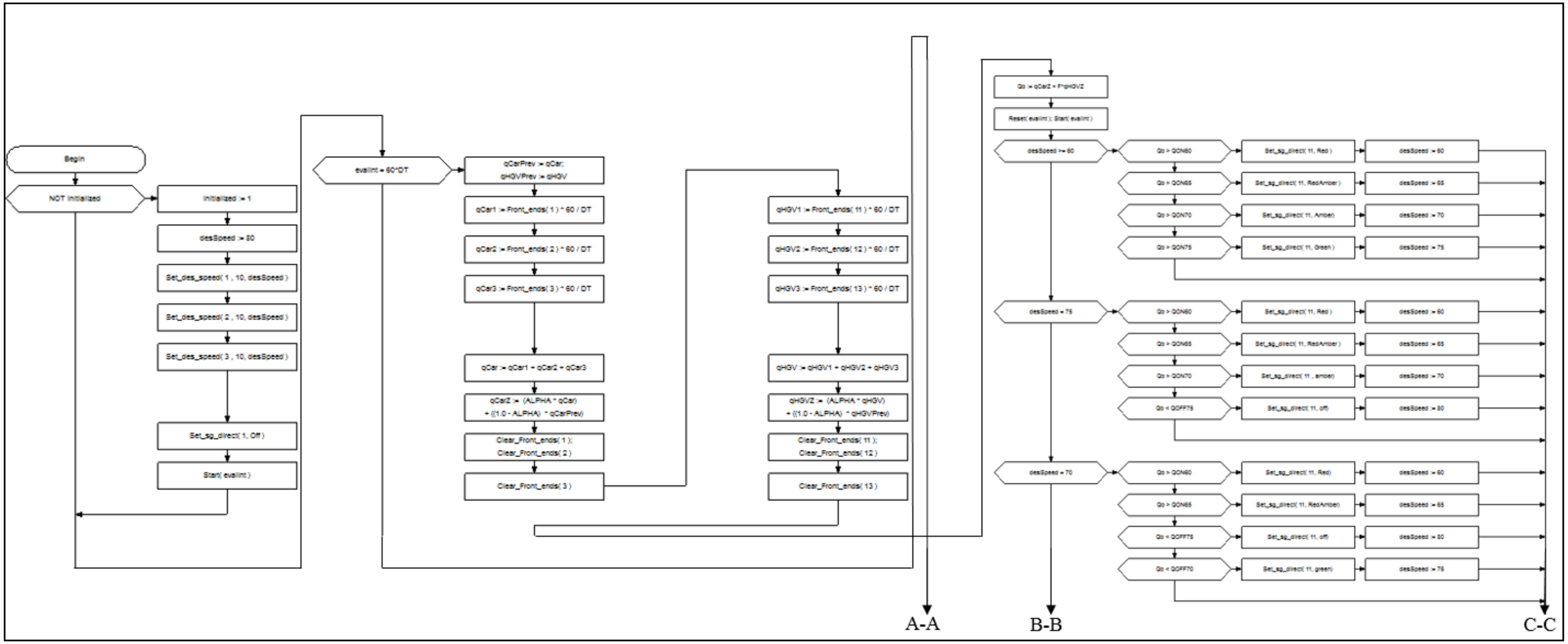
Figure 8.11: Input Values for a Complete Day - Morning Peak, Inter Peak, Evening Peak and Off-Peak flow

Refer to the Volumes and Distributions file available on the attached flash disk. The folder contains excel files describing the distribution of vehicle volumes and vehicle inputs. The procedure followed for distributing the traffic in the network may be found on the attached flash disk (*Vehicle Volume Distributions*). The following table provides an example of the distribution of traffic along the M5 heading South Bound (Route 1):

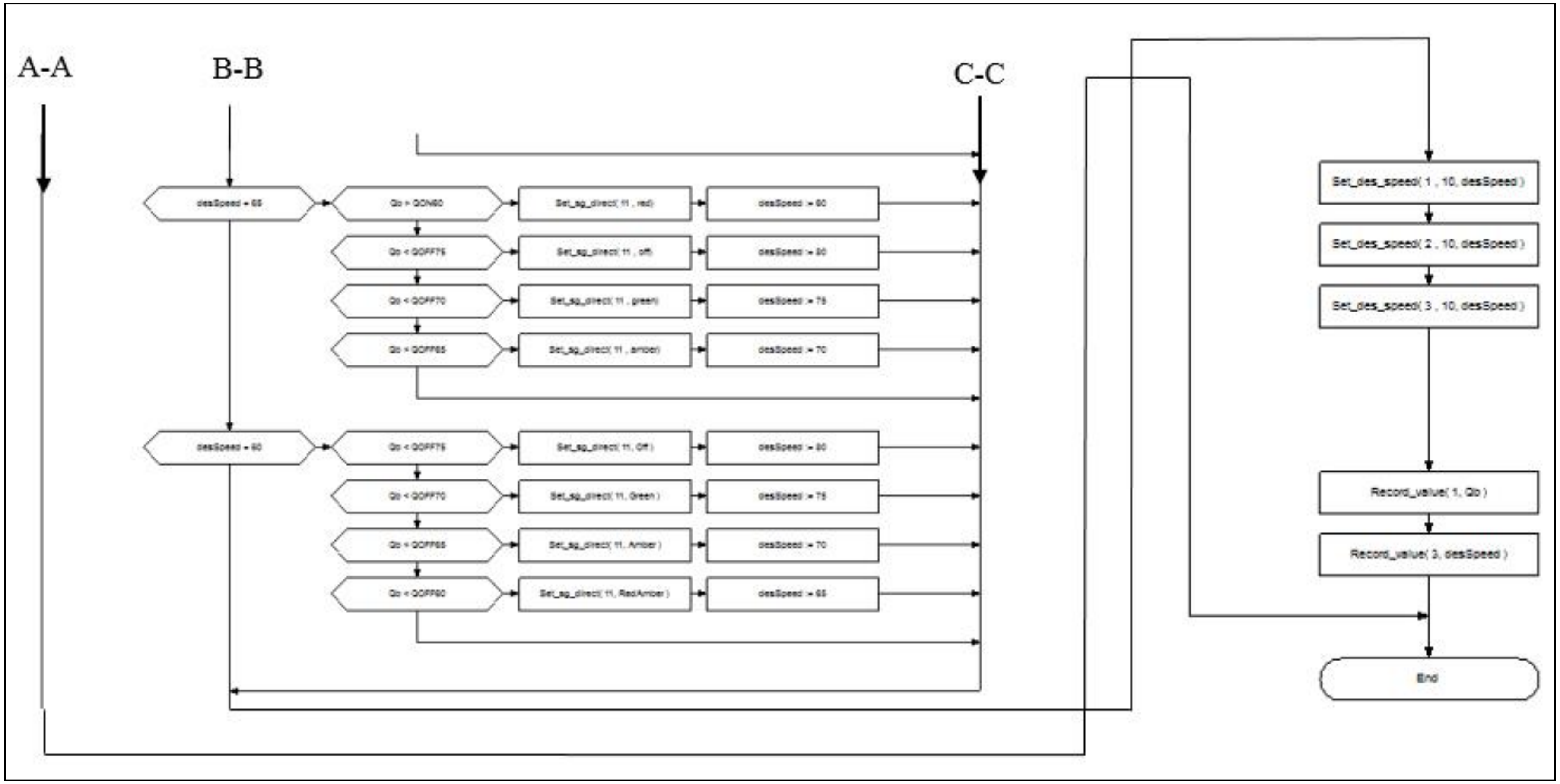
	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
M5 South Bound	3750	3876	3893	3680	3905	4063	3878	4287	4830	3621	3118	3878	2794	1847	1579	1563
M5 OB Exit to N2 OB	973	1139	1150	1061	915	752	601	483	412	396	431	509	611	713	780	772
M5 OB Dis	7.41	7.06	7.05	7.12	7.66	8.15	8.45	8.87	9.15	8.91	8.62	8.69	7.81	6.14	5.06	5.06
M5 Off-Ramp Dis	2.59	2.94	2.95	2.88	2.34	1.85	1.55	1.13	0.85	1.09	1.38	1.31	2.19	3.86	4.94	4.94
N2 OB Off-Ramp to M5 OB	640	772	780	713	611	509	431	396	412	483	601	752	915	1061	1150	1139
Total vehicles before exit	3417	3509	3523	3332	3601	3820	3708	4201	4830	3708	3288	4121	3098	2195	1949	1930
M5 Off-Ramp to N2 IB	953	1087	1098	1027	910	775	647	543	473	444	455	500	565	633	679	672
M5 OB Dis	7.21	6.90	6.88	6.92	7.47	7.97	8.25	8.71	9.02	8.80	8.61	8.79	8.17	7.11	6.51	6.52
M5 Off-Ramp Dis	2.79	3.10	3.12	3.08	2.53	2.03	1.75	1.29	0.98	1.20	1.39	1.21	1.83	2.89	3.49	3.48
Total Vehicles After M5 SB exit to N1 IB	2464	2422	2425	2305	2691	3044	3061	3658	4357	3263	2832	3621	2533	1562	1270	1257

VISVAP: SPEED HARMONISATION

The following figure indicates the logic used to determine a suitable travelling speed along the Route 1 freeway:



Begin
NOT Initialized
Initialized := 1
desSpeed := 80
Set_des_speed(1 , 10, desSpeed)
Set_des_speed(2 , 10, desSpeed)
Set_des_speed(3 , 10, desSpeed)
Set_sg_direct(1, Off)
Start(evalInt)
evalInt = 60*DT
qCarPrev := qCar;
qHGVPrev := qHGV
qCar1 := Front_ends(1) * 60 / DT
qCar2 := Front_ends(2) * 60 / DT
qCar3 := Front_ends(3) * 60 / DT
qCar := qCar1 + qCar2 + qCar3
qCarZ := (ALPHA * qCar)
+ ((1.0 - ALPHA) * qCarPrev)
Clear_Front_ends(1);
Clear_Front_ends(2)
Clear_Front_ends(3)
qHGV1 := Front_ends(11) * 60 / DT
qHGV2 := Front_ends(12) * 60 / DT
qHGV3 := Front_ends(13) * 60 / DT
qHGV := qHGV1 + qHGV2 + qHGV3
qHGVZ := (ALPHA * qHGV)
+ ((1.0 - ALPHA) * qHGVPrev)
Clear_Front_ends(11);
Clear_Front_ends(12)
Clear_Front_ends(13)
Qb := qCarZ + F*qHGVZ
Reset(evalInt); Start(evalInt)
desSpeed >= 80
Qb > QON60
Set_sg_direct(11, Red)
desSpeed := 60
Qb > QON65
Set_sg_direct(11, RedAmber)
desSpeed := 65
Qb > QON70
Set_sg_direct(11, Amber)
desSpeed := 70
Qb > QON75
Set_sg_direct(11, Green)
desSpeed := 75
desSpeed = 75
Qb > QON60
Set_sg_direct(11, Red)
desSpeed := 60
Qb > QON65
Set_sg_direct(11, RedAmber)
desSpeed := 65
Qb > QON70
Set_sg_direct(11 , amber)
desSpeed := 70
Qb < QOFF75
Set_sg_direct(11, off)
desSpeed := 80
desSpeed = 70
Qb > QON60
Set_sg_direct(11, Red)
desSpeed := 60
Qb > QON65
Set_sg_direct(11, RedAmber)
desSpeed := 65
Qb < QOFF75
Set_sg_direct(11, off)
desSpeed := 80
Qb < QOFF70
Set_sg_direct(11, green)
desSpeed := 75
A-A
B-B
C-C


A-A
B-B
C-C
desSpeed = 65
Qb > QON60
Set_sg_direct(11 , red)
desSpeed := 60
Qb < QOFF75
Set_sg_direct(11 , off)
desSpeed := 80
Qb < QOFF70
Set_sg_direct(11 , green)
desSpeed := 75
Qb < QOFF65
Set_sg_direct(11 , amber)
desSpeed := 70
desSpeed = 60
Qb < QOFF75
Set_sg_direct(11, Off)
desSpeed := 80
Qb < QOFF70
Set_sg_direct(11, Green)
desSpeed := 75
Qb < QOFF65
Set_sg_direct(11, Amber)
desSpeed := 70
Qb < QOFF60
Set_sg_direct(11, RedAmber)
desSpeed := 65
Set_des_speed(1 , 10, desSpeed)
Set_des_speed(2 , 10, desSpeed)
Set_des_speed(3 , 10, desSpeed)
Record_value(1, Qb)
Record_value(3, desSpeed)
End

This logic was developed by Vissim and is available as an example experiment. The logic was adapted for use in the simulations conducted for this study.

SCRIPT-FILE

The figure below shows the script-file used to enable CV behaviour for a varying percentage of vehicles in the simulations conducted:

V2V Script - Queue Warning and Speed Harmonisation.py

```
# This (V2V) example demonstrates how to model communication between vehicles.
# At simulation second 1200, there is an accident between two vehicles. At the time of
accident, the vehicle sends out a warning message.
# Vehicles receiving this message will drop their speed and adjust their driving
behavior until they passed the incident.

def Initialization():
    # Global Parameters:
    global distDistr
    global Vehicle_Type_V2V_no_message
    global Vehicle_Type_V2V_HasCurrentMessage
    global speed_incident

    distDistr = 1 # number of Distance distribution used for sending out a V2V message
    Vehicle_Type_V2V_no_message = '101' # number of V2V vehicle type (no active
message) has to be a string!
    Vehicle_Type_V2V_HasCurrentMessage = '102' # number of V2V vehicle type with
active message has to be a string!
    speed_incident = 60 # Speed of vehicles receiving the V2V message in kph
    return


def Main():

    # Get several attributes of all vehicles:
    Veh_attributes = Vissim.Net.Vehicles.GetMultipleAttributes(('RoutDecType',
'RoutDecNo', 'VehType', 'No'))

    if len(Veh_attributes) > 0: # Check if there are any vehicles in the network:

        # Filter by VehType V2V:
        Veh_V2V_attributes = [item for item in Veh_attributes if item[2] ==
Vehicle_Type_V2V_no_message or item[2] == Vehicle_Type_V2V_HasCurrentMessage]

        # For all V2V vehicles: check if there is an incident | incident is modelled
as parking routing decision #1
        for cnt_V2V_veh in range(len(Veh_V2V_attributes)):
            if Veh_V2V_attributes[cnt_V2V_veh][0] == 'PARKING' and
Veh_V2V_attributes[cnt_V2V_veh][1] == 1:
decision #1)
                Veh_sending_Msg =
Vissim.Net.Vehicles.ItemByKey(Veh_V2V_attributes[cnt_V2V_veh][3])
                Coord_Veh = Veh_sending_Msg.AttValue('CoordFront') # reading the world
coordinates (x y z) of the vehicle
                PositionXYZ = Coord_Veh.split(" ")

                Pos_Veh_SM = Veh_sending_Msg.AttValue('Pos') # relative position on
the current link
                Veh_sending_Msg.SetAttValue('V2V_HasCurrentMessage', 1)
                Veh_sending_Msg.SetAttValue('V2V_SendingMessage', 1)
                Veh_sending_Msg.SetAttValue('V2V_MessageOrigin', Pos_Veh_SM)

                # Getting vehicles which receive the message:
                Veh_Rec_Message = Vissim.Net.Vehicles.GetByLocation(PositionXYZ[0],
PositionXYZ[1], distDistr)

                # Reading Attribut of all Vehicles who are receiving the V2V message
(Note: all vehicle classes involved, also non V2V vehicles)
                Attributes = ('Pos', 'VehType', 'V2V_HasCurrentMessage',
'V2V_MessageOrigin', 'V2V_Message', 'DesSpeed', 'V2V_DesSpeedOld')
```

V2V Script - Queue Warning and Speed Harmonisation.py

```
                Veh_attributes_Rec_Message =
list(Veh_Rec_Message.GetMultipleAttributes(Attributes))

                # Adjusting the attributes of the V2V vehicles because of this message:
                for cnt_Veh_Rec_Message in range(len(Veh_attributes_Rec_Message)):
                    atts_current = Veh_attributes_Rec_Message[cnt_Veh_Rec_Message]
                    pos_cur = atts_current[0]
                    veh_type_cur = atts_current[1]
                    pos_V2V_cur = atts_current[3]
                    des_speed_cur = atts_current[5]
                    des_speed_old_cur = atts_current[6]
                    if (veh_type_cur == Vehicle_Type_V2V_no_message or veh_type_cur ==
Vehicle_Type_V2V_HasCurrentMessage) and pos_cur < Pos_Veh_SM and Pos_Veh_SM >
pos_V2V_cur:
there is no other further downsteam message active
                        if des_speed_cur == speed_incident:
                            # if the attribute 'DesSpeed' was already set to
'speed_incident', don't overwrite 'V2V_DesSpeedOld' with with current 'DesSpeed' =
'speed_incident'
                            Veh_attributes_Rec_Message[cnt_Veh_Rec_Message] =
tuple([int(Vehicle_Type_V2V_HasCurrentMessage), 1, Pos_Veh_SM,
ahead!', speed_incident, des_speed_old_cur])
                        else:
                            Veh_attributes_Rec_Message[cnt_Veh_Rec_Message] =
tuple([int(Vehicle_Type_V2V_HasCurrentMessage), 1, Pos_Veh_SM,
ahead!', speed_incident, des_speed_cur])
                    else:
                        Veh_attributes_Rec_Message[cnt_Veh_Rec_Message] =
atts_current[1:]
position
                # Giving back the adjusted attributes to Vissim (note: attribute 'Pos'
is read-only)
                Veh_Rec_Message.SetMultipleAttributes(Attributes[1:],
Veh_attributes_Rec_Message)

        # Check if vehicles with active meassage passed the position of the warning
message:
        Attributes = ('Pos', 'VehType', 'V2V_HasCurrentMessage', 'V2V_MessageOrigin',
'V2V_Message', 'DesSpeed', 'V2V_DesSpeedOld')
        Veh_attributes = list(Vissim.Net.Vehicles.GetMultipleAttributes(Attributes))

        for cnt_Veh in range(len(Veh_attributes)):
            atts_current = Veh_attributes[cnt_Veh]
            pos_cur = atts_current[0]
            veh_type_cur = atts_current[1]
            V2V_msg_active_cur = atts_current[2]
            pos_V2V_cur = atts_current[3]
            des_speed_old_cur = atts_current[6]
            # if the vehicle has an active V2V message AND the position is larger than
the V2V Position
            if V2V_msg_active_cur == 1 and pos_cur > pos_V2V_cur:
                Veh_attributes[cnt_Veh] = [int(Vehicle_Type_V2V_no_message), 0, '', '',
 des_speed_old_cur, '']
            else:
                Veh_attributes[cnt_Veh] = atts_current[1:] # no changes
        # Returning the adjusted attributes to Vissim (note: attribute 'Pos' is read-
only)
        Vissim.Net.Vehicles.SetMultipleAttributes(Attributes[1:], Veh_attributes)
    return
```

This code was developed by Vissim and is available as an example experiment. The code was adapted for use in the simulations conducted for this study.

APPENDIX E

The following tables provide the travel times obtained from the various scenarios simulated along the M5 and N1 path (Route 1) under free-flow conditions:

Base Condition

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turf	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	0: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	DIST (M)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	36.829721	23.38107	91.253659	32.72469	5.977458	72.323409	0.890747	32.703123	26.721776	66.608878	389.414531	6.490242183
	TRAVTM(10)	36.786347	22.854885	90.684429	32.72469	5.933401	72.09615	0.887871	32.595507	26.640748	66.608878	387.812906	6.463548433
	Travel Time (Cumulative All)	36.829721	60.210791	151.46445	184.18914	190.166598	262.490007	263.380754	296.083877	322.805653	389.414531		
	Travel Time (Cumalative Vehicles)	36.786347	59.641232	150.325661	183.050351	188.983752	261.079902	261.967773	294.56328	321.204028	387.812906		
Volume @ -10% AM Peak	TRAVTM(ALL)	36.712077	22.542172	100.609313	32.764637	5.931005	75.089035	0.960258	34.352605	29.145137	69.023779	407.130018	6.7855003
	TRAVTM(10)	36.66728	22.542172	100.325298	32.764637	5.910505	74.651325	0.953253	34.195893	29.052231	69.023779	406.086373	6.768106217
	Travel Time (Cumulative All)	36.712077	59.254249	159.863562	192.628199	198.559204	273.648239	274.608497	308.961102	338.106239	407.130018		
	Travel Time (Cumalative Vehicles)	36.66728	59.209452	159.53475	192.299387	198.209892	272.861217	273.81447	308.010363	337.062594	406.086373		
Volume @ AM Peak	TRAVTM(ALL)	38.5502	22.965285	96.451421	33.047762	6.002155	77.723677	1.036336	34.92543	28.4655	68.900607	408.068373	6.80113955
	TRAVTM(10)	38.496707	22.965285	95.872897	33.047762	5.963947	77.39699	1.030988	34.791522	28.384915	68.70034	406.651353	6.77752255
	Travel Time (Cumulative All)	38.5502	61.515485	157.966906	191.014668	197.016823	274.7405	275.776836	310.702266	339.167766	408.068373		
	Travel Time (Cumalative Vehicles)	38.496707	61.461992	157.334889	190.382651	196.346598	273.743588	274.774576	309.566098	337.951013	406.651353		
Volume @ -10% AM Peak	TRAVTM(ALL)	38.596082	23.164463	96.364506	33.595394	6.08829	77.950014	1.003989	35.10713	27.182235	67.975009	407.027112	6.7837852
	TRAVTM(10)	38.474586	23.164463	95.955833	33.595394	6.061966	77.669173	1.00108	34.944053	27.075462	67.975009	405.917019	6.76528365
	Travel Time (Cumulative All)	38.596082	61.760545	158.125051	191.720445	197.808735	275.758749	276.762738	311.869868	339.052103	407.027112		
	Travel Time (Cumalative Vehicles)	38.474586	61.639049	157.594882	191.190276	197.252242	274.921415	275.922495	310.866548	337.94201	405.917019		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.273002	22.643325	94.379074	33.141726	5.996229	75.651038	0.958773	33.927813	25.864379	71.163994	400.999353	6.68332255
	TRAVTM(10)	37.234946	22.485799	93.9338	33.141726	5.96187	75.377593	0.956355	33.780894	25.742971	71.163994	399.779948	6.662999133
	Travel Time (Cumulative All)	37.273002	59.916327	154.295401	187.437127	193.433356	269.084394	270.043167	303.97098	329.835359	400.999353		
	Travel Time (Cumalative Vehicles)	37.234946	59.720745	153.654545	186.796271	192.758141	268.135734	269.092089	302.872983	328.615954	399.779948		
Volume @ -25% AM Peak	TRAVTM(ALL)	37.563103	23.006417	92.836293	33.084673	6.027053	76.300582	1.02123	33.685722	25.711532	69.81087	399.047475	6.65079125
	TRAVTM(10)	37.466285	23.006417	92.568092	33.084673	5.98259	75.922569	1.014668	33.428096	25.632689	69.81087	397.916949	6.63194915
	Travel Time (Cumulative All)	37.563103	60.56952	153.405813	186.490486	192.517539	268.818121	269.839351	303.525073	329.236605	399.047475		
	Travel Time (Cumalative Vehicles)	37.466285	60.472702	153.040794	186.125467	192.108057	268.030626	269.045294	302.47339	328.106079	397.916949		

Accident (Queue Varning)

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turf	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	0: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.65	22.72	92.38	32.26	5.94	84.6	1.07	38.64	30.36	75.03	420.65	7.010833333
	TRAVTM(10)	37.53	22.53	92.03	32.26	5.91	84.51	1.07	38.59	30.3	75.03	419.76	6.996
	Travel Time (Cumulative All)	37.65	60.37	152.75	185.01	190.95	275.55	276.62	315.26	345.62	420.65		
	Travel Time (Cumalative Vehicles)	37.53	60.06	152.09	184.35	190.26	274.77	275.84	314.43	344.73	419.76		
Volume @ -10% AM Peak	TRAVTM(ALL)	38.23	22.97	95.67	33.5	5.97	106.43	1.31	46.75	38.94	91.08	480.85	8.014166667
	TRAVTM(10)	38.2	22.97	95.22	33.5	5.95	106.29	1.3	46.73	38.97	90.83	479.96	7.999333333
	Travel Time (Cumulative All)	38.23	61.2	156.87	190.37	196.34	302.77	304.08	350.83	389.77	480.85		
	Travel Time (Cumalative Vehicles)	38.2	61.17	156.39	189.89	195.84	302.13	303.43	350.16	389.13	479.96		
Volume @ AM Peak	TRAVTM(ALL)	41.8	23.53	100.76	31.6	12.34	162.96	1.26	47.7	38.92	93.38	554.25	9.2375
	TRAVTM(10)	41.72	23.53	100.02	31.32	12.4	163.13	1.26	47.76	38.91	93.18	553.23	9.2205
	Travel Time (Cumulative All)	41.8	65.33	166.09	197.69	210.03	372.99	374.25	421.95	460.87	554.25		
	Travel Time (Cumalative Vehicles)	41.72	65.25	165.27	196.59	208.99	372.12	373.38	421.14	460.05	553.23		
Volume @ -10% AM Peak	TRAVTM(ALL)	39.69	22.83	106.6	33.03	70.02	346.37	1.08	41.63	33.1	79.44	773.79	12.8965
	TRAVTM(10)	39.4	22.83	105.94	33.03	70	347.3	1.07	41.61	33.09	79.44	773.71	12.89516667
	Travel Time (Cumulative All)	39.69	62.52	169.12	202.15	272.17	618.54	619.62	661.25	694.35	773.79		
	Travel Time (Cumalative Vehicles)	39.4	62.23	168.17	201.2	271.2	618.5	619.57	661.18	694.27	773.71		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.08	22.47	91.57	256.73	97.74	400.36	0.88	32.75	26.48	68.3	1035.36	17.256
	TRAVTM(10)	37.94	22.47	91.26	256.73	97.92	399.66	0.87	32.61	26.41	68.3	1034.17	17.23616667
	Travel Time (Cumulative All)	38.08	60.55	152.12	408.85	506.59	906.95	907.83	940.58	967.06	1035.36		
	Travel Time (Cumalative Vehicles)	37.94	60.41	151.67	408.4	506.32	905.98	906.85	939.46	965.87	1034.17		
Volume @ -25% AM Peak	TRAVTM(ALL)	37.4	22.28	91.17	376.84	97.73	400.27	0.86	31.83	25.41	66.99	1150.78	19.17966667
	TRAVTM(10)	37.4	22.07	90.78	376.84	98.03	401.14	0.85	31.66	25.31	66.99	1151.07	19.1845
	Travel Time (Cumulative All)	37.4	59.68	150.85	527.69	625.42	1025.69	1026.55	1058.38	1083.79	1150.78		
	Travel Time (Cumalative Vehicles)	37.4	59.47	150.25	527.09	625.12	1026.26	1027.11	1058.77	1084.08	1151.07		

Queue Varning (1500)

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway)	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.646958	22.719767	92.379355	32.257515	5.93741	84.599683	1.071989	38.635615	30.554139	76.240952	422.043383	7.034056383
	TRAVTM(10)	37.528503	22.534658	92.030149	32.257515	5.90946	84.505018	1.070153	38.591973	30.498874	76.240952	421.167255	7.01945425
	Travel Time (Cumulative All)	37.646958	60.366725	152.74608	185.003595	190.941005	275.540688	276.612677	315.248292	345.802431	422.043383		
	Travel Time (Cumalative Vehicles)	37.528503	60.063161	152.09331	184.350825	190.260285	274.765303	275.835456	314.427429	344.926303	421.167255		
Volume @ -10% AM Peak	TRAVTM(ALL)	38.23426	22.9693	95.668178	33.49847	5.974426	106.430773	1.307761	46.747052	37.374397	88.234288	476.438905	7.940648417
	TRAVTM(10)	38.19623	22.9693	95.221466	33.49847	5.946198	106.285049	1.303122	46.726598	37.396119	88.026928	475.56948	7.926158
	Travel Time (Cumulative All)	38.23426	61.20356	156.871738	190.370208	196.344634	302.775407	304.083168	350.83022	388.204617	476.438905		
	Travel Time (Cumalative Vehicles)	38.19623	61.16553	156.386996	189.885466	195.831664	302.116713	303.419835	350.146433	387.542552	475.56948		
Volume @ AM Peak	TRAVTM(ALL)	41.839455	22.573723	100.562002	33.760986	14.582769	149.718281	1.254618	47.828453	38.56861	92.406361	543.095258	9.051587633
	TRAVTM(10)	41.775781	22.573723	99.748467	33.760986	14.69237	149.898247	1.25646	47.914372	38.656547	92.243232	542.520185	9.042003083
	Travel Time (Cumulative All)	41.839455	64.413178	164.97518	198.736166	213.318935	363.037216	364.291834	412.120287	450.688897	543.095258		
	Travel Time (Cumalative Vehicles)	41.775781	64.349504	164.097971	197.858957	212.551027	362.449574	363.706034	411.620406	450.276953	542.520185		
Volume @ -10% AM Peak	TRAVTM(ALL)	39.322515	22.573723	91.31201	33.439123	15.042073	391.458835	1.10363	42.156252	36.166581	83.715744	756.290486	12.60484143
	TRAVTM(10)	39.070605	22.573723	90.579879	33.439123	15.08382	393.437459	1.102176	42.137071	36.13705	83.715744	757.27665	12.6212775
	Travel Time (Cumulative All)	39.322515	61.896238	153.208248	186.647371	201.689444	593.148279	594.251909	636.408161	672.574742	756.290486		
	Travel Time (Cumalative Vehicles)	39.070605	61.644328	152.224207	185.66333	200.74715	594.184609	595.286785	637.423856	673.560906	757.27665		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.133992	22.573723	90.191548	32.956658	18.383587	316.389811	0.966195	36.303952	28.946795	72.344272	657.190533	10.95317555
	TRAVTM(10)	38.017019	22.573723	89.762962	32.956658	18.426121	316.393423	0.963004	36.224959	28.834234	72.344272	656.496375	10.94160625
	Travel Time (Cumulative All)	38.133992	60.707715	150.899263	183.855921	202.239508	518.629319	519.595514	555.899466	584.846261	657.190533		
	Travel Time (Cumalative Vehicles)	38.017019	60.590742	150.353704	183.310362	201.736483	518.129906	519.09291	555.317869	584.152103	656.496375		
Volume @ -25% AM Peak	TRAVTM(ALL)	37.293478	22.573723	89.515453	34.114707	18.509103	394.365417	0.877675	32.872857	26.078035	68.672382	724.87283	12.08121383
	TRAVTM(10)	37.263364	22.573723	89.233743	34.114707	18.175699	395.206833	0.872642	32.689126	26.026453	68.672382	724.828672	12.08047787
	Travel Time (Cumulative All)	37.293478	59.867201	149.382654	183.497361	202.006464	596.371881	597.249556	630.122413	656.200448	724.87283		
	Travel Time (Cumalative Vehicles)	37.263364	59.837087	149.07083	183.185537	201.361236	596.568069	597.440711	630.129837	656.15629	724.828672		

Queue-Varning (1800)

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway)	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.646957	22.719767	92.379356	32.257515	5.935063	72.962273	0.938755	32.972775	25.540813	66.624794	389.978068	6.499634467
	TRAVTM(10)	37.528503	22.534658	92.030151	32.257515	5.907089	72.733185	0.936511	32.881729	25.493763	66.624794	388.927898	6.482131633
	Travel Time (Cumulative All)	37.646957	60.366724	152.74608	185.003595	190.938658	263.900931	264.839686	297.812461	323.353274	389.978068		
	Travel Time (Cumalative Vehicles)	37.528503	60.063161	152.093312	184.350827	190.257916	262.991101	263.927612	296.809341	322.303104	388.927898		
Volume @ -10% AM Peak	TRAVTM(ALL)	38.234261	22.969301	95.668175	33.49847	5.942441	75.911575	0.941267	34.3666	26.943031	68.33519	402.810311	6.713505183
	TRAVTM(10)	38.196232	22.969301	95.221466	33.49847	5.913733	75.543793	0.935281	34.173161	26.791569	68.33519	401.578196	6.692969933
	Travel Time (Cumulative All)	38.234261	61.203562	156.871737	190.370207	196.312648	272.224223	273.16549	307.53209	334.475121	402.810311		
	Travel Time (Cumalative Vehicles)	38.196232	61.165533	156.386999	189.885469	195.799202	271.342995	272.278276	306.451437	333.243006	401.578196		
Volume @ AM Peak	TRAVTM(ALL)	41.79615	23.530941	100.759743	31.593475	10.78309	138.942627	0.86786	35.63287	25.988876	67.98465	477.880282	7.964671367
	TRAVTM(10)	41.721581	23.530941	100.018097	31.310755	10.798574	138.947342	0.863668	35.452709	25.827425	67.98465	476.455742	7.940929033
	Travel Time (Cumulative All)	41.79615	65.327091	166.086834	197.680309	208.463399	347.406026	348.273886	383.906756	409.895632	477.880282		
	Travel Time (Cumalative Vehicles)	41.721581	65.252522	165.270619	196.581374	207.379948	346.32729	347.190958	382.643667	408.471092	476.455742		
Volume @ -10% AM Peak	TRAVTM(ALL)	39.33242	21.726881	98.29847	33.408741	46.545929	322.106445	0.857998	31.742796	25.37248	67.266113	686.658273	11.44430455
	TRAVTM(10)	39.079746	21.726881	97.380913	33.408741	46.897991	322.005615	0.851705	31.547028	25.223116	67.266113	685.387849	11.42313082
	Travel Time (Cumulative All)	39.33242	61.059301	159.357771	192.766512	239.312441	561.418886	562.276884	594.01968	619.39216	686.658273		
	Travel Time (Cumalative Vehicles)	39.079746	60.806627	158.18754	191.596281	238.494272	560.499887	561.351592	592.89862	618.121736	685.387849		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.149651	23.530941	91.091927	34.832882	44.375095	395.144287	0.856859	31.834219	25.449404	67.234726	752.499991	12.54166652
	TRAVTM(10)	38.032845	23.530941	90.564278	34.832882	44.710072	393.797363	0.849964	31.674307	25.296249	67.234726	750.523627	12.50872712
	Travel Time (Cumulative All)	38.149651	61.680592	152.772519	187.605401	231.980496	627.124783	627.981642	659.815861	685.265265	752.499991		
	Travel Time (Cumalative Vehicles)	38.032845	61.563786	152.128064	186.960946	231.671018	625.468381	626.318345	657.992652	683.288901	750.523627		
Volume @ -25% AM Peak	TRAVTM(ALL)	37.280712	23.530941	89.538826	31.411011	24.621979	397.611786	0.857358	31.699055	25.201107	67.05365	728.806425	12.14677375
	TRAVTM(10)	37.250553	23.530941	89.140373	31.411011	24.580044	398.942413	0.848493	31.459364	25.030025	67.05365	729.246867	12.15411445
	Travel Time (Cumulative All)	37.280712	60.811653	150.350479	181.76149	206.383469	603.995255	604.852613	636.551668	661.752775	728.806425		
	Travel Time (Cumalative Vehicles)	37.250553	60.781494	149.921867	181.332878	205.912922	604.855335	605.703828	637.163192	662.193217	729.246867		

Speed Harmonisation

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.157727	22.664088	90.710459	34.401358	5.973066	84.873214	1.039413	38.489488	30.266607	78.654549	424.229969	7.070499483
	TRAVTM(10)	37.052258	22.477351	90.228582	34.401358	5.935798	84.781077	1.038469	38.450539	30.251072	78.654549	423.271053	7.05451755
	Travel Time (Cumulative All)	37.157727	59.821815	150.532274	184.933632	190.906698	275.779912	276.819325	315.308813	345.57542	424.229969		
	Travel Time (Cumalative Vehicles)	37.052258	59.529609	149.758191	184.159549	190.095347	274.876424	275.914893	314.365432	344.616504	423.271053		
Volume @ -10% AM Peak	TRAVTM(ALL)	37.006083	22.651406	93.562687	36.346269	6.015696	101.956541	1.24071	46.553932	35.319464	85.134618	465.787406	7.763123433
	TRAVTM(10)	36.962785	22.558348	93.10522	36.346269	5.99406	101.991661	1.241411	46.605836	35.348911	84.924824	465.079325	7.751322083
	Travel Time (Cumulative All)	37.006083	59.657489	153.220176	189.566445	195.582141	297.538682	298.779392	345.333324	380.652788	465.787406		
	Travel Time (Cumalative Vehicles)	36.962785	59.521133	152.626353	188.972622	194.966682	296.958343	298.199754	344.80559	380.154501	465.079325		
Volume @ AM Peak	TRAVTM(ALL)	40.098599	24.176922	110.156985	34.686126	6.168689	110.591296	1.301467	48.623858	38.290484	91.267578	505.362004	8.422700067
	TRAVTM(10)	40.005546	24.176922	109.596802	34.686126	6.116304	110.655346	1.30136	48.606326	38.29972	90.983632	504.428084	8.407134733
	Travel Time (Cumulative All)	40.098599	64.275521	174.432506	209.118632	215.287321	325.878617	327.180084	375.803942	414.094426	505.362004		
	Travel Time (Cumalative Vehicles)	40.005546	64.182468	173.77927	208.465396	214.5817	325.237046	326.538406	375.144732	413.444452	504.428084		
Volume @ -10% AM Peak	TRAVTM(ALL)	41.876944	22.812484	108.537115	30.275189	8.477004	112.682392	1.335636	51.797302	40.054105	96.254003	514.102174	8.568369567
	TRAVTM(10)	41.824649	22.812484	107.966515	30.275189	8.459402	112.633503	1.334854	51.78295	40.129499	96.057395	513.27644	8.554607333
	Travel Time (Cumulative All)	41.876944	64.689428	173.226543	203.501732	211.978736	324.661128	325.996764	377.794066	417.848171	514.102174		
	Travel Time (Cumalative Vehicles)	41.824649	64.637133	172.603648	202.878837	211.338239	323.971742	325.306596	377.089546	417.219045	513.27644		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.517807	22.356325	94.528068	32.811745	6.077558	99.901463	1.211828	47.115198	38.617031	92.855127	472.99215	7.8832025
	TRAVTM(10)	37.517807	22.213074	93.973281	32.811745	6.024827	99.887726	1.208974	47.062874	38.632589	92.755183	472.08808	7.868134667
	Travel Time (Cumulative All)	37.517807	59.874132	154.4022	187.213945	193.291503	293.192966	294.404794	341.519992	380.137023	472.99215		
	Travel Time (Cumalative Vehicles)	37.517807	59.730881	153.704162	186.515907	192.540734	292.42846	293.637434	340.700308	379.332897	472.08808		
Volume @ -25% AM Peak	TRAVTM(ALL)	37.87945	22.288822	91.058225	31.971519	5.921961	87.592645	1.071718	40.591366	33.996674	81.575359	433.947739	7.232462317
	TRAVTM(10)	37.766139	22.288822	90.770571	31.971519	5.895918	87.500199	1.069703	40.509194	33.937564	81.263829	432.973458	7.2162243
	Travel Time (Cumulative All)	37.87945	60.168272	151.226497	183.198016	189.119977	276.712622	277.78434	318.375706	352.37238	433.947739		
	Travel Time (Cumalative Vehicles)	37.766139	60.054961	150.825532	182.797051	188.692969	276.193168	277.262871	317.772065	351.709629	432.973458		

Q-Varn & Spd-Harm (1500)

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.160644	22.880851	92.212232	34.323974	6.013522	84.809047	1.049112	38.391742	30.334785	77.263426	425.439335	7.090655583
	TRAVTM(10)	38.160644	22.700216	91.932677	34.323974	5.948542	84.700277	1.04772	38.349815	30.303707	77.263426	424.730998	7.078849967
	Travel Time (Cumulative All)	38.160644	61.041495	153.253727	187.577701	193.591223	278.40027	279.449382	317.841124	348.175909	425.439335		
	Travel Time (Cumalative Vehicles)	38.160644	60.86086	152.793537	187.117511	193.066053	277.76633	278.81405	317.163865	347.467572	424.730998		
Volume @ -10% AM Peak	TRAVTM(ALL)	37.614025	22.935316	95.158079	35.559632	5.99727	99.354975	1.202975	44.917112	36.178337	82.573158	461.490879	7.69151465
	TRAVTM(10)	37.572618	22.788769	94.820902	35.559632	5.97344	99.314267	1.202106	44.908417	35.966201	82.493504	460.599856	7.676664267
	Travel Time (Cumulative All)	37.614025	60.549341	155.70742	191.267052	197.264322	296.619297	297.822272	342.739384	378.917721	461.490879		
	Travel Time (Cumalative Vehicles)	37.572618	60.361387	155.182289	190.741921	196.715361	296.029628	297.231734	342.140151	378.106352	460.599856		
Volume @ AM Peak	TRAVTM(ALL)	38.954312	23.020692	101.142266	34.544236	9.469225	185.131446	1.268582	49.202073	38.773411	94.907478	576.413721	9.60689535
	TRAVTM(10)	38.848796	23.020692	100.383845	34.544236	9.316799	185.349437	1.269467	49.240247	38.794988	94.60702	575.375527	9.589592117
	Travel Time (Cumulative All)	38.954312	61.975004	163.11727	197.661506	207.130731	392.262177	393.530759	442.732832	481.506243	576.413721		
	Travel Time (Cumalative Vehicles)	38.848796	61.869488	162.253333	196.797569	206.114368	391.463805	392.733272	441.973519	480.768507	575.375527		
Volume @ -10% AM Peak	TRAVTM(ALL)	43.216932	23.020692	94.704999	30.56615	38.151513	360.154229	1.027441	39.800634	32.557411	74.754271	737.954272	12.29923787
	TRAVTM(10)	42.981319	23.020692	94.085207	30.56615	38.399157	361.347795	1.024949	39.768652	32.538408	74.754271	738.4866	12.30811
	Travel Time (Cumulative All)	43.216932	66.237624	160.942623	191.508773	229.660286	589.814515	590.841956	630.64259	663.200001	737.954272		
	Travel Time (Cumalative Vehicles)	42.981319	66.002011	160.087218	190.653368	229.052525	590.40032	591.425269	631.193921	663.732329	738.4866		
Volume @ -20% AM Peak	TRAVTM(ALL)	37.45011	23.020692	89.15576	32.100844	32.457225	415.61374	0.853412	31.714624	25.537801	67.853308	755.757516	12.5959586
	TRAVTM(10)	37.416149	23.020692	88.85401	32.100844	32.550759	415.607183	0.84927	31.64793	25.461076	67.853308	755.361221	12.58935368
	Travel Time (Cumulative All)	37.45011	60.470802	149.626562	181.727406	214.184631	629.798371	630.651783	662.366407	687.904208	755.757516		
	Travel Time (Cumalative Vehicles)	37.416149	60.436841	149.290851	181.391695	213.942454	629.549637	630.398907	662.046837	687.507913	755.361221		
Volume @ -25% AM Peak	TRAVTM(ALL)	40.098656	23.020692	90.222426	34.30699	26.396687	410.806768	0.85099	31.656579	25.17259	66.573584	749.105962	12.48509937
	TRAVTM(10)	40.079537	23.020692	90.079213	34.30699	25.787238	409.446603	0.845595	31.464141	24.941854	66.573584	746.545447	12.44242412
	Travel Time (Cumulative All)	40.098656	63.119348	153.341774	187.648764	214.045451	624.852219	625.703209	657.359788	682.532378	749.105962		
	Travel Time (Cumalative Vehicles)	40.079537	63.100229	153.179442	187.486432	213.27367	622.720273	623.565868	655.030009	679.971863	746.545447		

Q-Varn & Spd - Harm (1800)

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	0: N1 start to Nelson Mandela Blvd	Travel Time (sec	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
lume @ -20% AM Peak	TRAVTM(ALL)	38.160644	22.880851	92.212232	34.323974	6.013522	84.809047	1.049112	38.391742	30.334785	77.263426	425.439335	7.090655583
	TRAVTM(10)	38.160644	22.700216	91.932677	34.323974	5.948542	84.700277	1.04772	38.349815	30.303707	77.263426	424.730998	7.078849967
	Travel Time (Cumulative All)	38.160644	61.041495	153.253727	187.577701	193.591223	278.40027	279.449382	317.841124	348.175909	425.439335		
	Travel Time (Cumalative Vehicles)	38.160644	60.86086	152.793537	187.117511	193.066053	277.76633	278.81405	317.163865	347.467572	424.730998		
olume @ -10% AM Peak	TRAVTM(ALL)	37.614025	22.935316	95.158079	35.559632	5.99727	99.354975	1.202975	44.917112	36.178337	82.573158	461.490879	7.69151465
	TRAVTM(10)	37.572618	22.788769	94.820902	35.559632	5.97344	99.314267	1.202106	44.908417	35.966201	82.493504	460.599856	7.676664267
	Travel Time (Cumulative All)	37.614025	60.549341	155.70742	191.267052	197.264322	296.619297	297.822272	342.739384	378.917721	461.490879		
	Travel Time (Cumalative Vehicles)	37.572618	60.361387	155.182289	190.741921	196.715361	296.029628	297.231734	342.140151	378.106352	460.599856		
Volume @ AM Peak	TRAVTM(ALL)	39.231242	23.434695	101.777912	32.134061	10.164554	185.131446	1.268582	49.202073	38.773411	94.907478	576.025454	9.600424233
	TRAVTM(10)	39.147072	23.361113	101.215807	32.021721	10.170919	185.349437	1.269467	49.240247	38.794988	94.60702	575.177791	9.586296517
	Travel Time (Cumulative All)	39.231242	62.665937	164.443849	196.57791	206.742464	391.87391	393.142492	442.384565	481.117976	576.025454		
	Travel Time (Cumalative Vehicles)	39.147072	62.508185	163.723992	195.745713	205.916632	391.266069	392.535536	441.775783	480.570771	575.177791		
olume @ -10% AM Peak	TRAVTM(ALL)	43.254125	27.914954	94.505229	48.488892	83.576263	362.964386	1.019741	38.880607	31.187645	76.859827	808.651669	13.47752782
	TRAVTM(10)	43.021213	25.134438	93.716924	48.488892	83.363436	364.46549	1.016778	38.82345	31.026896	76.538045	805.595562	13.4265927
	Travel Time (Cumulative All)	43.254125	71.169079	165.674308	214.1632	297.739463	660.703849	661.72359	700.604197	731.791842	808.651669		
	Travel Time (Cumalative Vehicles)	43.021213	68.155651	161.872575	210.361467	293.724903	658.190393	659.207171	698.030621	729.057517	805.595562		
lume @ -20% AM Peak	TRAVTM(ALL)	37.45011	27.914954	89.426528	60.399159	104.453846	422.132759	0.860208	32.113176	26.584888	70.07752	871.413148	14.52355247
	TRAVTM(10)	37.416149	25.134438	88.980943	60.399159	104.879763	422.203687	0.855434	31.96843	26.367615	69.629267	867.834885	14.46391475
	Travel Time (Cumulative All)	37.45011	65.365064	154.791592	215.190751	319.644597	741.777356	742.637564	774.75074	801.335628	871.413148		
	Travel Time (Cumalative Vehicles)	37.416149	62.550587	151.53153	211.930689	316.810452	739.014139	739.869573	771.838003	798.205618	867.834885		
lume @ -25% AM Peak	TRAVTM(ALL)	40.098653	27.914954	89.229271	54.648777	88.350389	449.861046	0.849404	31.54007	25.19124	66.426355	874.110159	14.56850265
	TRAVTM(10)	40.079534	25.134438	88.974733	54.648777	88.44538	450.332009	0.844933	31.364279	25.085502	66.426355	871.33594	14.52226567
	Travel Time (Cumulative All)	40.098653	68.013607	157.242878	211.891655	300.242044	750.10309	750.952494	782.492564	807.683804	874.110159		
	Travel Time (Cumalative Vehicles)	40.079534	65.213972	154.188705	208.837482	297.282862	747.614871	748.459804	779.824083	804.909585	871.33594		

CV 40%

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	0: N1 start to Nelson Mandela Blvd	Travel Time (sec	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
lume @ -20% AM Peak	TRAVTM(ALL)	38.834482	21.80341	91.944268	32.52995	5.833504	73.644277	0.983034	35.441869	25.695466	65.18221	391.89247	6.531541167
	TRAVTM(10)	38.331309	22.27554	92.508824	33.609294	5.850524	73.339413	0.980215	35.17436	25.753659	67.056573	394.879711	6.581328517
	Travel Time (Cumulative All)	38.834482	60.637892	152.58216	185.11211	190.945614	264.589891	265.572925	301.014794	326.71026	391.89247		
	Travel Time (Cumalative Vehicles)	38.331309	60.606849	153.115673	186.724967	192.575491	265.914904	266.895119	302.069479	327.823138	394.879711		
olume @ -10% AM Peak	TRAVTM(ALL)	39.822693	23.11187	95.445757	34.754061	5.870807	72.955408	0.921583	32.822778	26.732508	65.289457	397.726922	6.628782033
	TRAVTM(10)	40.012132	23.242236	95.046877	37.239536	5.875806	73.178712	0.926252	32.92021	26.750384	67.231045	402.42319	6.707053167
	Travel Time (Cumulative All)	39.822693	62.934563	158.38032	193.134381	199.005188	271.960596	272.882179	305.704957	332.437465	397.726922		
	Travel Time (Cumalative Vehicles)	40.012132	63.254368	158.301245	195.540781	201.416587	274.595299	275.521551	308.441761	335.192145	402.42319		
Volume @ AM Peak	TRAVTM(ALL)	38.913876	22.950412	93.891425	31.670698	6.442418	143.13846	0.933727	34.784636	31.05783	68.649779	472.433261	7.873887683
	TRAVTM(10)	37.961166	23.242236	93.701201	33.778671	6.442554	144.545936	0.927444	33.695606	29.723159	69.922531	473.940504	7.8990084
	Travel Time (Cumulative All)	38.913876	61.864288	155.755713	187.426411	193.868829	337.007289	337.941016	372.725652	403.783482	472.433261		
	Travel Time (Cumalative Vehicles)	37.961166	61.203402	154.904603	188.683274	195.125828	339.671764	340.599208	374.294814	404.017973	473.940504		
olume @ -10% AM Peak	TRAVTM(ALL)	43.887171	23.242236	90.134131	30.934349	30.120175	333.573144	0.846707	33.120648	26.699087	63.708218	676.265866	11.27109777
	TRAVTM(10)	43.988918	23.242236	90.49999	32.587434	26.694891	337.267379	0.848975	32.013393	25.595512	65.072078	677.810806	11.29684677
	Travel Time (Cumulative All)	43.887171	67.129407	157.263538	188.197887	218.318062	551.891206	552.737913	585.858561	612.557648	676.265866		
	Travel Time (Cumalative Vehicles)	43.988918	67.231154	157.731144	190.318578	217.013469	554.280848	555.129823	587.143216	612.738728	677.810806		
olume @ -20% AM Peak	TRAVTM(ALL)	38.806823	23.242236	88.763759	30.480649	23.389538	407.755971	0.843997	33.185478	26.569532	65.571181	738.609164	12.31015273
	TRAVTM(10)	39.132852	23.242236	88.733347	31.638246	21.666666	399.806918	0.843538	31.976562	25.715031	67.427964	730.18336	12.16972267
	Travel Time (Cumulative All)	38.806823	62.049059	150.812818	181.293467	204.683005	612.438976	613.282973	646.468451	673.037983	738.609164		
	Travel Time (Cumalative Vehicles)	39.132852	62.375088	151.108435	182.746681	204.413347	604.220265	605.063803	637.040365	662.755396	730.18336		
olume @ -25% AM Peak	TRAVTM(ALL)	43.188943	23.242236	89.247507	29.729658	15.845061	421.95565	0.842393	33.418043	27.2183	66.165505	750.853296	12.5142216
	TRAVTM(10)	43.53446	23.242236	89.114403	33.011772	15.624908	416.690383	0.839015	31.842443	25.854196	68.042675	747.796491	12.46327485
	Travel Time (Cumulative All)	43.188943	66.431179	155.678686	185.408344	201.253405	623.209055	624.051448	657.469491	684.687791	750.853296		
	Travel Time (Cumalative Vehicles)	43.53446	66.776696	155.891099	188.902871	204.527779	621.218162	622.057177	653.89962	679.753816	747.796491		

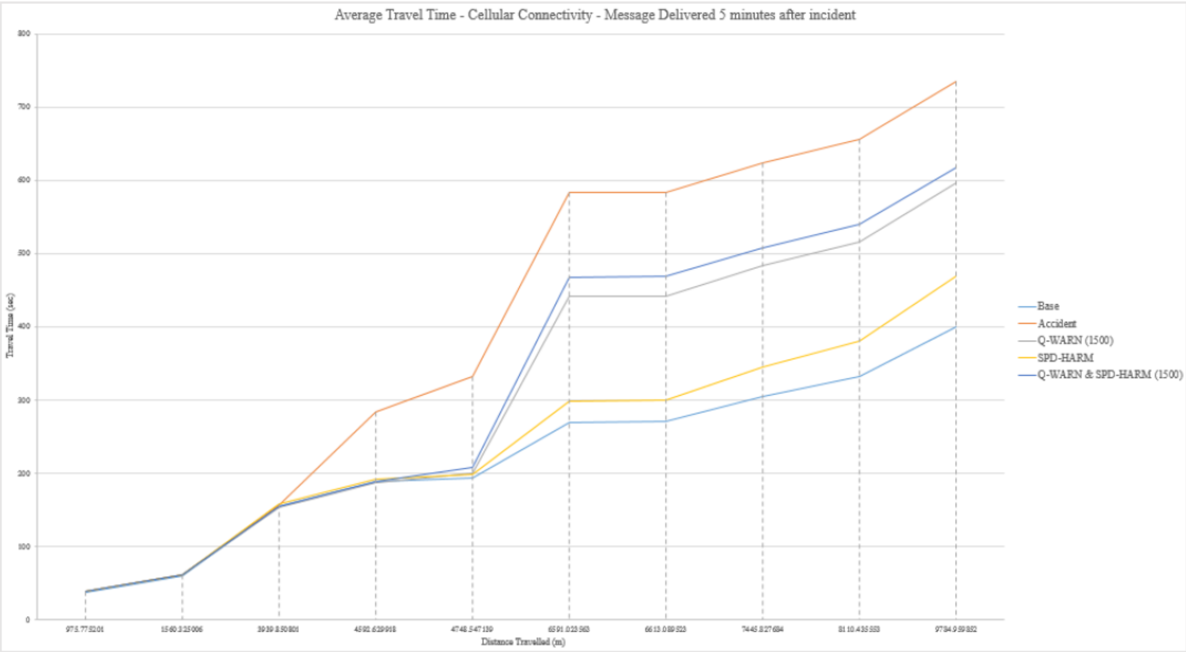
CV 50%

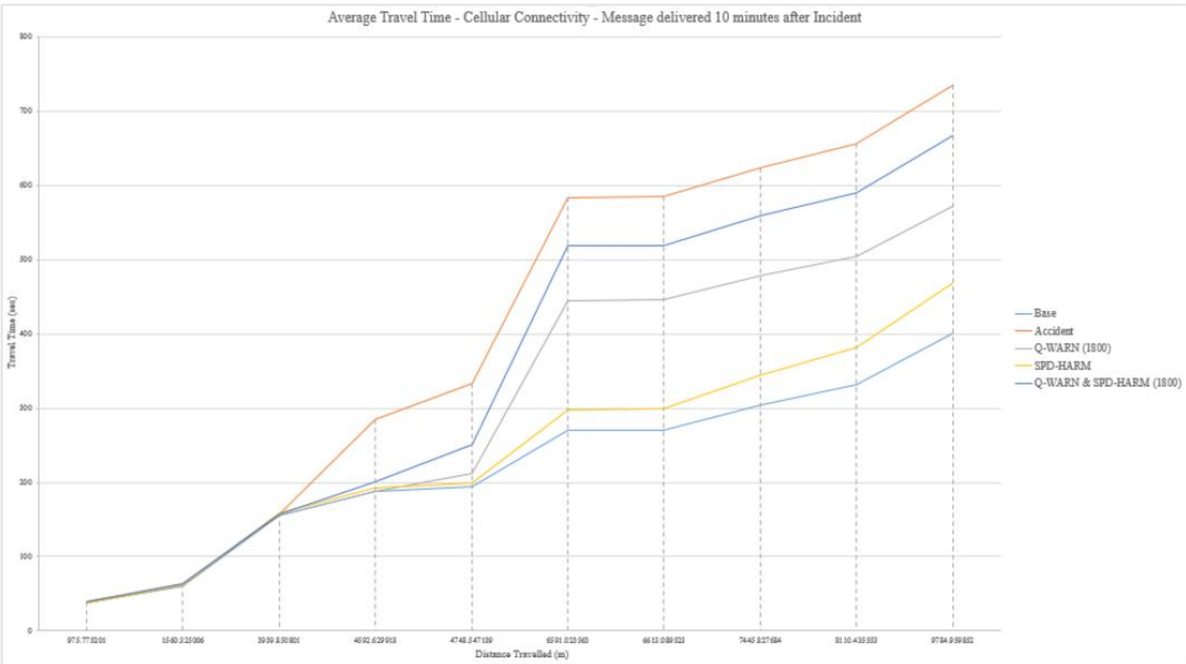
	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	39.230949	22.929858	90.983632	31.324109	5.838572	74.426472	0.950459	32.129176	26.042488	64.758771	388.614486	6.4769081
	TRAVTM(10)	38.695237	22.480146	91.605129	33.929662	5.793656	73.956432	0.946021	31.904684	26.242413	67.643336	393.196716	6.5532786
	Travel Time (Cumulative All)	39.230949	62.160807	153.144439	184.468548	190.30712	264.733592	265.684051	297.813227	323.855715	388.614486		
	Travel Time (Cumalative Vehicles)	38.695237	61.175383	152.780512	186.710174	192.50383	266.460262	267.406283	299.310967	325.55338	393.196716		
Volume @ -10% AM Peak	TRAVTM(ALL)	40.005756	22.799927	93.364932	32.207895	5.869528	78.900156	1.034364	33.361369	27.127229	66.000891	400.672047	6.67786745
	TRAVTM(10)	40.228324	22.664027	93.342994	33.502199	5.895169	78.3246	1.032082	33.349577	27.654188	69.294274	405.287434	6.754790567
	Travel Time (Cumulative All)	40.005756	62.805683	156.170615	188.37851	194.248038	273.148194	274.182558	307.543927	334.671156	400.672047		
	Travel Time (Cumalative Vehicles)	40.228324	62.892351	156.235345	189.737544	195.632713	273.957313	274.989395	308.338972	335.99316	405.287434		
Volume @ AM Peak	TRAVTM(ALL)	38.833837	28.376259	95.59025	33.159242	6.495293	157.326949	0.901603	35.460058	27.801254	67.373954	491.318699	8.188644983
	TRAVTM(10)	38.002482	31.007984	93.993006	33.159242	6.525979	162.53332	0.896673	33.975607	26.908279	70.038792	497.041364	8.284022733
	Travel Time (Cumulative All)	38.833837	67.210096	162.800346	195.959588	202.454881	359.78183	360.683433	396.143491	423.944745	491.318699		
	Travel Time (Cumalative Vehicles)	38.002482	69.010466	163.003472	196.162714	202.688693	365.222013	366.118686	400.094293	427.002572	497.041364		
Volume @ -10% AM Peak	TRAVTM(ALL)	44.08087	28.376259	90.203323	30.445424	18.973965	354.799104	0.838347	33.763829	27.131325	65.169283	693.781729	11.56302882
	TRAVTM(10)	44.072279	31.007984	90.027832	32.887792	17.852941	348.441377	0.83422	32.073708	25.785034	67.83491	690.818077	11.51363462
	Travel Time (Cumulative All)	44.08087	72.457129	162.660452	193.105876	212.079841	566.878945	567.717292	601.481121	628.612446	693.781729		
	Travel Time (Cumalative Vehicles)	44.072279	75.080263	165.108095	197.995887	215.848828	564.290205	565.124425	597.198133	622.983167	690.818077		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.802775	28.376259	88.534003	32.150632	22.930095	448.065341	0.839125	33.80396	26.819721	64.942922	785.264833	13.08774722
	TRAVTM(10)	39.429391	31.007984	88.300489	34.152203	22.110911	437.734949	0.835714	31.856574	25.097647	66.578318	777.10418	12.95173633
	Travel Time (Cumulative All)	38.802775	67.179034	155.713037	187.863669	210.793764	658.859105	659.69823	693.50219	720.321911	785.264833		
	Travel Time (Cumalative Vehicles)	39.429391	70.437375	158.737864	192.890067	215.000978	652.735927	653.571641	685.428215	710.525862	777.10418		
Volume @ -25% AM Peak	TRAVTM(ALL)	43.152271	28.376259	89.029283	34.044438	21.186439	425.728919	0.841457	33.562791	26.863064	64.42115	767.206066	12.78676777
	TRAVTM(10)	44.059234	31.007984	88.810108	34.044438	19.575965	430.252927	0.840616	31.959928	25.473697	66.963146	772.988043	12.88313405
	Travel Time (Cumulative All)	43.152271	71.52853	160.557813	194.602251	215.78869	641.517609	642.359066	675.921857	702.784921	767.206066		
	Travel Time (Cumalative Vehicles)	44.059234	75.067218	163.877326	197.921764	217.497729	647.750656	648.591272	680.5512	706.024897	772.988043		

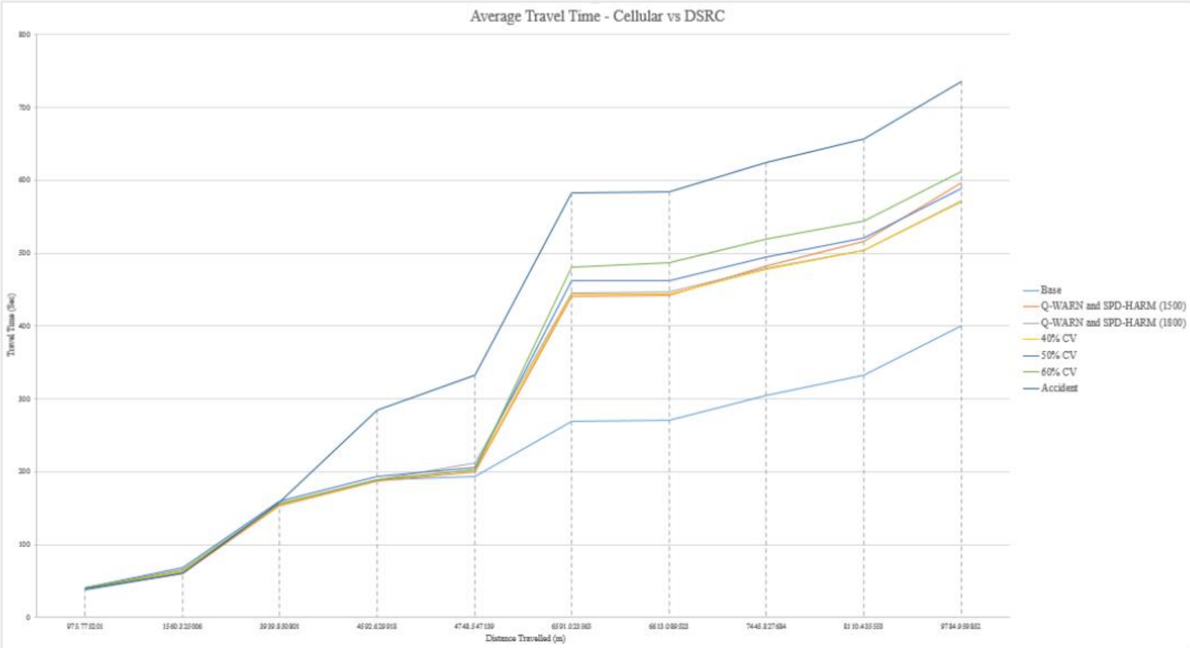
CV 60%

	N1 Route	2: N2 Start to Kromboom Int	3: M5 and Kromboom turn	4: M5	5: M5 into N1	6: M5 and N1 merge	21: N1 (M5 merge) to Int. 4 (part 1)	22: N1 into Int. 4 (part 2)	8: Int 4. to Int 3. (to M176 end) on N1	28: N1 (M176 to Ramp Freeway	10: N1 start to Nelson Mandela Blvd	Travel Time (sec)	Travel Time (min)
	Distance (m)	975.775201	584.549805	2379.5258	652.779117	155.917221	1842.476424	22.06596	832.738161	664.607869	1674.524299	9784.959852	9.784959852
	Distance Cumulative (m)	975.775201	1560.325006	3939.8508	4592.62992	4748.547139	6591.023563	6613.089523	7445.827684	8110.435553	9784.959852		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.810514	22.440371	90.739887	30.384912	5.822443	71.511773	0.862135	32.198496	25.88333	64.625243	383.279104	6.387985067
	TRAVTM(10)	38.352502	22.577292	90.349119	32.319986	5.828899	71.173257	0.856906	32.044003	25.771476	66.828184	386.101624	6.435027067
	Travel Time (Cumulative All)	38.810514	61.250885	151.990772	182.375684	188.198127	259.7099	260.572035	292.770531	318.653861	383.279104		
	Travel Time (Cumalative Vehicles)	38.352502	60.929794	151.278913	183.598899	189.427798	260.601055	261.457961	293.501964	319.27344	386.101624		
Volume @ -10% AM Peak	TRAVTM(ALL)	39.561511	24.038949	94.903314	31.87719	5.874964	76.877595	0.964336	32.791513	26.35196	67.962956	401.204288	6.686738133
	TRAVTM(10)	38.141955	23.938561	95.065552	33.231706	5.85349	76.481914	0.977732	32.779976	26.358493	70.442736	403.272115	6.721201917
	Travel Time (Cumulative All)	39.561511	63.60046	158.503774	190.380964	196.255928	273.133523	274.097859	306.889372	333.241332	401.204288		
	Travel Time (Cumalative Vehicles)	38.141955	62.080516	157.146068	190.377774	196.231264	272.713178	273.69091	306.470886	332.829379	403.272115		
Volume @ AM Peak	TRAVTM(ALL)	38.748169	26.202276	92.875465	31.986178	8.368507	273.202606	30.770889	34.309765	29.211454	65.178705	630.854014	10.51423357
	TRAVTM(10)	37.670871	26.202276	93.068819	34.152459	8.450014	273.25004	33.865403	32.625433	26.615206	66.247926	632.148447	10.53580745
	Travel Time (Cumulative All)	38.748169	64.950445	157.82591	189.812088	198.180595	471.383201	502.15409	536.463855	565.675309	630.854014		
	Travel Time (Cumalative Vehicles)	37.670871	63.873147	156.941966	191.094425	199.544439	472.794479	506.659882	539.285315	565.900521	632.148447		
Volume @ -10% AM Peak	TRAVTM(ALL)	43.649504	26.202276	90.668951	31.389548	20.003119	361.043034	0.844128	34.342335	27.499336	63.939712	699.581943	11.65969905
	TRAVTM(10)	45.101166	26.202276	90.777403	32.465287	19.181667	367.154366	0.843881	32.383667	25.753342	66.947208	706.810263	11.78017105
	Travel Time (Cumulative All)	43.649504	69.85178	160.520731	191.910279	211.913398	572.956432	573.80056	608.142895	635.642231	699.581943		
	Travel Time (Cumalative Vehicles)	45.101166	71.303442	162.080845	194.546132	213.727799	580.882165	581.726046	614.109713	639.863055	706.810263		
Volume @ -20% AM Peak	TRAVTM(ALL)	38.879762	26.202276	90.534572	30.550024	20.750683	431.65327	0.839303	34.517532	27.360746	64.740871	766.029039	12.76715065
	TRAVTM(10)	39.24503	26.202276	89.953852	31.346893	18.336875	442.137164	0.834931	32.234183	25.25808	66.693095	772.242379	12.87070632
	Travel Time (Cumulative All)	38.879762	65.082038	155.61661	186.166634	206.917317	638.570587	639.40989	673.927422	701.288168	766.029039		
	Travel Time (Cumalative Vehicles)	39.24503	65.447306	155.401158	186.748051	205.084926	647.22209	648.057021	680.291204	705.549284	772.242379		
Volume @ -25% AM Peak	TRAVTM(ALL)	43.140323	26.202276	89.603756	28.330424	20.915503	417.476843	0.842464	34.384178	27.303585	64.299738	752.49909	12.5416515
	TRAVTM(10)	44.470276	26.202276	88.861127	29.10327	20.47334	438.641838	0.841689	32.280753	25.36238	66.264288	772.501237	12.87502062
	Travel Time (Cumulative All)	43.140323	69.342599	158.946355	187.276779	208.192282	625.669125	626.511589	660.895767	688.199352	752.49909		
	Travel Time (Cumalative Vehicles)	44.470276	70.672552	159.533679	188.636949	209.110289	647.752127	648.593816	680.874569	706.236949	772.501237		

The free-flow travel times for the remaining routes may obtained from the *Travel Time Results* folder on the attached flash disk.


Average Travel Time - Cellular Connectivity - Message Delivered 5 minutes after incident
Travel Time (sec)
0
100
200
300
400
500
600
700
800
975.775201
1560.325006
3939.850801
4592.629918
4748.547139
6591.023563
6613.089523
7445.827684
8110.435553
9784.959852
Distance Travelled (m)
Base
Accident
Q-WARN (1500)
SPD-HARM
Q-WARN & SPD-HARM (1500)


Average Travel Time - Cellular Connectivity - Message delivered 10 minutes after Incident
Travel Time (sec)
0
100
200
300
400
500
600
700
800
975.775201
1560.325006
3939.850801
4592.629918
4748.547139
6591.023563
6613.089523
7445.827684
8110.435553
9784.959852
Distance Travelled (m)
Base
Accident
Q-WARN (1800)
SPD-HARM
Q-WARN & SPD-HARM (1800)



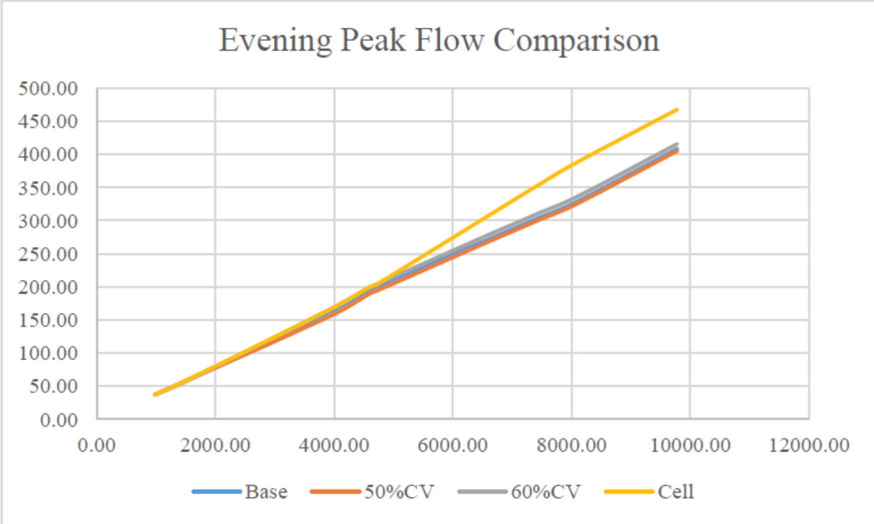
The following tables provide the travel times obtained from the various scenarios simulated along the M5 and N1 path (Route 1) under congested conditions for the evening Peak:

Cellular PM Peak

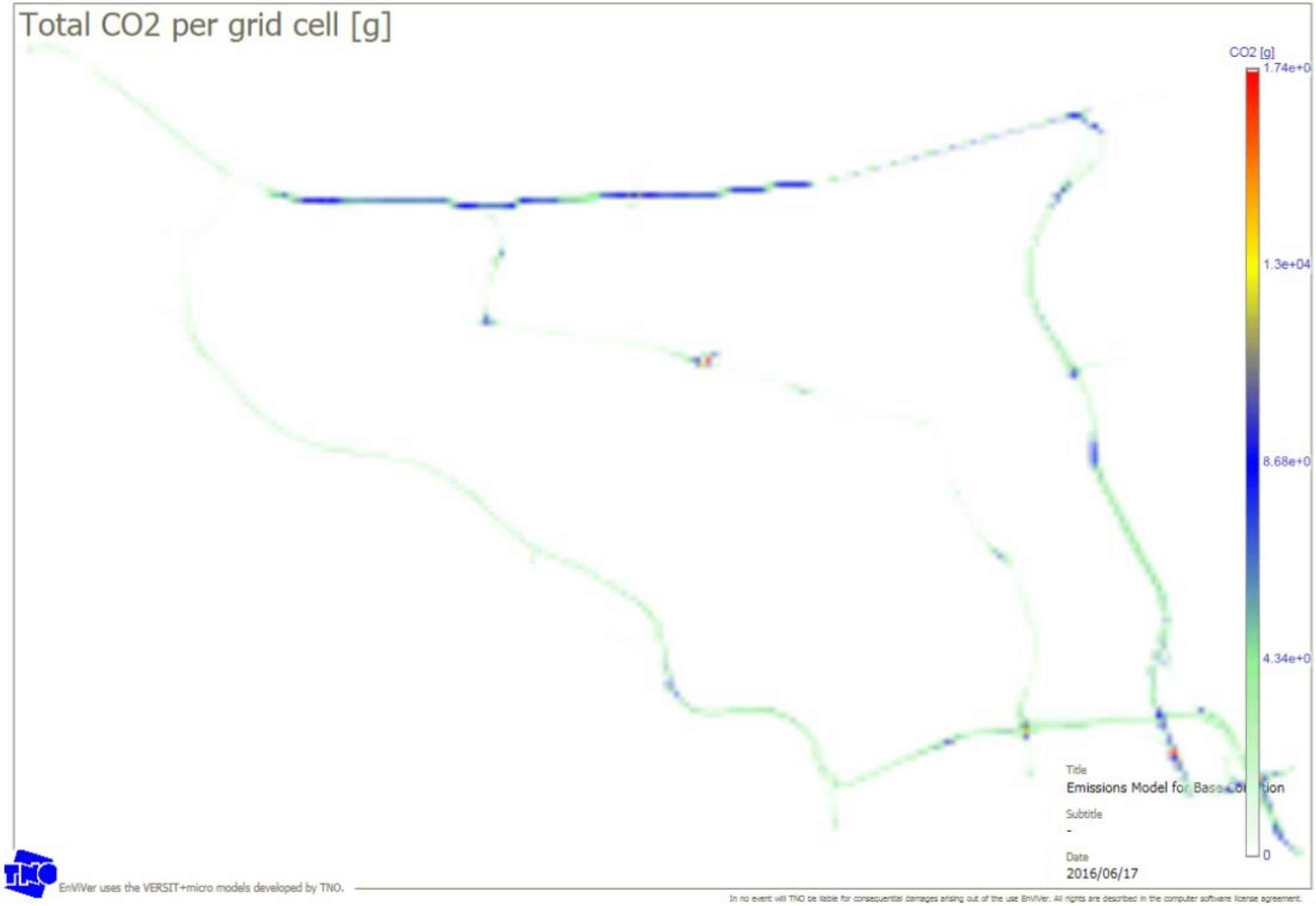
				Warmup		Period 1		Period 2		Period 3		Period 4	
	N1 Route	Distance	Cumulative Dis	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)
2	2: N2 Start to Kromboom Int.	975.7752	975.775201	36.41539	36.41539	36.99258	36.99258	37.205311	37.205311	37.965252	37.965252	37.263462	37.263462
3	3: M5 and Kromboom turn	584.5498	1560.32501	22.355122	58.770512	24.132559	61.125139	22.740171	59.945482	23.327032	61.292284	24.601583	61.865045
4	4: M5	2379.526	3939.8508	87.309326	146.079838	105.15979	166.284929	104.08987	164.035356	95.230186	156.52247	116.9409	178.805948
5	5: M5 into N1	652.7791	4592.62992	31.59	177.669838	34.659103	200.944032	33.859531	197.894887	31.754667	188.277137	32.443207	211.249155
6	6: M5 and N1 merge	155.9172	4748.54714	5.804136	183.473974	5.889679	206.833711	5.844805	203.739692	5.868469	194.145606	5.883854	217.133009
21	21: N1 (M5 merge) to Int. 4 (part 1)	1842.476	6591.02356	68.008659	251.482633	94.088058	300.921769	102.71261	306.4523	107.61985	301.765456	102.09281	319.225821
22	22: N1 into Int. 4 (part 2)	22.06596	6613.08952	0.814107	252.29674	1.149347	302.071116	1.248014	307.700314	1.242955	303.008411	1.224616	320.450437
8	8: Int 4. to Int 3. (to M176 end) on N	832.7382	7445.82768	30.798307	283.095047	42.821243	344.892359	47.358788	355.059102	46.682915	349.691326	46.546093	366.99653
28	28: N1 (M176 to Ramp Freeway)	664.6079	8110.43555	23.949301	307.044348	31.859335	376.751694	36.618633	391.677735	35.78186	385.473186	35.722347	402.718877
10	10: N1 start to Nelson Mandela Blvd	1674.524	9784.95985	79.14	386.184348	79.14	455.891694	79.14	470.817735	79.14	464.613186	79.14	481.858877
	Travel Time (sec)	9784.96		386.18435		455.89169		470.81774		464.61319		481.85888	
	Travel Time (min)	9.78496		6.4364058		7.5981949		7.8469623		7.7435531		8.0309813	

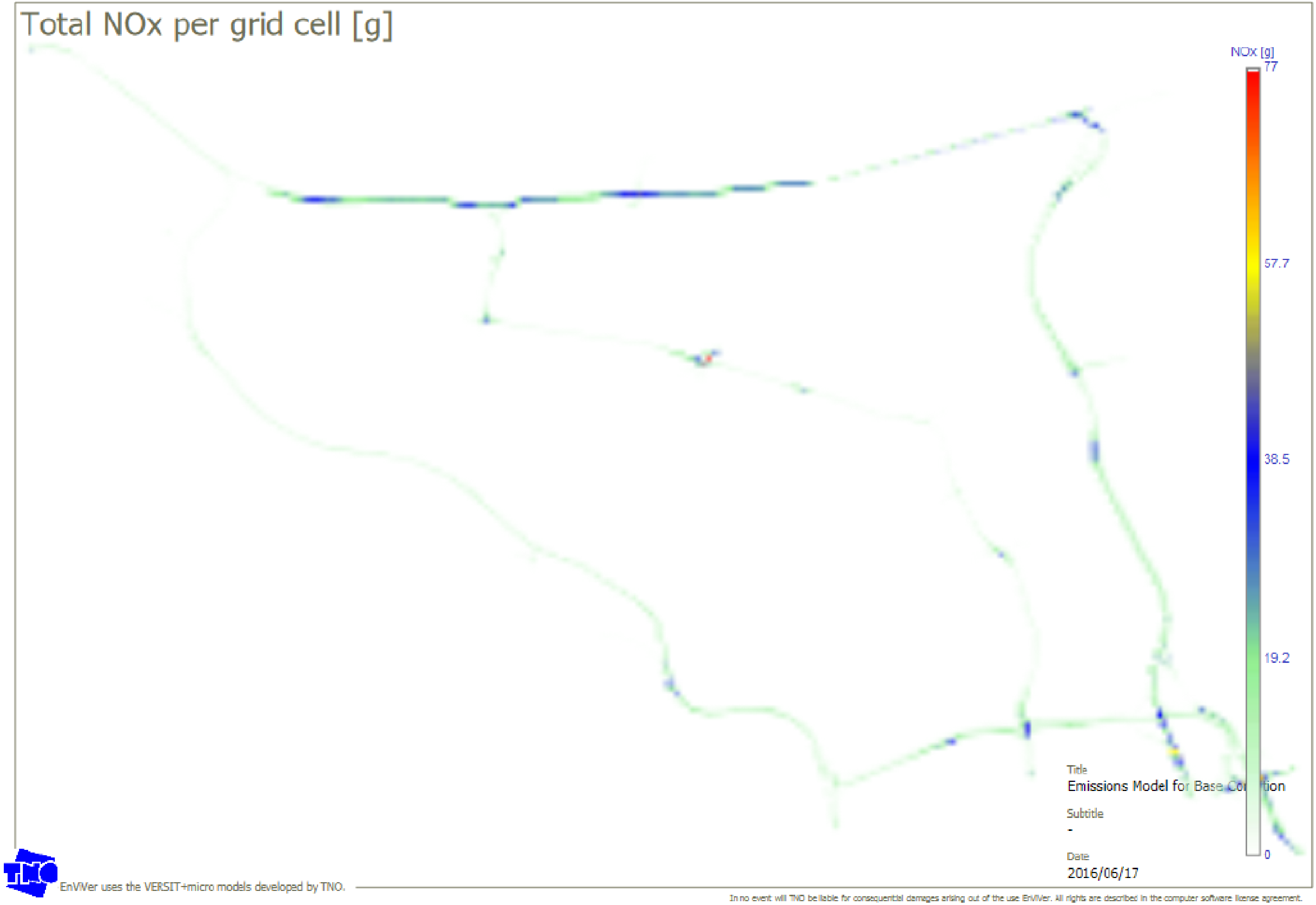
CV 60% PM Peak

				Warm up		Period 1		Peroid 2		Period 3		Period 4	
	N1 Route	Distance	Cumulative Dis	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)	TRAVTM(10)	Travel Time (Cumalative Vehicles)
2	2: N2 Start to Kromboom Int.	975.775201	975.775201	36.569873	36.569873	36.744613	36.744613	37.03436	37.03436	37.178649	37.178649	36.861622	36.861622
3	3: M5 and Kromboom turn	584.549805	1560.325006	22.521222	59.091095	22.730994	59.475607	22.358117	59.392477	22.760456	59.939105	23.598478	60.4601
4	4: M5	2379.525795	3939.850801	86.510086	145.601181	96.141468	155.617075	118.130536	177.523013	96.532788	156.471893	116.706357	177.166457
5	5: M5 into N1	652.779117	4592.629918	31.01	176.611181	30.206491	185.823566	33.029096	210.552109	33.523759	189.995652	34.018847	211.185304
6	6: M5 and N1 merge	155.917221	4748.547139	5.536719	182.1479	5.807186	191.630752	5.775784	216.327893	5.833313	195.828965	5.773316	216.95862
21	21: N1 (M5 merge) to Int. 4 (part 1)	1842.476424	6591.023563	66.820905	248.968805	69.382935	261.013687	70.633477	286.96137	76.81268	272.641645	75.653757	292.612377
22	22: N1 into Int. 4 (part 2)	22.06596	6613.089523	0.794291	249.763096	0.840698	261.854385	0.832644	287.794014	0.843501	273.485146	0.837105	293.449482
8	8: Int 4. to Int 3. (to M176 end) on N1	832.738161	7445.827684	30.451338	280.214434	31.541675	293.39606	32.504057	320.298071	32.632163	306.117309	31.533546	324.983028
28	28: N1 (M176 to Ramp Freeway)	664.607869	8110.435553	23.724938	303.939372	25.126875	318.522935	26.198176	346.496247	26.721199	332.838508	25.042632	350.02566
10	10: N1 start to Nelson Mandela Blvd	1674.524299	9784.959852	79.14	383.079372	79.14	397.662935	79.14	425.636247	79.14	411.978508	79.14	429.16566
	Travel Time (sec)	9784.959852		383.079372		397.662935		425.636247		411.978508		429.16566	
	Travel Time (min)	9.784959852		6.3846562		6.62771558		7.09393745		6.86630847		7.152761	



The following emissions data was obtained from the analysis of all the scenarios mentioned under free-flow conditions. These figures and tables provide the format and presentation of the Base Condition and Accident scenarios




Total NOx per grid cell [g]
NOx [g]
77
57.7
38.5
19.2
0
Title
Emissions Model for Base Co tion
Subtitle
-
Date
2016/06/17
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Total PM10 per grid cell [g]
PM10 [g]
2.41
1.81
1.2
0.602
0
Title
Emissions Model for Base Co tion
Subtitle
-
Date
2016/06/17
TNO
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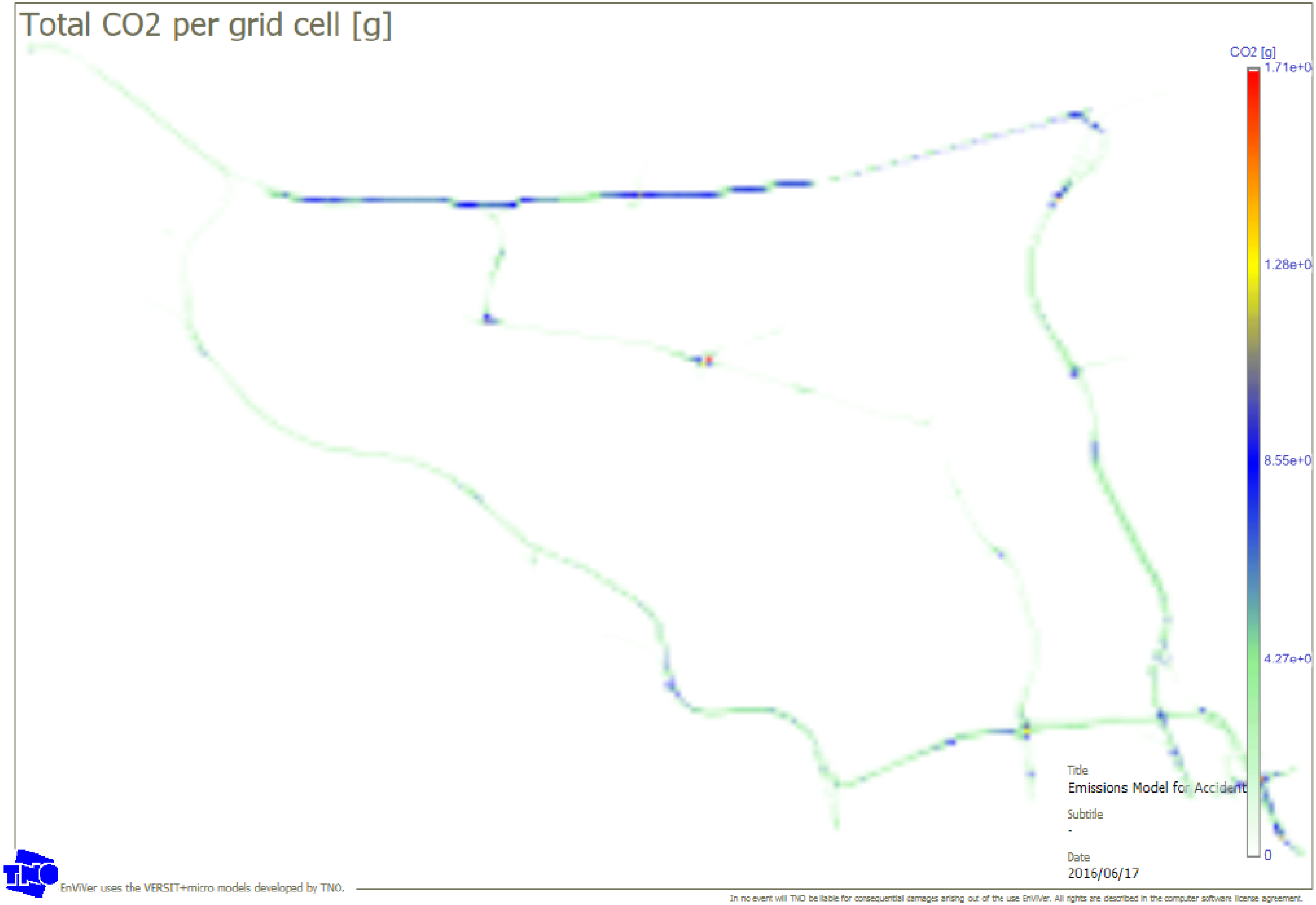
Total CO2 per grid cell [g]
CO2 [g]
1.71e+0
1.28e+0
8.55e+0
4.27e+0
0
Title
Emissions Model for Accident
Subtitle
-
Date
2016/06/17
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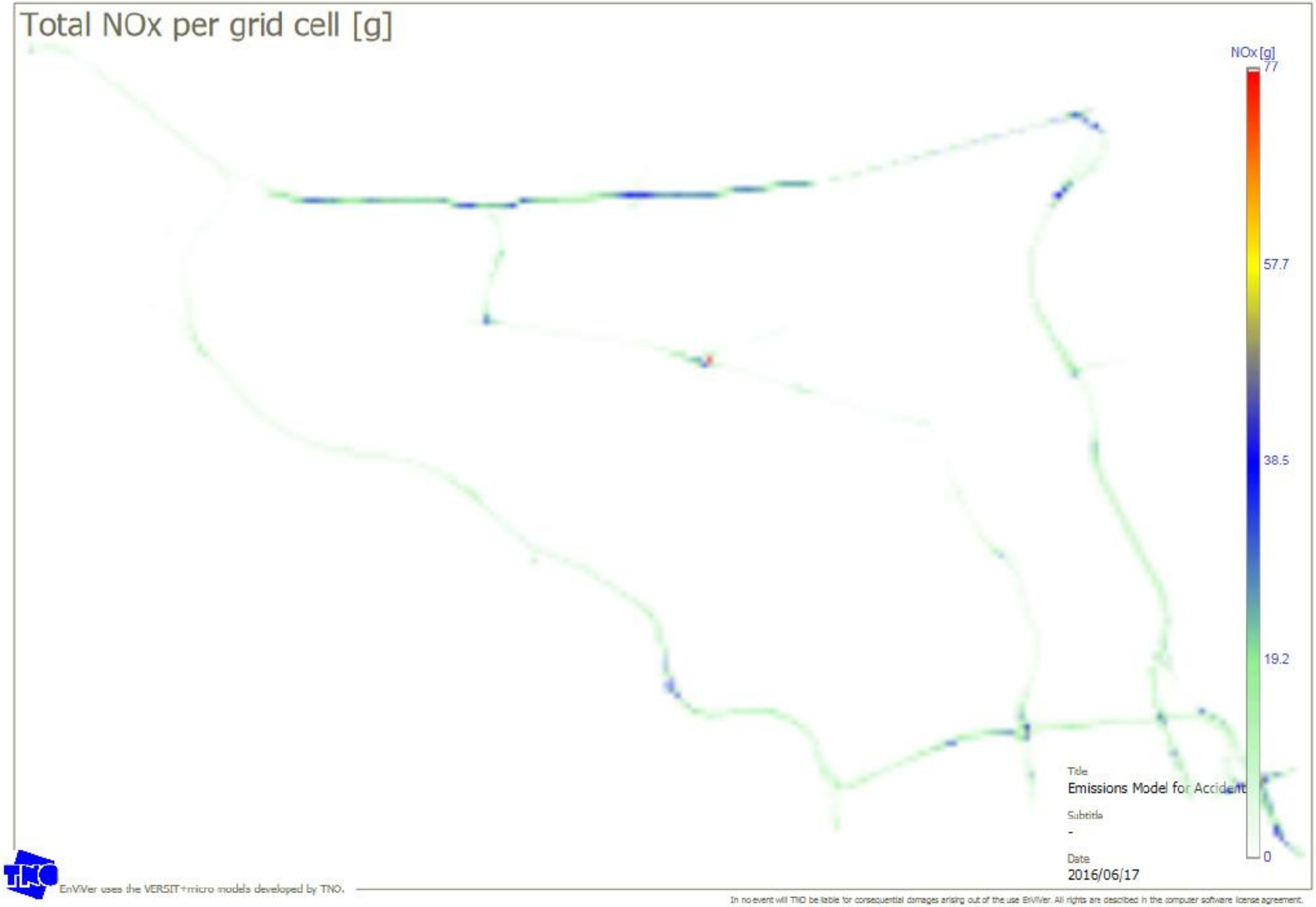
Total NOx per grid cell [g]
NOx [g]
77
57.7
38.5
19.2
0
Title
Emissions Model for Accident
Subtitle
-
Date
2016/06/17
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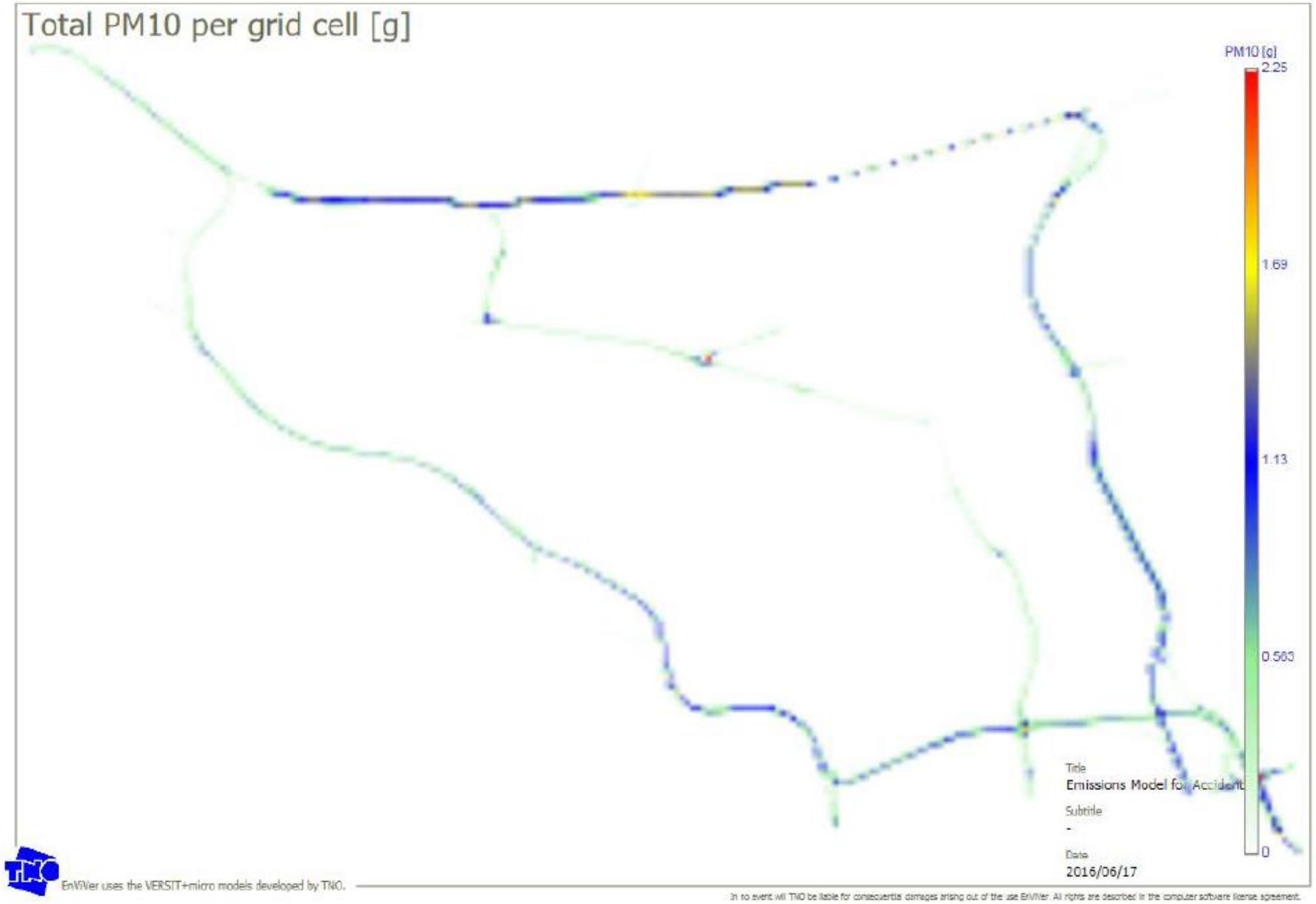
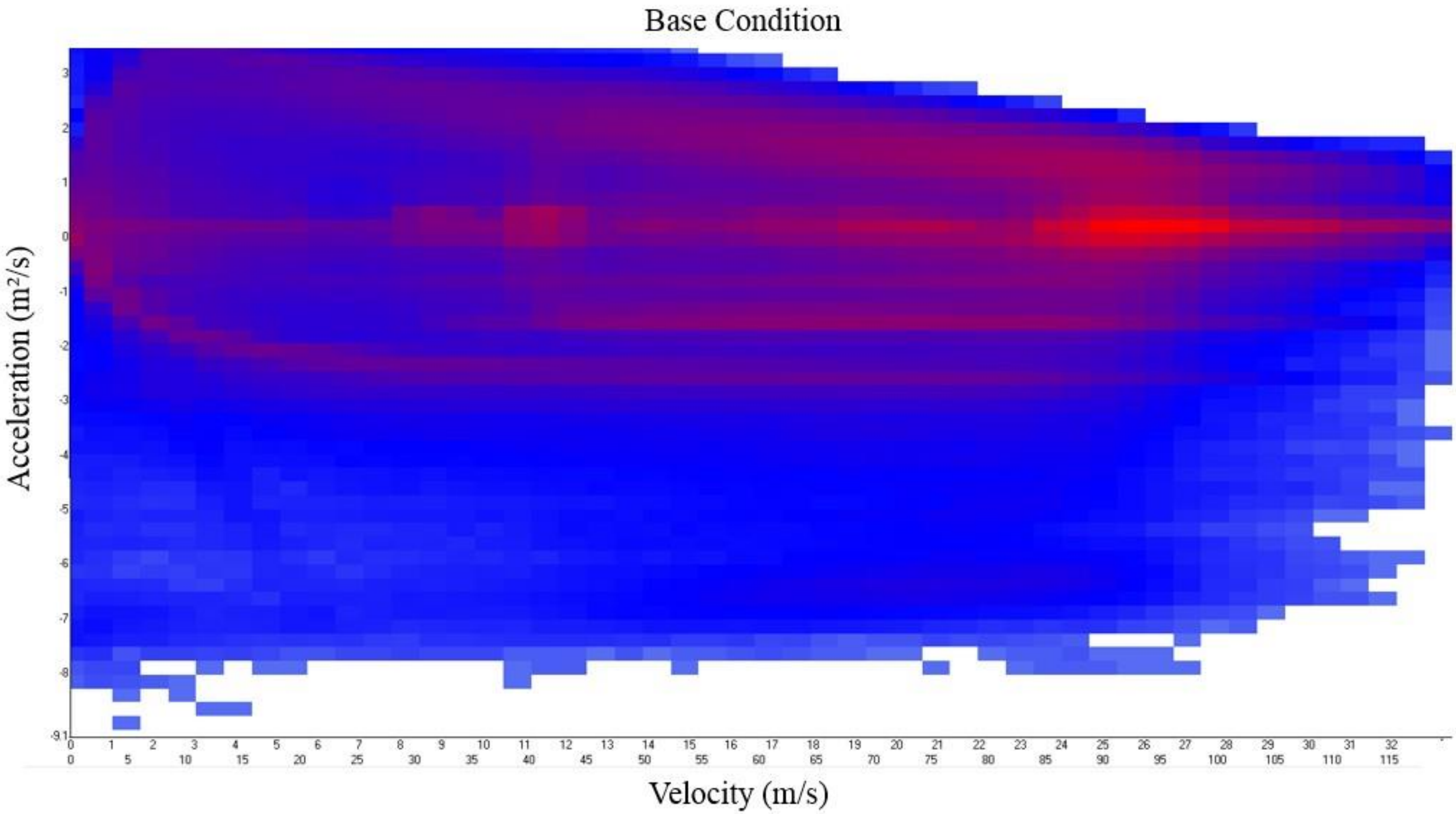
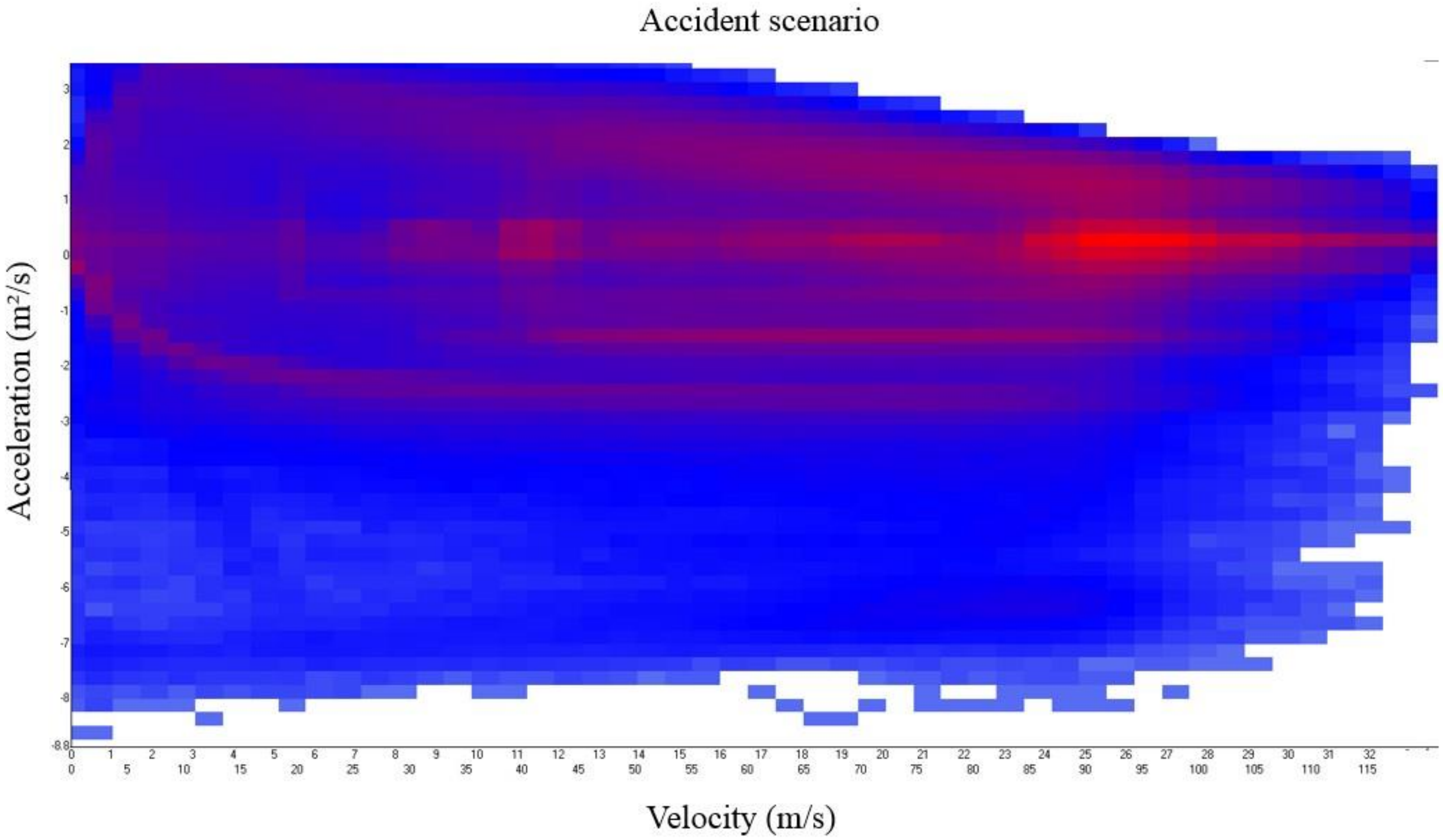


The remaining output (Accident, Speed-Harmonization and Queue-Warning) may be obtained from the flash disk under the *Emissions Data* file.

The following diagrams illustrate the Speed-Acceleration Relationships obtained during the simulations for the Base Condition and Accident scenarios respectively:


Base Condition
Acceleration (m²/s)
Velocity (m/s)



The output of the remaining scenarios may be obtained from the attached flash disk under the *Emissions Data* file.

APPENDIX F

The following cost information was obtained from the report compiled by the Federal Highway Administration (Write et al., 2014) in the report *National Connected Vehicle Field Infrastructure Footprint Analysis: Final Report* (2014), for the cost information relating to the construction of a Connected Vehicle environment:

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Number of Sites	50	2680	55	1	-
DSRC RSU*	$3,750	$1,000	$3,500	$3,500	$3,000
RSU Incidentals*	$1000	$1,000	No data	$1,100	$1,030
Communication Connection Equipment*	$1,300	$1,300	$1,300	$600	$1,125
Power Connection Equipment*	$300	$300	$300	$400	$325
Additional Installation Equipment*	$3,500	$600	$3,300	$600	$2,000
Total Cost for Hardware	**$9,850**	**$4,200**	**$8,400**	**$6,100**	**$7,450**

* Costs reported by deployed sites are underlined.

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Total Cost for Installation Labor*	$2,500	$2,400	$2,500	$2,500	$2,475
Construction Inspection (15% of Hardware Cost)	$1,500	$600	$1,200	$1,000	$1,075
Total Installation Cost	**$4,000**	**$3,000**	**$3,700**	**$3,500**	**$3,550**

* Costs reported by deployed sites are underlined.

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Radio Survey per site	$1,000	$1,000	$1,000	$1,000	$1,000
Map / GID Generation	$1,000	$1,000	$1,000	$1,000	$1,000
Planning	$700	$400	$600	$500	$550
Design	$2,100	$1,100	$1,800	$1,400	$1,600
System Integration & License	$1,500	$1,500	$1,500	$1,500	$1,500
Traffic Control	$1,000	$1,000	$1,000	$1,000	$1,000
Total Implementation Cost	**$7,300**	**$6,000**	**$6,900**	**$6,400**	**$6,650**

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Connected Vehicle DSRC Hardware	$9,850	$4,200	$8,400	$6,100	$7,450
Installation Labor	$4,000	$3,000	$3,800	$3,400	$3,550
Design and Planning	$7,300	$5,900	$6,900	$6,400	$6,600
Total Direct Connected Vehicle Costs	**$21,150**	**$13,100**	**$19,100**	**$15,900**	**$17,600**

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Reported Backhaul Cost*	$31,100	$1,700	$2,000	$18,900	$13,400
Planning	$4,700	$300	$300	$2,800	$2,000
Design	$6,200	$300	$400	$3,800	$2,700
Construction Inspection	$4,700	$300	$300	$2,800	$2,100
System Integration & License	$1,500	$1,500	$1,500	$1,500	$1,500
Traffic Control	$0	$0	$0	$0	$0

Type of Location/Backhaul		Number of Sites	Cost Per Site
Signalized Locations	Integration of Existing Equipment (10%)	24,880	$3,000
	"Easy" Upgrade (20%)	49,760	$22,000
	"Hard" Upgrade (30%)	74,640	$40,000
	Installation of New Backhaul (40%)	99,520	$40,000
Freeway Locations	Integration of Existing Equipment (75%)	18,750	$3,000
	"Hard" Upgrade or Installation of New Equipment (25%)	6,250	$40,000

Element	Cost (2013$) at Signalized Intersection with Controller Upgrade	Cost (2013$) at Signalized Intersection without Controller Upgrade	Cost (2013$) at Other (Non-signalized) Location
(DSRC) Equipment and Site Deployment	$17,600	$17,600	$17,600
Backhaul Upgrades and Deployment (Weighted Average)	$30,800	$30,800	$30,800
Traffic Signal Controller Upgrades	$3,200	-	-
Total Potential Site/Unit Cost	$51,600	$48,400	$48,400

Cost Element	Per Device Cost per Year
Power	$100
Traditional Maintenance	$500
License/Maintenance Agreements	$200
SCMS Certificate License	$50
Annualized Replacement Cost (every five to ten years)	$1100 - $2200
Total	**$1950 - $3050**

Equipment Component	Unit Cost
DSRC After-market Safety Device	$1,000
Cabling Management/Installation Kits	$150
Installation Labor	$3,000
Video Data Collection System (optional)	$5,050
Total Cost Per Vehicle (with video)	**$9,200**

The report may be obtained online or from the attached flash disk under *Chapter 5, Cost Benefit Analysis.*

EXISTING NETWORK: COSTS AND BENEFITS

Costs	Interest rate	7%	Discount Rate	5%
Year	**Maintenance**	**License Payment**	**Total Payment**	**Present Value**
0	-87692.16	-3782.5	-91474.66	-91474.66
1	-87692.16	-3782.5	-91474.66	-89764.85327
2	-87692.16	-3782.5	-91474.66	-88087.00555
3	-87692.16	-3782.5	-91474.66	-86440.51946
4	-87692.16	-3782.5	-91474.66	-84824.80882
5	-87692.16	-3782.5	-91474.66	-83239.29837
6	-87692.16	-3782.5	-91474.66	-81683.42364
7	-87692.16	-3782.5	-91474.66	-80156.63067
8	-87692.16	-3782.5	-91474.66	-78658.37589
9	-87692.16	-3782.5	-91474.66	-77188.12588
10	-87692.16	-3782.5	-91474.66	-75745.35717
11	-87692.16	-3782.5	-91474.66	-74329.5561
12	-87692.16	-3782.5	-91474.66	-72940.2186
13	-87692.16	-3782.5	-91474.66	-71576.85003
14	-87692.16	-3782.5	-91474.66	-70238.96498
15	-87692.16	-3782.5	-91474.66	-68926.08713
16	-87692.16	-3782.5	-91474.66	-67637.74906
17	-87692.16	-3782.5	-91474.66	-66373.49206
18	-87692.16	-3782.5	-91474.66	-65132.86604
19	-87692.16	-3782.5	-91474.66	-63915.4293
20	-87692.16	-3782.5	-91474.66	-62720.74837
			Total Present Value	-R 1 601 055.02

Penetration after year 5

Costs	Interest rate	7%	Discount Rate	5%
Year	Maintenance	License Payment	Total Payment	Present Value
0	-65769.12	-3782.5	-69551.62	-69551.62
1	-65769.12	-3782.5	-69551.62	-68251.58972
2	-65769.12	-3782.5	-69551.62	-66975.85907
3	-65769.12	-3782.5	-69551.62	-65723.97385
4	-65769.12	-3782.5	-69551.62	-64495.48836
5		-7565	-7565	-6883.931486
6		-7565	-7565	-6755.25987
7		-7565	-7565	-6628.99333
8		-7565	-7565	-6505.086913
9		-7565	-7565	-6383.496503
10		-7565	-7565	-6264.178812
11		-7565	-7565	-6147.091357
12		-7565	-7565	-6032.192453
13		-7565	-7565	-5919.441193
14		-7565	-7565	-5808.797432
15		-7565	-7565	-5700.221779
16		-7565	-7565	-5593.675577
17		-7565	-7565	-5489.120894
18		-7565	-7565	-5386.520503
19		-7565	-7565	-5285.837877
20		-7565	-7565	-5187.037169
			Total Present Value	-R 430 969.41

Penetration after year 10

Costs	Interest rate	7%	Discount Rate	5%
Year	Maintenance	License Payment	Total Payment	Present Value
0	-65769.12	-3782.5	-69551.62	-69551.62
1	-65769.12	-3782.5	-69551.62	-68251.58972
2	-65769.12	-3782.5	-69551.62	-66975.85907
3	-65769.12	-3782.5	-69551.62	-65723.97385
4	-65769.12	-3782.5	-69551.62	-64495.48836
5	-65769.12	-3782.5	-69551.62	-63289.96521
6	-65769.12	-3782.5	-69551.62	-62106.97521
7	-65769.12	-3782.5	-69551.62	-60946.09717
8	-65769.12	-3782.5	-69551.62	-59806.91778
9	-65769.12	-3782.5	-69551.62	-58689.03147
10		-7565	-7565	-6264.178812
11		-7565	-7565	-6147.091357
12		-7565	-7565	-6032.192453
13		-7565	-7565	-5919.441193
14		-7565	-7565	-5808.797432
15		-7565	-7565	-5700.221779
16		-7565	-7565	-5593.675577
17		-7565	-7565	-5489.120894
18		-7565	-7565	-5386.520503
19		-7565	-7565	-5285.837877
20		-7565	-7565	-5187.037169
			Total Present Value	-R 702 651.63

Penetration after year 15				
Costs	**Interest rate**	**7%**	**Discount Rate**	**5%**
Year	**Maintenance**	**License Payment**	**Total Payment**	**Present Value**
0	-65769.12	-3782.5	-69551.62	-69551.62
1	-65769.12	-3782.5	-69551.62	-68251.58972
2	-65769.12	-3782.5	-69551.62	-66975.85907
3	-65769.12	-3782.5	-69551.62	-65723.97385
4	-65769.12	-3782.5	-69551.62	-64495.48836
5	-65769.12	-3782.5	-69551.62	-63289.96521
6	-65769.12	-3782.5	-69551.62	-62106.97521
7	-65769.12	-3782.5	-69551.62	-60946.09717
8	-65769.12	-3782.5	-69551.62	-59806.91778
9	-65769.12	-3782.5	-69551.62	-58689.03147
10	-65769.12	-7565	-73334.12	-60724.12963
11	-65769.12	-7565	-73334.12	-59589.09917
12	-65769.12	-7565	-73334.12	-58475.28423
13	-65769.12	-7565	-73334.12	-57382.28827
14	-65769.12	-7565	-73334.12	-56309.72213
15		-7565	-7565	-5700.221779
16		-7565	-7565	-5593.675577
17		-7565	-7565	-5489.120894
18		-7565	-7565	-5386.520503
19		-7565	-7565	-5285.837877
20		-7565	-7565	-5187.037169
			Total Present Value	-R 964 960.46

User costs:

Cost per user	
Suction mount	350
Charger	250
Internet connection	500
	1100

Costs	Interest rate		7%	Discount Rate	5%
Year	**Once-Off**	**Backhaul Upgrade**	**Maintenance**	**Total Payment**	**Present Value**
0	-1 532 400.00	-666 690.22		-2 199 090.22	-2 199 090.22
1			-116 980.97	-116 980.97	-114 794.40
2			-116 980.97	-116 980.97	-112 648.72
3			-116 980.97	-116 980.97	-110 543.13
4			-116 980.97	-116 980.97	-108 476.90
5			-116 980.97	-116 980.97	-106 449.30
6			-116 980.97	-116 980.97	-104 459.59
7			-116 980.97	-116 980.97	-102 507.08
8			-116 980.97	-116 980.97	-100 591.06
9			-116 980.97	-116 980.97	-98 710.85
10			-116 980.97	-116 980.97	-96 865.79
11			-116 980.97	-116 980.97	-95 055.21
12			-116 980.97	-116 980.97	-93 278.48
13			-116 980.97	-116 980.97	-91 534.96
14			-116 980.97	-116 980.97	-89 824.02
15			-116 980.97	-116 980.97	-88 145.07
16			-116 980.97	-116 980.97	-86 497.50
17			-116 980.97	-116 980.97	-84 880.72
18			-116 980.97	-116 980.97	-83 294.17
19			-116 980.97	-116 980.97	-81 737.27
20			-116 980.97	-116 980.97	-80 209.47
				Total Payment	-R 4 129 593.89

Item	Amount	Unit Cost (R)	Total Cost (R)
Staff	15	519 915.40	7 798 731.00
DSRC and CV equipment	1	6 704.29	132 725.54
Aftermarket	1	2 554.00	118 234.75
Retro-fitting Cost	1	3 716.07	122 292.12
Self-Contained	1	3 141.42	120 285.72
Vehicle Awareness Device	1	1 034.37	112 928.92
Standard Equipment	1	14 770.32	160 888.24
Standard Equipment With Video Equipment	1	79 295.54	386 179.15

Fuel Consumption saving (R):			
	Q-WARN	**CV-T**	**CV**
ave. imp.	8.4307275	5.678129	14.23858
x2	16.861455	11.35626	28.47716
x250	4215.3637	2839.065	7119.29

Travel Time (R)			
saving (R):			
	Q-WARN	CV-T	CV
ave. imp.	16.1784319	9.833414011	10.71166
total	18 702	18 702	18 702
benefit	3025.69	1839.05	2003.29

Emissions		
saving (R)		
Q-WARN	CV-T	CV
3.2	4	2
240	300	150
120000	150000	75000

FINAL TOTAL COSTS AND BENEFITS

Table 8.10: Costs and Benefits to Users

Decision	Option	Total Present Cost (Minimum) (R)	Total Present Cost (Maximum) (R)	Total Present Benefit (R)	Cost Benefit Ratio (Min)	Cost Benefit Ratio (Max)
Alternative 0	-	-	-	-	-	
Alternative 1	Option 1: Added to Vehicle	132 725.54	242 043.90	182 215	1.37	0.75
	Option 2: Aftermarket	118 234.75	156 717.36	182 215*	1.54	1.16
	Option 3: Retro-fitted	122 292.12	231 609.48	182 215	1.49	0.79
	Option 4: Self-Contained	120 285.72	229 603.08	182 215	1.51	0.79
	Option 5: VAD	112 928.92	222 246.28	182 215*	1.61	0.82
	Option 6: Standard Equipment (SE)	160 888.24	270 205.60	182 215*	1.13	0.67
	Option 7: SE with Video	386 179.15	495 496.51	182 215*	0.47	0.37
Alternative 2	1: Min. Delay	40 099.90	75 554.20	158 730.30	3.49	1.77
	2: Max. Delay	40 099.90	75 554.20	101 324.80	2.53	1.34

Table 8.11: Costs and Benefits to Management Agencies

Decision		Total Present Cost (Design Area)	Total Present Benefit	Total Net Benefit
Alternative 0	From 2015	- R1 601 055	-	- R1 601 055
Alternative 1	40%	- R13.928 mil	R17.22 mil	R3.295 mil
	50%		R20.73 mil	R6.80 mil
	60%		R23.96 mil	R10.03 mil
Alternative 2	At 2020	-R430 970	-	-R430 970
	At 2025	-R702 652	-	-R702 652
	At 2030	-R949 875	-	-R949 875