# The introduction of Average Speed over Distance cameras as a road safety tool to reduce excessive speeds and accidents on the roads of the Western Cape, South Africa

**by**

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## Declaration

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March 2017

## Abstract

Road safety is a joint responsibility of the road users, design engineers, maintenance teams, law enforcement teams and the various departments within governments that are related to transport and road safety. Road safety has a major impact on society. The number of road accidents is a serious problem in most societies as they impact negatively on many people, either directly or indirectly, as well as on the economy.

Concerted efforts are being made to reduce the number of fatalities on the roads. Although there has been an improvement, South Africa still ranks high of the list of countries with the most fatalities on their roads. The World Health Organisation (WHO) listed South Africa as 38th in the world, with 25.1 deaths per 100 000 population in 2013.

The Western Cape Government implemented Average-Speed-Over-Distance (ASOD) technology on the roads of the Western Cape in South Africa in an effort to reduce excessive speeding and accidents. ASOD was introduced into the province in 2011 with a pilot project on the R61 route between Beaufort West and the Eastern Cape border towards the town of Aberdeen. Since 2011, another five phases covering a total of 451 km of the Western Cape Province's most dangerous roads were rolled out.

This study evaluated the impact of ASOD on three rural routes, the R27 West Coast Road between Cape Town and Langebaan, the N1 between Touwsriver and Riemhoogte and the N2 over the Sir Lowry's Pass between Somerset West and Grabouw. The impact of ASOD was evaluated on two levels: excessive speeding (speeds more than 10 km/h above the speed limit, and 85th percentile speeds) and accidents. A time series analysis was conducted on the data obtained from permanent CTO-stations installed across the province. A comparative study on 85th percentile speeds was conducted on industry provided probe data. A numerical analysis was done on the corresponding accident data. A benefit-costs analysis was also conducted on the project.

The interrupted time series analysis found that there was an abrupt and permanent reduction in excessive speeds on the R27 route after the implementation of ASOD. The number of vehicles exceeding the 130 km/h mark reduced from 12 292 vehicles to 6 122 within three months, a reduction of 50%.

The time series analysis conducted on the N1 did not find any statistical significant reductions in excessive speed due to the implementation of ASOD – neither had there been on the control route.

The time series analysis found that there was an abrupt and permanent reduction in excessive speeds on the N2 across Sir Lowry's Pass.

Probe data was analysed for the R27 West Coast Road with a 120 km/h speed limit. The study found that the $85^{th}$ percentile speeds dropped from 125.5 km/h before ASOD implementation to 116.4 km/h post-ASOD implementation. A dataset two years later revealed a 115.2 km/h $85^{th}$ percentile speed. The probe data analysis confirmed the findings of the time series analysis: there was a significant reduction is speed after the implementation of ASOD.

The numerical analysis of the accident data on the R27 West Coast Road concluded that the reduction in the number of accidents after the ASOD implementation was much greater than the theoretical value, as determined by Nilsson's Power Model. Also, in the year after ASOD implementation, there was not a single fatal accident on the N1 section under investigation.

The benefit cost analysis, based on the benefits and costs for the first year of implementation on the N1 between Beaufort West and Riemhoogte, revealed a 2.13:1 ratio.

It was therefore concluded that ASOD had made a significant impact on the reduction in the number of excessive speedsters. This finding was supported by the reduction in the number of accidents and injuries. This ultimately played a role in the improvement of road safety in the Western Cape Province, South Africa.

## Opsomming

Padveiligheid is ‘n gesamentlike verantwoordelikheid tussen padgebruikers, ontwerp ingenieurs, onderhoudspanne, wetstoepassingsbeamptes en verkeie departmente binne die regering. Padveiligheid het ‘n groot impak op die samelewing as ‘n geheel. Die aantal ongelukke en die erns daarvan is ‘n ernstige probleem in vele samelewings, omdat dit ‘n negatiewe impak het op die mense, ongeag direk of indirek, asook die ekonomie.

Daar word daadwerklike pogings aangewend om die aantal padsterftes te verminder, veral oor die feesseisoene. Alhoewel daar ‘n verbetering was, rang Suid Afrika steeds in die top van lande met die meeste padsterftes per kapita. Die Wêreld Gesondheidsraad het Suid Afrika as 38ste in die wêreld gelys, met 25.1 sterftes per 100 000 mense in 2013.

Die Weskaap Provinsiale Regering het Gemiddelde Spoed Oor Afstand tegnologie op die paaie van die Weskaap ingespan. Die projek het ten doel gehad om oormatige spoed en daarmee saam ongelukke te verminder. Die projek is in 2011 geloots op die R61 tussen Beaufort Wes en die Oos-Kaap se grens, oppad na Aberdeen. Intussen is daar vyf fases uitgerol regoor die Weskaap Provinsie.

Die studie het die impak van die tegnologie op drie landelike roetes analiseer. Hierdie roetes is die R27 tussen Kaapstad en Langebaan, die N1 tussen Touwsrivier en Riemhoogte en die N2 oor die Sir Lowry’s pas tussen Somerset-wes en Grabouw. The impak van die tegnologie is op twee vlakke geanaliseer, naamlik oormatige spoed (spoed meer as 10 km/h oor die spoed grens, en 85ste persentiel spoed) en ongelukke. ‘n Tydreeks analise is gedoen op die data soos opgeneem deur telstasies op verskeie plekke binne die provinsie. ‘n Vergelykende studie op 85$^{ste}$ persentiel spoed is gedoen op intydse data. ‘n Numeriese analise van die ongeluksdata is gedoen, asook ‘n voordeel-koste analise op die projek as ‘n geheel.

Die tydreeksanalises het getoon dat daar op beide die R27 en N2 ‘n skielike en permanente verandering was in die spoed op die roetes. Daar kon wel nie ‘n statistiese beduidende verandering op die N1 waargeneem word nie.

Die “Probe data” was geanaliseer op die R27 Weskuspad met ‘n 120 km/h spoedgrens. Die studie het gevind dat die 85$^{ste}$ persentiel spoed van 125.5 km/h voor die implementering van gemiddelde spoed oor afstand kameras, gedaal het na 116.4 km/h. ‘n Datastel twee jaar later se analise het getoon dat die 85$^{ste}$ persentiel spoed nog verder gedaal het na 115.2 km/h. Die “probe data” analise het dus die bevindinge van die tydreeksanalise bevestig: daar was ‘n beduidende vermindering in spoed sedert die implementering van die gemiddelde spoed oor afstand kameras.

Die numeriese analise van die ongeluksdata op die R27 het wel getoon dat die vermindering in ongelukke na die implementering van die projek, veel meer was as die teoretiese-berekende waarde. Daar was in die jaar na die implementering nie een enkele noodlottige ongeluk nie.

Die voordeel-koste analise op die N1 tussen Beaufort Wes en Riemhoogte het ‘n verhouding van 2.13 tot 1 getoon, gebasseer op die voordele en die kostes in die eerste jaar van die projek na implementering.

Die studie het dus bevind dat gemiddelde spoed oor afstand kameras ‘n beduidende impak gehad het op die hoeveelheid oormatige spoed oortredings, tesame met ‘n vermindering teweeggebring in die aantal ernstige ongelukke. Dit het meegebring dat daar ‘n verbetering in die padveiligheid situasie binne die Weskaap Provinsie in Suid Afrika is.

## Acknowledgements

The financial assistance of the Institute for Transportation Technology (ITT) towards this research is hereby acknowledged. The opinions expressed and conclusions arrived at, are those of the author and are not necessarily attributed to the ITT.

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## Dedications

I would like to dedicate this work to my wife, Melanie van Velden. Without you this would not have been possible.

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$V_{85}$ = 85th percentile speed

$A_1$ = Number of accidents before change in speed limit

$A_2$ = Number of accidents after change in speed limit

$v_1$ = speed before change in speed limit

$v_2$ = speed after change in speed limit

$y_0$ = number of accidents before implementation

$z_0$ = number of injured before implementation

$z_1$ = number of injured after implementation

## List of Abbreviations / Acronyms

| | |
|---|---|
| **ACF** | Autocorrelation Function |
| **ADT** | Annual Daily Traffic |
| **ADTT** | Annual Daily Truck Traffic |
| **ANPR** | Automatic Number Plate Recognition |
| **ARIMA** | Autoregressive Integrated Moving Average Model |
| **ASOD** | Average Speed over Distance |
| **B/C** | Benefit-Cost |
| **BCA** | Benefit-Cost Analysis |
| **CS** | Counting Station |
| **CTO** | Continuous Traffic Observation |
| **eNATIS** | Electronic National Traffic Information System |
| **GCM** | Gross Combination Mass |
| **GSL** | General Speed Limit |
| **GVM** | Gross Vehicle Mass |
| **HMV** | Heavy motor vehicle with a GVM exceeding 9 000 kilograms |
| **iPAS** | Integrated Provincial Accident System |
| **IR** | Infrared |
| **NTP** | Network Time Protocol |
| **OCR** | Optical Character Recognition |
| **PACF** | Partial Autocorrelation Function |
| **RTMC** | Road Traffic Management Corporation |
| **Safely Home** | Western Cape Government road safety campaign |
| **SAPS** | South African Police Service |
| **VCP** | Vehicle Check Point |
| **VRM** | Vehicle Registration Mark, also known as number plate number |

# 1 Introduction and background

## 1.1 Background

Transportation, whether it be for the purpose of commuting or for the purpose of transportation of goods, plays a pivotal role in all areas of society. The different modes of transport include rail (trains), air (aircraft), sea (ships), pipelines and road (cars, trucks, donkey-cars, amongst others). In terms of goods transportation, road transport is usually responsible for the 'last mile' of the transport chain – delivering the goods to a point-of-sale for the end-user. In South Africa, road transport is also responsible for the largest portion of commuter transport in the form of private vehicles, minibus taxis and buses.

A great deal of effort goes into the construction, optimisation and maintenance of transport infrastructure. In addition to the purpose of the transport, other things need to be considered. It is very important to take into consideration the elements that contribute to road safety. Road safety is a joint responsibility of the road users, design engineers, maintenance teams, law enforcement teams and the various departments within governments related to transport and road safety. The number of accidents occurring is a serious problem in many societies which impacts negatively on many people, whether directly or indirectly, as well as the economy.

Concerted efforts are being made to reduce the number of fatalities on the roads, especially over the various festive seasons. Although there has been an improvement, South Africa still ranks high on the list of countries with the most fatalities on their roads per head of population. The World Health Organisation (WHO) listed South Africa as 38$^{th}$ in the world with 25.1 deaths per 100 000 population in 2013 (World Health Organisation, 2015).

As part of the Decade of Action for Road Safety (2011-2020), the WHO identified various interventions to be implemented to improve road safety. These interventions include:

- The reduction of speed.
- Enforcement of motorcyclist safety measures - especially the wearing of helmets.
- Reduction of drunk-driving.
- Increased use of seat-belts.
- Reduction of drug-driving.
- Reduction of distracted driving.
- Enforcement of minimum safety standards on vehicles.

These recommendations were implemented in 2011 by the Western Cape Government and out of this the Safely Home Programme of the Department of Transport and Public Works was born. The Safely Home Programme put its focus on smart enforcement, for attaining the WHO goal of a reduction of speed on the roads.

One such effort was the implementation of Average-Speed-Over-Distance (ASOD) technology on the roads of the Western Cape in South Africa. The Western Cape Government introduced ASOD into the province in 2011 with a pilot project on the R61 route between Beaufort West (A) and the Eastern Cape border towards the town of Aberdeen (C).


**Figure 1.1: Average-Speed-Over-Distance Pilot Project 2011**

The stretch of ASOD covered a total of 71.7 kilometres (point A to point B in Figure 1.1) – one of the longest stretches of ASOD in the world.

The pilot project’s initial results showed a great improvement in terms of the reduction of both excessive speeding and accidents.

Figure 1.2 below shows the reduction in the percentage of vehicles exceeding 130 km/h:

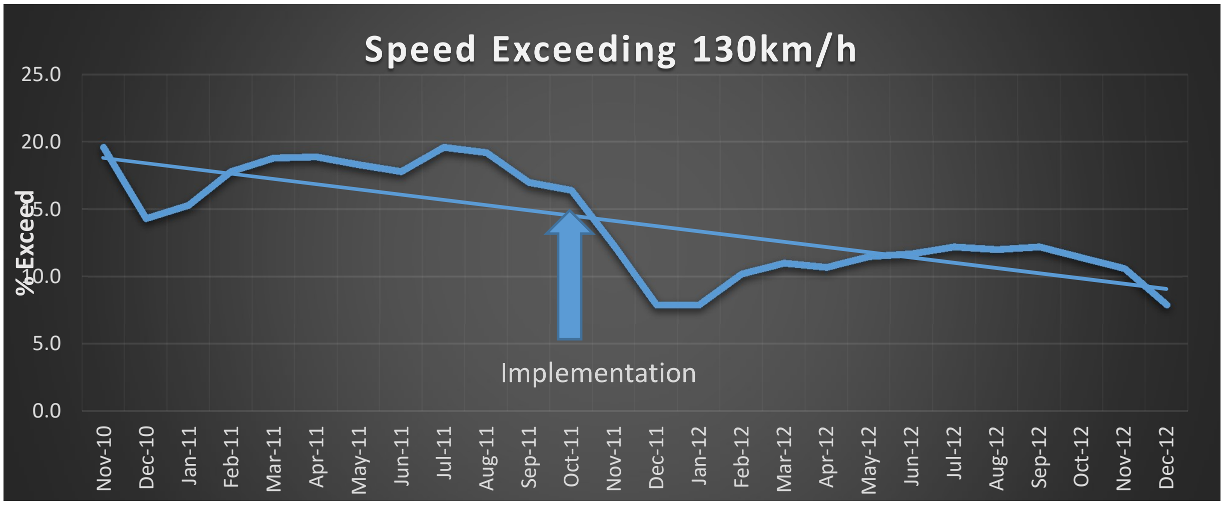


**Figure 1.2: Reduction in percentage of vehicles exceeding 130 km/h on R61 after ASOD implementation**

The success of the pilot led to the project being further rolled out in the following phases, with the pilot project being Phase 1:

- Phase 2 (December 2012): N1-8 between Beaufort West and Riemhoogte, a stretch of 31.8 km.
- Phase 3 (October 2013): R27 between Ganzekraal and Langebaan. This phase comprises of three back-to-back ASOD sections, covering a total of 57.2 km.
- Phase 4 (December 2013): N1-5, N1-6 and N1-7 between Laingsburg and Beaufort West, also of comprising three back-to-back sections, covering a total of 190.6 km.
- Phase 5 (October 2014): N1-4 between Touwsriver and Laingsburg. This phase covers two ASOD sections, back-to-back, covering a total of 72.1 km.
- Phase 6 (April 2015): N2-2 between Somerset West and the Houwhoek Pass. This phase covers two ASOD sections, back-to-back. The first section covers Sir Lowry's Pass, and the second section is on a stretch of road notorious for side-swipe and head-on accidents. The phase covers 28.8 km.

There are plans to roll out ASOD on other provincial routes as well.

The roll-out of ASOD across the province is regarded as a tool to improve the road safety situation in the province.

## 1.2 Objective

The objective of this study is to investigate the impact of ASOD implementation on vehicle speeds and accidents and the way it impacts road safety. The reduction of excess speeds and a reduction in accidents are the outcomes of the project. This study aims at quantifying these outcomes and also determine whether the costs justify the benefits.

## 1.3 Chapter overview

The study commences with a literature review aimed at the environment required for road safety, the effect of speed on road safety and the effect of technological interventions, such as ASOD, as a tool to curb excessive speeding. The literature review is found in Chapter 2. Hypotheses are formulated based on the literature review.

In Chapter 3, the study sites are selected and described. The methodology against which the hypothesis is tested is presented in Chapter 4 against which the hypotheses is tested, followed by a summary of the available data.

Chapter 5 presents the analysis of the data, as set out in the methodology. The results of the study are also discussed. The study is concluded in Chapter 6 where recommendations and suggestions on possible future research are made.

# 2 Literature Review

## 2.1 Introduction

The review of literature to follow will be primarily focused on the road safety environment – both globally and locally in South Africa. The role of speed in the cause of accidents is discussed, as well as the implementation of ASOD technology as a measure to reduce speed in other parts of the world.

## 2.2 The causes of road accidents

The topic of road accidents is widely researched. The World Health Organisation (WHO) published a report in 2015 called the *Global Status Report on Road Safety*. The report was published against the backdrop of the Decade of Action for Road Safety 2011–2020, an international initiative aimed at reducing road traffic deaths and accidents by 50% by 2020 (World Health Organisation, 2015). The WHO reported that the number of road traffic deaths worldwide accumulated to 1.25 million per year. Additional to the 1.25 million deaths, 50 million people are affected by non-fatal injuries as a result of road accidents. The aim of this section is to give a brief overview of typical causes of accidents. This will form part of the basis for the case of speed as a contributing factor to accidents.

### 2.2.1 Vehicle factors

Vehicle factors contribute to the occurrence and severity of road accidents. Currently legislation in South Africa requires vehicles to undergo a roadworthy test only when there is a change of ownership of the vehicle. This means that some vehicles undergo only one or two roadworthy tests in their lifetime. Vehicles that are not roadworthy contribute to accidents, as their basic safety elements such as brakes, lights, tyres and steering do not fall within the manufacturers' specifications. These elements are not always the direct cause of accidents, but if they had been up to standard, an accident might have been preventable.

The number of motorcycles worldwide has grown by 27% between 2010 and 2013, according to the WHO (World Health Organisation, 2015). With this increase in motorcycles, and their need to share the road with trucks, buses, fast-moving cars and pedestrians, the risks of accidents and fatalities have grown. The WHO found that if a motorcyclist wears a helmet, the risk of death is reduced by almost 40% and the risk of severe injury by approximately 70%. If motorcyclists changed their behaviour to regard helmets as standard equipment with their vehicles (motorcycles), their chances of fatal accidents could be significantly reduced.

### 2.2.2 Human factors

It is well documented that drinking and driving increases the probability of car accidents (Dinga, 2014). The WHO found that young and novice drivers were at an even higher risk of road traffic accidents when driving under the influence of alcohol (World Health Organisation, 2015). Drivers are also subject to psychological variables. Quimby *et al*. makes reference to factors such as a decision making style, mild social deviance, willingness to commit driving violations, sensation seeking propensity, intolerance, driving stress and general driving style (Quimby, et al., 1999). Statistically, these factors are highly inter-correlated and play a role in the behaviour of drivers on the road.

Human factors such as fatigue also influence drivers' ability to navigate roads responsibly. In the case of this specific study on the N1 in the Western Cape, this is particularly relevant. The cause of many of the accidents on this route is attributed to driver fatigue. Specific detail on this cause is mentioned at a later stage in this study.

Other factors in terms of road safety include the use of seatbelts and child-restraint systems. Distracted driving in the form of mobile phone use while driving has also increased dramatically over the last few years. In 2015, 139 countries had legislation prohibiting the use of mobile phones while driving (World Health Organisation, 2015).

### 2.3 Road safety interventions

Road traffic injuries are a leading cause of preventable death (World Health Organisation, 2015). In response to the road injury epidemic worldwide, the Decade of Action for Road Safety was launched in 2011, running to 2020. Road safety interventions are applied to all road users, including pedestrians, cyclists and motorcyclists. Road traffic deaths among these groups remain very high.

Several interventions are currently being implemented as part of the Decade of Road Action Plan. These interventions include:

- The reduction of speed, as speed is a critical risk factor in road accidents. This is discussed in Chapter 2.4.
- The increased use of helmets by motorcyclists. Motorcycle use has escalated dramatically over the past few years – thereby increasing the urgency of the adoption of laws and guidelines on helmet-use for the motorcyclists' own safety.
- Reduction of drink-driving. Many countries have adopted laws where blood alcohol concentration (BAC) limits are used as a measure which is enforced upon motorists. It is critical that these laws be enforced, otherwise their effectiveness would be reduced.

- An increase in the use of seat-belts and child restraints.
- The reduction of drug-driving. This is an emerging road safety issue, and many countries are experiencing difficulty in addressing this issue. As this is an emerging issue, some countries do not yet have adequate legislation supporting the enforcement of this issue. The law enforcement officials will need to be trained to detect and enforce these laws.
- Reduction in the incidence of distracted driving. The mobile phone and smart phone boom over the past decade has had a considerable impact on road safety. It is a growing threat, as more road users make use of their mobile phones while driving. Research have shown that crash risks increase fourfold when the driver is talking on a mobile phone while driving. These risks are even higher when drivers text while driving as they take their eyes completely off the road. These issues are still very difficult to address effectively.
- In terms of vehicle safety, many countries do not apply minimum safety standards to new cars. These standards include occupancy protection from front and side impacts, electronic stability control as a driver aid in emergency situations, improved vehicle design to better protect pedestrians, and standards for child restraint systems and fixtures.

This research focuses on the first point: the reduction in speed as a road safety intervention.

## 2.4 Speed as a factor contributing to road accidents

It is almost impossible to talk about road safety without mentioning the relationship between speed and road accidents. Discussions on this topic usually come with strong emotions and opinions.

Speed not only has an effect on the number of accidents, it plays a vital role in the severity of an accident (Aarts & van Schagen, 2006).

### 2.4.1 The transport system according to Nilsson

Goran Nilsson, a Swedish road safety researcher, states that a transport system is described by three main components and their subgroups (Nilsson, 2004):

1. The driver/road user. This includes, but is not limited to, the transportation mode, and the age and gender of the driver/road user.
2. The vehicles. This refers to the different types of vehicles, their condition and the speed at which they travel.
3. The roads. This includes streets, freeways, the road width, number of lanes, speed limit, light and weather conditions, etc.

According to Nilsson, the above three components interact within three dimensions, namely exposure, risk and consequence (Nilsson, 2004). The interaction between and within these three components relays to the safety within the transport system. Accidents occur due to a break in the optimal interaction between these components.

The exposure component is defined as the magnitude of traffic, or the number of situations in which interaction is occurring between the driver, vehicle and road. Data can be accumulated in order to determine the exposure. This can be in the form of vehicle detections loops, for example.

The risk factor can be defined as the expected number of accidents in a specific time period and their consequences. It is the ratio between exposure and the number of accidents/fatalities. This risk factor increases or decreases the probability of an accident. The risk factor also influences the accident’s consequences and not only the risk of an accident occurring (Nilsson, 2004).

The accident consequences are described in the accident information. It could be the number of fatalities, or injuries, or damage to vehicles or property. The injury consequence to the people involved is measured by the amount of harm caused to the human body (Nilsson, 2004).

In summary, the safety situation is presented in terms of accidents, the number of injuries or fatalities, the corresponding risks, and exposure to risk for the different combinations of drivers, vehicles and roads.

### 2.4.2 Speed behaviour

Fildes *et al.* conducted a study in rural Victoria, Australia, where they aimed at describing the relationship between driver and vehicle characteristics, travel distances and times, and driver attitudes to speeding, compared to their actual on-road speed behaviour (Fildes, et al., 1991). The research put a focus on the upper and lower 15% of the speed distribution.

The study highlighted the following findings:

- Drivers aged below 34 were more likely to exceed the speed limit and drive excessively fast at all locations.
- Drivers with a vehicle age less than four years old were more likely to excessively exceed the speed limit. However, older vehicles and vehicles towing a trailer were less likely to exceed the speed limit.
- Single-occupied vehicles where only the driver was in the vehicle also tended to exceed the speed limit excessively. Vehicles with two or more occupants were less likely to exceed the speed limit.

- Drivers travelling for business purposes displayed a higher likelihood of exceeding the speed limit than those travelling for recreational purposes. Also, if there was no particular travel schedule, drivers were less likely to exceed the mean traffic speed.
- Drivers who had to cover great distances on a regular basis were more likely to exceed the speed limit and travel at excessive speeds for most of the way. This was especially evident in urban areas.
- A substantial number of drivers were of the belief that excessive speeding (anything in excess of 30 km/h above the posted speed limit) did not pose a danger to themselves or other road users.
- Drivers who reported having been in accidents previously were the ones more likely to travel above the mean speed of the traffic and the speed limit. There was a trend for these people: a higher likelihood of reporting being hospitalised after an accident. People travelling at excessively slow speeds reported no severe injuries.

### 2.4.3 The speed and accident relationship

The concept of the relationship between speed and accidents (also referred to as crashes in the literature), has been researched extensively.

It is commonly known that speed limits are frequently violated. By speeding, drivers are rewarded with a sense of excitement. In most cases the consequence of the speeding is only a reward. It seldom is the case that the consequences of speeding are unwanted. It is thus possible that drivers perceive that they are able to exceed speed limits and manage higher speeds. This, in turn, has a knock-on effect where drivers start to speed excessively as they have not yet borne any negative consequences.

Safety is typically defined in terms of crashes or crash rates (Transportation Research Board, 1998). Crashes due to the effects of speed are defined by two measures: crash probability and crash severity.

At the moment of a crash, all the kinetic energy will be absorbed in the crash:

$$Kinetic\ energy = \frac{1}{2}mv^2$$

**Equation 2.1: Kinetic energy**

*where* *m = mass*

*v = velocity* of the vehicle

The above equation demonstrates that there is an exponential relationship between the speed at which the vehicle is travelling and the kinetic energy that has to be dissipated in the crash. This means that an increase in speed exponentially increases the severity of a crash.

There have been various studies that describe the relationship between speed and crash rate. Most studies draw the relationship between speed and crashes either by means of individual vehicle speeds, or at road section level.

Fildes *et al.*, (1991) applied a self-reporting method for a study in Australia. They found that travelling at excessive speeds above the mean traffic speeds had negative consequences in terms of higher accident involvement and greater injury severity (Fildes, et al., 1991). Their study was based on rural and urban roads although the sample size was very small.

Kloeden *et al.*, (2002) found that illegal speeding in Adelaide's 60 km/h speed zones, accounted for 25% of all casualty crashes in those zones (Kloeden, et al., 2002). This established a mathematical relationship between speed and crashes – albeit mainly for urban areas with low speed limits.

Kloeden *et al.*, (2001) also did a study on the speed-crash relationship on rural roads. Aarts & van Schagen, (2006) concluded that the results reported by Kloeden *et al.*, (2001) and Kloeden *et al.*, (2002) indicated that crash rates on urban roads increased more with increasing speed than did those on rural roads (Aarts & van Schagen, 2006). Irrespective of location, however, all the studies indicated that crash rates increased with speed.

In the United Kingdom, Maycock *et al.*, (1998) and Quimby *et al.*, (1999) applied the self-reporting method. Both of these studies showed the same trends: an increase in speed increased crashed liability.



The results of the study by Quimby *et al.*, in 1999 study suggested that a 1% change in an individual driver's speed was associated with a 7.75% change in their accident liability (Quimby, et al., 1999). Quimby *et al.* also noted that the apparent association between speed and accidents does not necessarily suggest that there is a link between speed and accidents.

Maycock *et al.*, in 1998, on the other hand, obtained a relationship between speed and accidents, suggesting that a 1% change in an individual driver's speed will bring about a 13.1% change in the driver's accident liability (Maycock, et al., 1998). They also noted the same as had Quimby *et al.* in1999, stating that there is a strong association between speed and accidents, but that it does not necessarily mean that there is a causal link between the two (Maycock, et al., 1998).

Many before and after studies have also been done in order to relate speed and accidents – the most famous being that of Goran Nilsson, a Swedish road safety researcher. The above equation in 2.4.3 forms the basis of Nilsson's proposed relationship between the speed and injury severity of crashes by means of the Power Model. The Power Model estimates the effect that the change in speed has on the number of accidents and the severity of injuries at those accidents by means of a set of power functions (Elvik, et al., 2004).

Nilsson studied the before-and-after effects of a change in the speed limit on Swedish rural roads. He used sections where there were no speed limits changes as control sections. Nilsson found that the average speed came down with the speed limit being brought down. He also found that the number of accidents decreased.

Nilsson adapted the formula for kinetic energy. He eliminated the effect of mass, as mass is a constant before and after the accidents. He then came up with the following formula:

$$A_2 = A_1 \left(\frac{v_2}{v_1}\right)^2$$

**Equation 2.2: Nilsson's Power equation for all accidents**

*where* $A_1 = \textbf{number of accidents before reduction in speed}$

$A_2 = \textbf{number of accidents after reduction in speed}$

$v_1 = \textbf{speed before reduction in speed (in km/h)}$

$v_2 = \textbf{speed after reduction in speed (in km/h)}$

Nilsson also reasoned that the number of severe accidents would increase faster with an increase in speed (Aarts & van Schagen, 2006). He used Equation 2.2 as a basis and increased the power of the function. For severe accidents he increased the power to 3. For fatal accidents the power was increased to 4.

## 2.5 Road safety in South Africa

If one were to draw a picture of South African road safety, it would be a bleak one. On an almost daily basis, newspaper headlines are filled with reports of major road accidents – most of these with high fatality rates. Statistics South Africa recorded a total of 458 933 deaths in the country in 2013. The number of deaths due to transport accidents totalled 13 273, as reported by the WHO (World Health Organisation, 2015). This figure accounts for 12.1% of non-natural causes of death (Statistics South Africa, 2014). It is important to note that there are discrepancies in this statistic, depending on which source is consulted. Accident statistics depend very much on the quality of feedback from the various role players. This is discussed in more depth in Chapter 3.2.3 in this dissertation.

Over the last few decades the South African government – on a national and on provincial level – has by various initiatives attempted to reduce the number of accidents on the roads. These initiatives have included the Arrive Alive campaign – a campaign that was initiated by a private person. Other initiatives include the Road Traffic Management System (RTMS) developed by the CSIR for the compliance of heavy motor vehicle operators, the 'Decade of Road Safety' and the annual Transport Month in the month of October.

In 1996 the National Department of Transport (NDoT) sent a delegation to Victoria, Australia to investigate the world's best practice on road safety in that state (NSW Centre for Road Safety, 1996). The delegation introduced these practices in Kwazulu-Natal in the project named Project Victoria and then rolled it out nationally prior to the Arrive Alive campaign. The success of Project Victoria in Kwazulu-Natal of a 31% reduction in accidents between 1996 and 1999 was unprecedented – especially in the developing world, according to Dr Wendy Watson, General Manager of Land Transport Legislation at the National Department of Transport.

Originally, the NDoT launched the Arrive Alive Road Safety Campaign as a short term initiative to reduce the road carnage. The first campaign ran from October 1997 to the end of January 1998. Although this campaign involved all nine of the provinces, the campaign focused mainly on Gauteng, KwaZulu-Natal and the Western Cape (NSW Centre for Road Safety, 1996). Up to 1997 the campaign was regarded as one of the best road safety initiatives in South Africa and as a positive step in initiating a change in the attitude of road users, due to widespread awareness. It was reported that the number of accidents and fatalities had decreased significantly since the campaign's launch.

Several other campaigns were run in the succeeding years – from a driver fatigue programme at the start of 1998 to a pedestrian safety and awareness campaign in October 1998.

The World Health Organization's World Report on Road Traffic Injury specified six actions that governments need to take in the road safety effort (Peden, et al., 2004). These are:

1. Identify a lead agency in government to guide the national road traffic safety effort.
2. Assess the problem, policies and institutional settings relating to road traffic injury and the capacity for road traffic injury prevention in each country.
3. Prepare a national road safety strategy and plan of action.
4. Allocate financial and human resources to address the problem.
5. Implement specific actions to prevent road traffic crashes, minimize injuries and their consequences and evaluate the impact of these actions.
6. Support the development of national capacity and international cooperation.

These recommendations were implemented by the Western Cape Government and out of this the Safely Home Programme, run by the Department of Transport and Public Works, was born.

### 2.6 Western Cape Province – The Safely Home Programme

The Safely Home Programme, led by Robin Carlisle, the Minister of Transport and Public Works, aimed to reduce the number of people killed on the province's roads by 50% by the end of 2014 (Western Cape Government, n.d.).

The Safely Home interventions were focused on the traditional four E's: Enforcement, Engineering, Education and Evaluation. (October, 2015). Various plans were formulated for each of these focus areas:

- **Enforcement** of compliance with road traffic laws through visible and smart means. In this case smart refers to the use of technology in the enforcement process.
- Implement **engineering** and infrastructure improvement projects to reduce road crashes.
- Various **education** initiatives, including building capacity within the organisation to improve road safety education and awareness, engagement of communities in road safety awareness projects, design and implementation of communication campaigns with specific focus on drunk-driving, seat-belts and child restraint systems. The education also included learner transport policies, a strategy for road safety ambassadors, protocols for traffic and SAPS officers at operations such as vehicle check points and road blocks.
- All of the above were to be **evaluated** by developing systems and collecting, verifying and processing data and statistics to ensure that the projects were intelligence-driven.

One such project where all of the E's were incorporated, was the Average-speed-over-distance (ASOD) project. The smart technology and smart enforcement that came with the system attained all the strategic objectives as described above. This project is the focus of this research.

### 2.7 Average Speed over Distance Technology

Average Speed Over Distance (ASOD) technology is known by different names in different countries. In Scotland it is called an average speed camera (ASC) system (Transport Scotland, n.d.). In other countries, such as Italy, it is called Point-to-Point (P2P) speed enforcement (Montella, et al., 2015). Some countries refer to it purely as "Section Control" or Automated Section Speed Control (ASSC).

In essence, ASOD encourages speed compliance by road users in maintaining the speed limit of the road. ASOD enforcement involves the installation of a series of Automatic Number Plate Recognition (ANPR) cameras along a stretch of road. Two consecutive cameras linked to each other form an ASOD section. As a vehicle enters the ASOD section at Camera A, its number plate is captured and OCR is done on the plate. This record, consisting of images of the vehicle and number plate and read-data, is uploaded to a central server. Once the vehicle exits the ASOD section at Camera B, all the above data is uploaded to the server and then the server matches the two records by means of the Vehicle Registration Mark (VRM). The average speed is calculated by dividing the distance travelled by the time taken to travel between the two cameras. The distance is usually determined by a certified entity such as a land surveyor. The time is determined by a GPS timestamp on the record or in other cases the computer clock synced to a Network Time Protocol (NTP) server.

Figure 2.1 displays the process as described above:

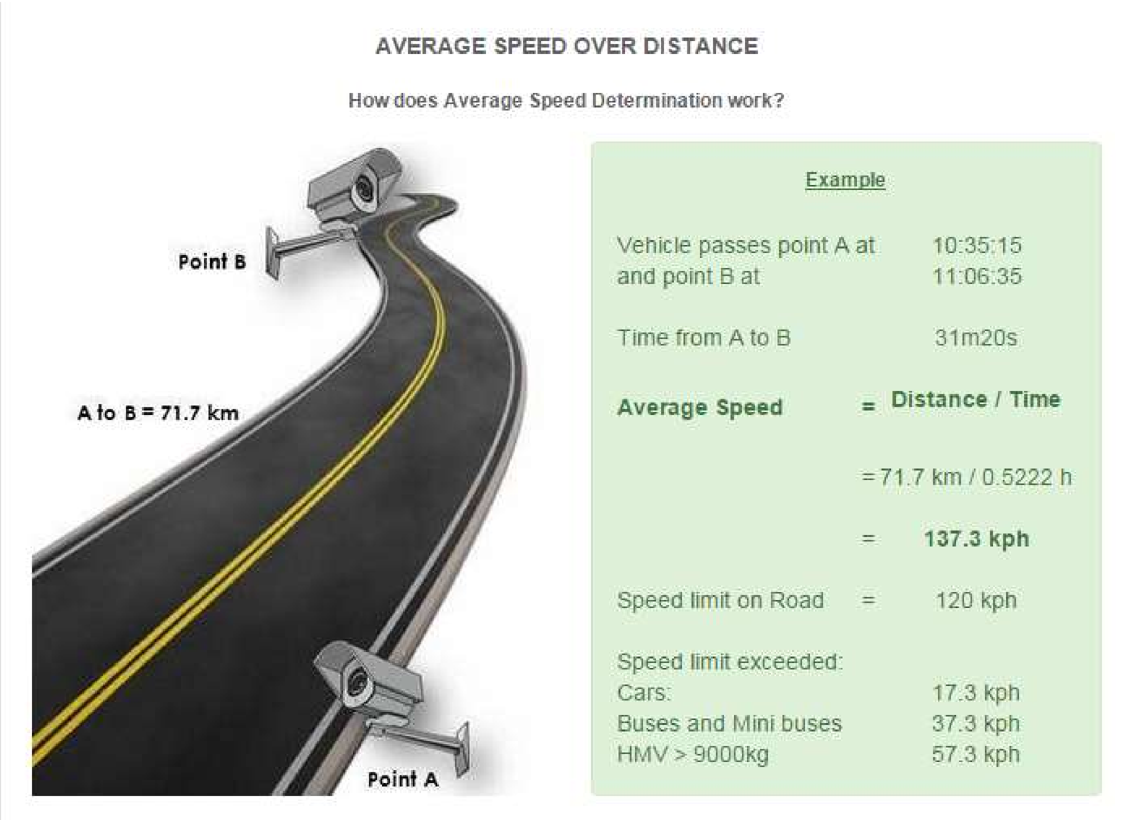


**Figure 2.1: Pamphlet explaining Average Speed Over Distance**

If the average speed, as calculated by the system, exceeds the posted speed limit, the ASOD record is flagged by the system as an offence. These offences are transmitted to a back-office system that does the offence processing. In some countries the offences are pushed to roadside enforcement officers in real-time so that the offence can be issued to the offending driver. If no immediate intervention on the offence has taken place, the offence information is sent to an offence capturing- and follow-up system.

In most cases an enforcement tolerance is implemented, also known as a grace over the speed limit. In South Africa, this tolerance is 10 km/h above the speed limit. This means that if the posted speed limit is 120 km/h, drivers will only be regarded as offenders when exceeding 130 km/h.

The automated nature of the ASOD-system allows for almost fully automated back-office processing as well. In almost all current installations worldwide, some degree of human verification is done to assess the validity of the infringements (Soole, et al., 2013). Validated offences are issued infringement notices.

Average speed enforcement, as it is called in the United Kingdom and Australia, is a relatively new approach to law enforcement and road safety. There is a growing body of knowledge pointing to the positive benefits of the implementation of the technology. Benefits associated with road safety include a high compliance to speed limits, reductions in the average and 85$^{th}$ percentile speeds ($V_{85}$) and a reduced variability between vehicles (Soole, et al., 2013).

Pilot projects in various countries have proved highly successful. In the Netherlands a pilot project was launched in 1997 with a permanent installation in 2002 on the A13 motorway near the Rotterdam district of Overschie. The main purpose of the deployment of this technology was compliance with a resolution to improve air quality levels. By reducing the speed limit on the road, the $NO_2$ concentrations were reduced. The section-control speed enforcement assisted in enforcing these standards. A bonus to the strict enforcement of the speeds was that there was a more homogeneous traffic flow as well as reduced noise levels (Olde Kalter, et al., 2005). Later studies also revealed a great increase in traffic safety. The section control enforcement resulted in less than 0.5% of drivers exceeding the speed limit, and the number of casualties had halved (Montella, et al., 2011; Olde Kalter, et al., 2005).



The United Kingdom started with a pilot of average speed enforcement technology in Kent in 1999 (Collins & McConnell, 2008). The first full implementation was in Nottinghamshire in July 2000 (Soole, et al., 2013).

In Italy, the Safety Tutor system – an ASOD system – on the A1 Motorway between Milan and Naples, was introduced in 2007. An empirical study by Montella *et al.* estimated a total crash reduction of 21.2% (Montella, et al., 2012). This reduction was mostly due to a reduction in severe crashes and crashes at curves. Severe crashes showed a reduction of 55.6% while a reduction of 26.6% was shown for non-severe crashes. The study also revealed that the initial reduction in crashes (39.4%) in the first semester was far more drastic than, for example, the fifth semester after activation where the reduction was only 18.7%. The study strongly supported the implementation of the technology due to highly significant and substantial safety effects.

A P2P speed enforcement system was also activated on the A56 urban motorway in Italy in 2009. Montella *et al.* in their 2015 study found a 10% reduction in the average speed of light vehicles.

The $V_{85}$ decreased by 14%. The percentage of vehicles exceeding the speed limit decreased by 45%. They confirmed previous studies' findings stating that the system was more effective in reducing excessive speeding behaviour (Montella, et al., 2015).

In addition to speed enforcement, ASOD is used for purposes such as variable speed limit enforcement, tracking of stolen vehicles, lane and toll enforcement, identification of unlicensed and unroadworthy vehicles, and crime intelligence.

ASOD enforcement is a relatively new technology, especially in South Africa. It was first introduced in 2010 in the KwaZulu-Natal province as a pilot on the N3 between Nottingham Road interchange and Balgowan interchange.

The technology was later introduced into the Western Cape Province in 2011 on the R61 between Beaufort West and Aberdeen. Before the implementation of ASOD on the R61, there was a total of 509 accidents within a 12-year period. 75 of these were fatal accidents, resulting in the death of 149 people. (October, 2015)

The installations of these sites in the Western Cape are either utility powered (by Eskom or the local authorities) or solar powered, as may be seen in Figure 2.2 and Figure 2.3.

**Figure 2.2: Solar powered ANPR site with ANPR cameras, solar panels and wind turbines**


**Figure 2.3: Image displaying 120 km/h Average Speed Enforcement road sign with ANPR site in the background**

The application of ASOD in South Africa is unique, as the distances covered by ASOD are much greater than those in the European and other Western countries where the system has been implemented. The pilot project section between Beaufort West and the Eastern Cape border towards Aberdeen covered just over 71 kilometres. This was the longest recorded ASOD-section in the world at that time. This unique setup brought other challenges in terms of the enforcement of the system. The Director of Public Prosecutions gave permission for ASOD to be implemented within only a single magisterial boundary, according to South African law. It would otherwise not have been possible to determine in whose jurisdiction the offences were committed.

In South Africa, the information captured by the ANPR cameras also retrieves the eNATIS information for all the vehicles that pass through the cameras. The information returned by eNATIS allows the system to classify the vehicles so that their respective speed limits can be enforced. These speed limits are:

- 120 km/h for light motor vehicles
- 100 km/h for minibus taxis and buses
- 80 km/h for heavy motor vehicles (with a GVM exceeding 9 000 kg)

The eNATIS system also returns information about vehicles such as licencing status, roadworthy status and clearance marks provided by the South African Police Service (SAPS). All of this information can assist law enforcement officers in their task of making the roads safer. The information can, for example, assist these officers in identifying unroadworthy and unlicensed vehicles – vehicles that have a higher risk of being in an accident.

As part of the Safely Home Campaign, these pamphlets, which can be seen below, were handed out to the public to explain the ASOD system:

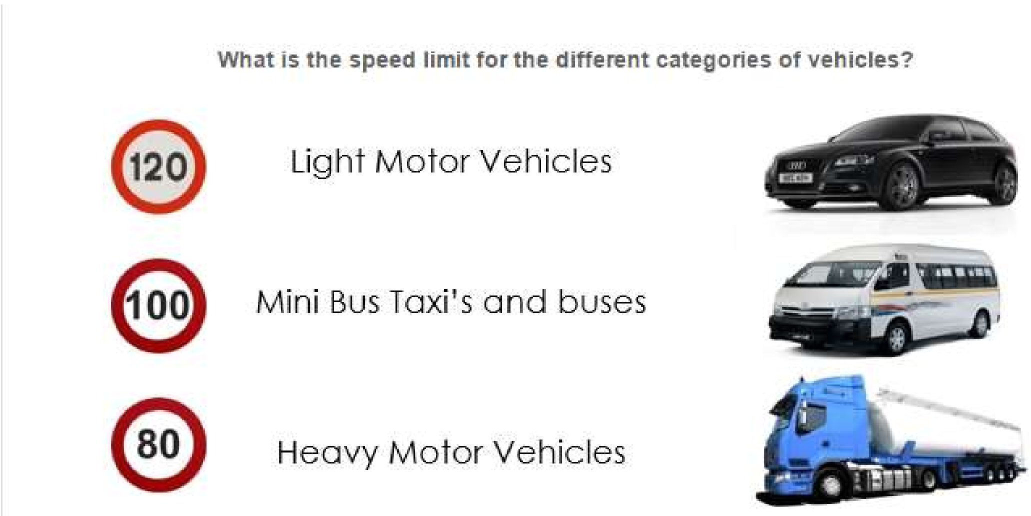


**Figure 2.4: Pamphlet explaining the speed limits for the different vehicle classes**

### LICENSING PLATES:

If you are driving with a licensing plate that is not to the standard as prescribed i.e.:

A. Licensing Plates **MUST** be affixed in the prescribed manner:
   a. Pop-Riveted to …
   b. Must not be concealed/obscured or illegible
   c. Numbering and Lettering must be as prescribed
B. **NOTE: If your vehicle is found not to be in compliance your vehicle may be discontinued**;
C. It is Illegal to drive without Number Plates or False Number Plates

### OVERLOADING:

A. Overloading contributes to a high number of deaths and injuries on our roads;
B. Overloading also causes damage to the road infrastructure amounting to millions of rands;
C. An overloaded vehicle is unbalanced and dangerous!

### DRIVERS:

A. Make sure that the number of passengers and goods do not exceed the specifications on the certificate of the fitness of the vehicle
B. Make sure that loads are safely contained and fastened within the vehicle

### COMMUTERS:

A. Take less luggage on your trip to avoid unnecessary delays and inconvenience
B. Do not distract the Driver while in transit;
C. Always wear your seatbelt;

All drivers of public transport and private vehicles must ensure the safety of their passengers, goods and the safety of other road users.

### ROADWORTHINESS:

A. Ensure that your vehicle is roadworthy before taking a trip by checking that the lights, steering column, shock absorbers, windscreen wipers and brakes are in good working condition;
B. Fit only manufacturer recommended tyres

### ON THE ROAD:

A. KEEP YOUR DISTANCE! *"Two-thousand-and-one… Two-Thousand-and-two…"*
B. When walking on the roads – walk as far right of the road verge facing on coming vehicles as possible and ALWAYS wear bright clothing;
C. Cross the road at designated pedestrian crossings or where it is safe to do so;
D. NEVER walk on the roads while intoxicated;

### FATIGUE:
### YOU ARE GETTING TIRED WHEN:

A. Your eyes start to feel heavy and you can't see too well;
B. You feel uncomfortable, you move around in your seat a lot and you get angry quickly;
C. You don't look carefully at what's happening on the road anymore;
D. It is difficult for you to keep your taxi/bus/heavy- or light motor vehicle on the road;
E. You yawn a lot and feel like you want to sleep;

### STAY FRESH BY:

A. Have a good night's rest before your trip;
B. STOP and REST for at least 15 minutes at every 2 HOUR journey!
C. Talking to your passengers keeps your mind active;
D. DO NOT Travel more than 8 to 10 Hours per day
E. SHARE the driving
F. Take regular fluids while driving –

### ABOVE ALL: BE COURTEOUS ON THE ROAD. KEEP LEFT PASS RIGHT

**Figure 2.5: Pamphlet with road safety information and tips**

The system is only as effective as the actions it requires on the information generated by it. In terms of speed violations, road users can receive two types of notices:

a) Section 56 of the Criminal Procedures Act, 1977 (Act 51 of 1977). This is a notice issued to the driver by a traffic officer at the roadside. The notice summons the respondent to appear before court for the charges listed on the notice.

b) Section 341 of the Criminal Procedures Act, 1977 (Act 51 of 1977). This is a notice of intended prosecution. A Section 341 notice is generated by each municipality's back-office service provider and posted to the registered owner of the vehicle.

In terms of law enforcement, (a) above is much more effective in changing road user behaviour. With (b) owners often cite reasons, like not receiving the notice, as an excuse for non-payment. With (a) – if the driver does not appear in court, a warrant of arrest is issued for that person's arrest. The process of getting a Section 341 notice to the same point in court takes much longer as there are more steps – each with its own lead times - that need to be followed before a warrant of arrest is issued.

The nature of the ASOD system, being completely automated, takes away any opportunity of corruption. The only human intervention is at the roadside – and even then feedback from the law enforcement official is required.

The Western Cape Government has implemented a system whereby traffic officers receive violation information in real time. This information is displayed on a handheld device. This allows a traffic officer to address the offending road user within seconds of a contravention. The contraventions refers to both speed related offences as well as offences generated by the system's interrogation of the eNatis data. An unroadworthy vehicle can, for example, be stopped as it enters the Western Cape Province just outside Beaufort West – thereby reducing the risk of an unroadworthy vehicle causing an accident as it drives through the province. The real-time access to information also allows the traffic officers to work more smartly. They can focus their attention on the vehicles that have violations, rather than running an operation where they stop and check random vehicles and, in the process, miss the vehicles that have contravened.

The ASOD system therefore encourages drivers to adhere to their speed limits at all times. It is not a case where drivers may know locations of fixed speed cameras and therefore just slow down for the camera and the continue speeding again. The nature of the system allows drivers to exceed the speed limit in those cases where they lose concentration momentarily, and exceed the speed limit. They can then immediately reduce their speed and will not be prosecuted for exceeding the speed limit. Over and above speed, the ASOD system also encourages vehicle owners to make sure that their vehicles are licenced and roadworthy.

## 2.8 Conclusion

From Section 2.2 it was learnt that there are several factors that play a role in the causes of road accidents. The two major factors were found to be human factors and vehicle factors.

Section 2.3 discussed the road traffic safety interventions, as determined and monitored by the World Health Organisation.

In Section 2.4 the role of speed as a contributing factor to accidents was discussed. It was found that speed is a major contributing factor in accidents – both as the cause and in its influence on the severity of the accidents.

Sections 2.5, 2.6 and 2.7 discussed the road safety situation and how government has implemented technologies such as ASOD in order to improve road safety by reducing excessive speeds and addressing the problem of un-roadworthy and unlicensed vehicles. The implementation of ASOD in countries such as Scotland, the United Kingdom, Italy and Australia all have yielded positive results.

# 3 Average Speed Over Distance status quo in the Western Cape, South Africa

## 3.1 Site characteristics

The Western Cape is located on the south-western corner of South Africa. The province stretches approximately 400 kilometres north along the Atlantic coast and approximately 500 kilometres along the southern coast. Cape Town is the capital of the province with a population of over three million people. The Western Cape has a live vehicle population of approximately 1 850 000 vehicles, which is divided up into the following categories (approximate figures):

**Table 3.1: Western Cape Live Vehicle Population (Tasima (Pty) Ltd, 2015)**

| **Vehicle Type** | **Number of vehicles** |
|---|---:|
| Heavy vehicle with a GVM exceeding 3 500 kg, e.g. goods truck | 59 000 |
| Light load vehicle with a GVM less than 3 500 kg, e.g. bakkie | 438 000 |
| Heavy passenger vehicle (12 or more passengers) , e.g. bus | 6 500 |
| Light passenger vehicle (less than 12 passengers), e.g. private car | 1 175 000 |
| Minibus | 32 000 |
| Motorcycle / Motor tricycle / Quadrucycle | 86 000 |
| Special / Unknown vehicles | 53 500 |
| **Total** | **1 850 000** |



Note that the figures above reflect only vehicles that are registered in the Western Cape Province. It is not a reflection of all the vehicles on the roads, as vehicles from all the provinces of South Africa make use of the roads.

ASOD has been implemented in the Western Cape since 2011. The locations of all the ANPR cameras in the province are indicated in Figure 3.1.

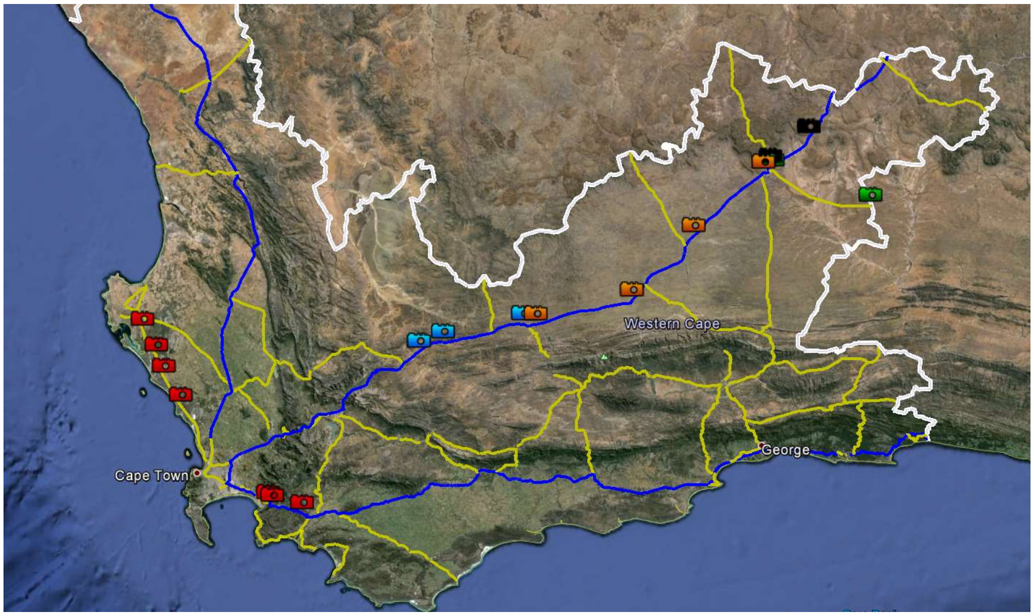


**Figure 3.1: Western Cape Provincial ANPR network (Google Earth, 2013)**

There are cameras on the N1 between the towns of Touwsriver and Nelspoort/Three Sisters, indicated by the blue, orange and black camera icons in Figure 3.1. The N2 is covered between Somerset West, over Sir Lowry's Pass, towards the Houwhoek Pass just before the town of Botriver, as indicated by red camera icons east of Cape Town in Figure 3.1. The R27 West Coast Road is covered between Ganzekraal and the turn-off to the town of Langebaan – indicated by the red camera icons north of Cape Town. The R61 is covered between the town of Beaufort West and the border between the Western Cape and Eastern Cape towards the town of Aberdeen – indicated by the green camera icons.

The N1, R27 and N2 routes as used for this study are explained below.

### 3.1.1 The National Route 1 (N1)

The N1 runs all through the heart of the country from Cape Town all the way to the Zimbabwean border at Musina. In the Western Cape it runs from Cape Town to Three Sisters.

The N1 is covered by various ASOD-sections, implemented from 2012 to 2014:

a) Beaufort West to Riemhoogte (N1 Section 8) implemented in December 2012. (Figure 3.2)

b) Laingsburg to Beaufort West (N1 Sections 5, 6 and 7) implemented in September 2013. There are four ANPR cameras linking three back-to-back ASOD sections. (Figure 3.3). The reason for the three sections is mainly because the stretch between Laingsburg and Beaufort West crosses three magisterial boundaries and enforcement is only allowed within a single magisterial boundary. The middle two of the ANPR sites are on the borders of magisterial boundaries.

c) Touwsriver to Laingsburg (N1 Section 4) implemented in October 2014. There are three ANPR cameras linking two back-to-back ASOD sections. (Figure 3.4). In this case the middle site is also on a magisterial boundary.

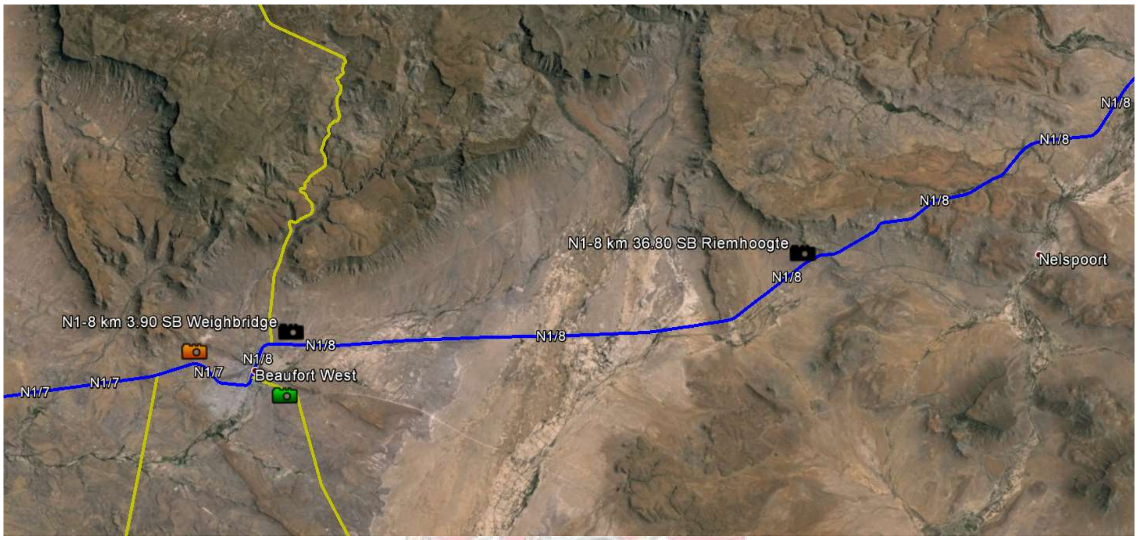


Figure 3.2: N1-8 between Beaufort West and Riemhoogte (Google Earth, 2013)

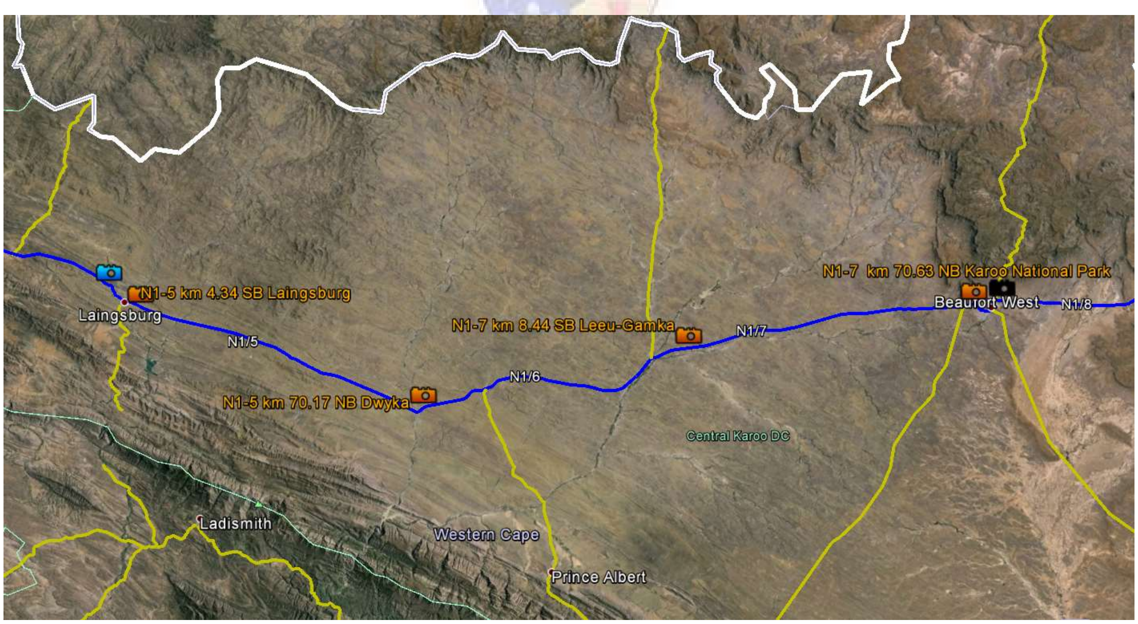


Figure 3.3: N1-5, N1-6 and N1-7 between Laingsburg and Beaufort West (Google Earth, 2013)


**Figure 3.4: N1-4 between Touwsriver and Laingsburg (Google Earth, 2013)**

The above covers approximately 295 kilometres. The only areas without ASOD coverage are immediately around the towns of Laingsburg and Beaufort West.

The general speed limit along all these sections (with the exception of the towns) is 120 km/h. In 2013, the average daily traffic (ADT) was 3370 vehicles. The average daily truck traffic (ADTT) was 1551 trucks, 46% of the ADT. Of these trucks, 75% were classified as long.

The N1 route going north from Touwsriver all the way to Riemhoogte was a very good candidate for ASOD implementation, as this route displayed many similar characteristics to those that Fildes *et al.* (1991) found in their study. These characteristics included the large number of long-distance heavy vehicles on this route. These vehicles have single/dual occupancy and most of their drivers travel along this route on a weekly basis. According to Fildes *et al.* 1991, this makes these drivers good candidates for exceeding the speed limit. Fildes *et al.* state that long distance drivers, as well as single-occupied vehicles' drivers, tend to speed excessively.

This route also carries many long-distance minibus taxis. These vehicles make weekly trips from Cape Town all the way to the Eastern Cape. There is a drive to have the shortest possible turnaround time so that more trips can be made. The passengers also have short periods of leave available for their visits, and thus want to make the best use of the limited time for their visit. The last thing they want is to travel for longer than required. Both of these factors drive the minibus taxi drivers to speed whenever they have the chance. It is to be noted that minibus taxis' speed is limited to 100 km/h.

### 3.1.2 The R27 West Coast Road

The R27 originates in Cape Town and runs all along the West Coast towards the town of Velddrif. Further north it continues from Vanrhynsdorp towards Niewoudtville, leaving the borders of the Western Cape in the process. The R27 eventually joins up with the N14 just before the town of Upington in the Northern Cape.

The section of the R27 between Cape Town and Langebaan has been commonly known as the "West Coast Highway" because of the numerous excessive speeders on the road. This route demonstrates characteristic similarities to the study of Fildes *et al.* There are many young drivers on the road. There are also many drivers who make use of this route for their daily commute from the West Coast towns of Saldanha, Langebaan and Vredenburg to Cape Town for business purposes. The occupancy of these relatively new vehicles is also very low, where in most cases only the driver is present in the vehicle. All these factors contribute to excessive speeding. The trends are somewhat different over weekends, when the majority of road users travel for recreational purposes.

It was for these reasons that this section was also earmarked for ASOD enforcement, with ASOD cameras being implemented since October 2013.

Trunk Route 77 Section 1 (part of the R27) is covered by three back-to-back ASOD sections between the 50.67 km marker and the 108.24 km marker – a total distance of approximately 57 km.

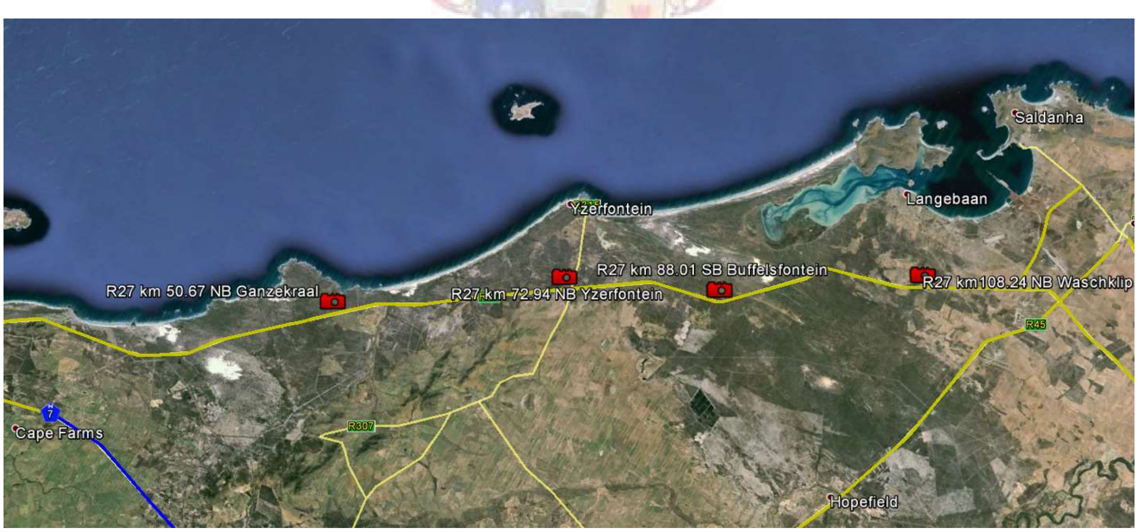


**Figure 3.5: R27 between Cape Town and Langebaan (Google Earth, 2013)**

### 3.1.3 The N2 between Sir Lowry's Pass and the Houwhoek Pass

The N2 over Sir Lowry's Pass carries heavy volumes of daily commute traffic between the farming community of Grabouw and surrounding areas. Heavy volumes are also common over weekends and school holidays, often leading to heavy congestion over the pass, both inbound to Cape Town and outbound towards the South Coast.

Sir Lowry's Pass is a four lane undivided roadway. Road users misjudge the gradient and sharp curves along the route and may speed in the process. The result of this is vehicles that enter the curves too fast causing them to oversteer into either oncoming traffic (head-on-head collisions) or oversteer into the guardrails along the shoulder of the road.

Before the ASOD implementation, there were lane specific speed limits. This had the effect of allowing a slow vehicle in the left lane to pass another even slower vehicle in the left lane by going over to the fast lane. The differential speed, combined with the curved road, led to numerous rear-end collisions.

The pass also has one hairpin bend towards the bottom off the pass – a curve littered with markings of numerous accidents.

The road authority investigated the possibility of installing fixed cameras at three strategic locations along the pass. This idea, however, was flawed in the sense that road users reduce their speed just before the cameras and then easily speed up again after the cameras thereby nullifying their use. The steep gradient of the pass also played a role. Although road signs indicate to road users to make use of their lowest gear to assist with breaking, some vehicles' friction brakes would overheat thereby losing their braking capability. If this were to happen on the way down the pass braking for the speed camera, the vehicle would be unable to brake for the actual hazard. Fixed cameras are also not able to differentiate between different vehicle classes and their respective speed limits. Also, the speed limits for the different lanes posed issues.

Excessive speed in the pass is confirmed by CTO-station data indicating 85$^{th}$ percentile speeds of up to 110 km/h in a 50/70 km/h zone.

The section of the N2 between Sir Lowry's Pass and the Houwhoek Pass takes one past a few informal settlements and numerous at-grade intersections with other arterials. The two-lane carriageway, combined with the high volumes of traffic, do not offer many opportunities for passing. Road users become impatient and then take chances. This leads to head-on collisions, as well as side-swipe accidents.

With all of the above taken into account, it was therefore decided to implement ASOD over Sir Lowry's Pass, continuing on to the foot of the Houwhoek Pass. The main purpose of ASOD over Sir Lowry's Pass was for speed reduction. The section between the Sir Lowry's and Houwhoek Passes was implemented as a traffic calming measure. Sir Lowry's Pass's speed limit was set to 80 km/h for all vehicles. The section between Sir Lowry's Pass and Houwhoek Pass was implemented with a general speed limit of 100 km/h (80 km/h for HMVs). The total distance covered by ASOD on the N2 sums to 28.8 kilometres.


**Figure 3.6: N2 between Somerset West and Houwhoek Pass (Google Earth, 2013)**

## 3.2 Data sources

The data for this project came from three different sources.

### 3.2.1 Provincial and SANRAL CTO's

There are inductive loop CTO-stations which are placed strategically all across the country. These continuous traffic observation (CTO) stations count and classify all vehicles on the road. All installations also allow for the determination of the speed of the vehicles. Traffic counts, by means of loop detectors, is a tried and tested technology and is therefore a reliable source of information. Figure 3.7 and Figure 3.8 are examples of a typical roadside installation.

**Figure 3.7: CTO-station 306 on the N1 close to Touwsriver**

Figure 3.8: CTO-station 306 on the N1 close to Touwsriver (solar powered)

The data is presented in hourly counts (volumes) of vehicles. For each hourly interval there are fields for the volumes of vehicles in each direction, classification as light or heavy vehicles, 85$^{th}$ percentile speeds and the volumes of vehicles in different speed bins of 10 km/h each.

The specific CTO-stations that were used in the research were numbers:

- 480: Beaufort West for the N1-8 between Beaufort West and Riemhoogte. The CTO-station is very close to the ASOD site at Beaufort West, still within the ASOD section and can thus be used as a reflection of speed within the section.
- 5050: Langebaan, for the R27 West Coast Road. This CTO-station lies just (approximately 1.8 km) outside the ASOD section. The road characteristics at the camera and the CTO-station are very similar. It is surmised that the effect of ASOD is still in play just outside the ASOD section. Also, the CTO-station is 1.3 km from a major at-grade intersection. The CTO-station is far enough from the intersection so that the effect of vehicles slowing down for the intersection is not reflected in the count. In terms of this before-and-after study, the intersection was not an effect that changed between before-and-after. Thus, if there had been an effect due to the intersection, it would already have been incorporated in the data.
- 1229: Prins Albert Road, for the N1 between Laingsburg and Beaufort West. There was an issue with this CTO-station, as it is in an 80 km/h zone at the turn-off to Prins Albert. For this reason it did not show a true reflection of the impact of ASOD. It was therefore not used in the analysis.

- 306: Touwsriver North. This CTO-station was used to analyse the effect on speed due to ASOD for the ASOD implementation between Touwsriver and Laingsburg.
- 1243: Sir Lowry's Pass. This CTO is situated in Sir Lowry's Pass, approximately one third of the way up the pass. This CTO-station was used to analyse the effect of implementation of ASOD on the pass.

These specific CTO-stations were chosen as they were the only CTO-stations within the proximity of the ASOD-sections.

### 3.2.2 Industry-provided probe data

Stellenbosch University partnered with TomTom® to enable studies to be made of travel times with the provided probe data.

This probe data makes use of a 'Floating Car Data Methodology'. Floating Car Data (FCD) is a method for measuring speeds and travel times. FCD data is provided by probe devices in the vehicles. These probe devices are most commonly cellular phones and/or GPS devices. As a result, FCD can measure speeds wherever the probe vehicle travels (TomTom, 2014). There are numerous advantages to this form of data collection. These advantages include:

- It does not require any roadside installation and maintenance, thereby reducing the capital cost of installation. This also means that there is no interruption in traffic flow for installation or maintenance purposes.
- There is no risk of theft or vandalism.
- It can measure speeds over long stretches, and in the process also measures variances in the speed.
- It provides accurate data on any trajectory.
- As the method makes use of probes, it is more representative in congested areas where there are more probes. This, in turn, increases accuracy and confidence in the data.
- The fact that the data is uploaded directly to a server means that it replaces an enormous amount of fieldwork. This provides cost savings, which allows the allocation of resources to solve the problems, rather than having to work through vast amounts of data to identify the problem areas.

The probe data provides data on speeds, travel times, percentile travel times and other indicators for all the defined road sections. These can be compared to different time sets, allowing one to differentiate between peak- and off-peak travel times and speeds. It is important to note that all data is anonymised, hence no specific vehicle can be traced with the available data. The probe data for South Africa goes back to the year 2008.

The one major advantage of probe data is that it gives one information along a route, rather than a fixed point – as is the case with a CTO-station. This allows for a more holistic view of the trends.

### 3.2.3 Western Cape Government Accident Database

The data of accidents for which a criminal case was opened, is kept by local police stations for the South African Police Service (SAPS). Alternatively the local authorities might keep accident reports for accidents that happened in their region. The accident information from these sources is captured on the Western Cape Government accident database called iPAS (Integrated Provincial Accident System).

Typical information for each accident contained in the database includes the location of the accident (kilometre marker and GPS coordinate), accident type, cause of the accident, vehicle types, number of people injured or killed in the accident and drivers' information such as age and gender. Below is a summary of typical causes of accidents and accident types:

**Table 3.2: Typical Causes of Accident (Source: iPAS)**

| **Causes of Accidents** | | |
|---|---|---|
| Animals in road | Entering traffic while conditions were unsafe | Passenger fell out of vehicle |
| Aquaplaning | Failing to keep left | Pedestrian |
| Bicycle | Falling asleep / blacking out | Poor visibility |
| Blinded | Falling object | Pothole |
| Passing a vehicle that turned | Hit and run | Severe weather conditions |
| Passing distance too close | Ignoring barrier lines | Slippery road – gravel |
| Passing on left side | Ignoring stop sign | Slippery road – oil |
| Passing with oncoming traffic | Ignoring traffic signal | Slippery road – wet |
| Change lane while unsafe | Insufficient following distance | Sudden stop |
| Cut in front of another vehicle | Lost control | Swerving |
| Driving on wrong side of the road | Making U-turn when unsafe | Turning in face of oncoming traffic |
| Driver error | Mechanical problems | Tyre burst |

| | | |
|---|---|---|
| Driving too fast | Object in road | Vehicle reversed |
| Drunk in charge | Parking in dangerous situation | |
| Drunk pedestrian | Parking without lights | |

**Table 3.3: Typical Accident Types (Source: iPAS)**

| **Accident Type** | | |
|---|---|---|
| Accident with animal | Approach at angle – one or both turning | Head/Rear end |
| Accident with fixed/other object | Approach at angle – both travelling straight | Jack knife |
| Accident with pedestrian | Head on | Other |
| Reversing | Single vehicle overturned | Turn right from wrong lane |
| Sideswipe – opposite direction | Single vehicle: left the road | Turn right in face of oncoming traffic |
| Side swipe – same direction | Turn left from wrong lane | Unknown |

Vanderschuren and Jobanpure made recommendations for the improvement of the data so that better evaluations could be done (Vanderschuren & Jobanpura, 2011). The Western Cape Government has gone to great lengths to ensure that the most accurate accident data is available by, for example, enriching accident reports with the reports from mortuaries. The data for this study was supplied by the Western Cape Government.

## 3.3 Control Section

A before-and-after study for areas covered under ASOD already provides insight into the change in driver behaviour after implementation of ASOD. However, it is important to do a control study on a section of road not covered under ASOD. This would indicate whether ASOD was the sole cause for a change in driver behaviour. By doing a control study, more transparency is also given to this study.

For purposes of this research, the section between Touwsriver and Laingsburg, before the implementation of ASOD, was used as one such control section. The data from CTO-station number 306 was used.

Another CTO-station, 064, between Hanover and Colesburg on the N1, was used as a control section outside the borders of the Western Cape. The road geometry, vehicle classification and other road characteristics are very similar to those found on the N1 between Beaufort West and Riemhoogte. Thus the data from this CTO-station was a good control for the ASOD section.

Seasonality and other trends that might have influenced the conclusions drawn from the ASOD study have been highlighted in this study.

On the R27, a CTO-station south of the ASOD sections just before the Atlantis turn-off (CTO-station number 5029) was considered, but the data could not be used as the traffic volumes and classification did not reflect the characteristics of the traffic within the ASOD-sections. Many vehicles, especially public transport vehicles, turn off at Atlantis.

With the above taken into consideration, a section of road north of the Langebaan turn-off was considered as a control study area. There is no CTO-traffic station north of Langebaan, thus the industry-provided probe data was considered for a control section analysis. A section of road that reflected the same topographical geometry, horizontal and vertical alignment, was chosen for this purpose.

# 4 Methodology

## 4.1 Introduction

Following from the literature reviewed in Chapter 2, the following parameters were identified as those to be investigated in this study with the implementation of Average Speed Over Distance enforcement:

- Reduction in the speed of vehicles on the road
- Reduction in the number of accidents

## 4.2 Hypothesis

From the literature review, it is expected that there is a relationship between road speed and accidents. The literature also indicates that Average Speed over Distance is an effective enforcement tool for reducing speed on roadways. This is yet to be proven in the Western Cape.

It is therefore hypothesised that the implementation of Average Speed over Distance cameras on the N1, N2 and R27 routes in the Western Cape have brought about a significant reduction in excessive speeding by motorists.

A case is made in the literature review for the reduction of accidents brought about the reduction in speed, thereby improving road safety in the Western Cape. If the hypothesis relating the speed holds true, the accident statistics should also indicate a downward trend.

## 4.3 Research approach

The qualitative research design method was used in this study whereby the hypothesis was to be proved or disproved by means of mathematical and statistical analyses. A control group was also included. Three different sets of data were examined.

The data obtained from the CTOs formed the basis of the experimental design. The raw data from the CTOs was converted to usable data. This usable data formed the basis input to a statistical analysis. The statistical analysis aimed at determining and quantifying the effect of the intervention of ASOD on the speeds of vehicles travelled. The routes were analysed separately and conclusions drawn for each analysis. Correlations were also drawn between the analyses.

The industry-provided probe data was also analysed, first for the possibility of using it in a similar application to that of the CTO data, and secondly, as a control measure to the CTO data.

Both the CTO and the probe datasets were used to examine the effect of ASOD on speed. The accident data was used to examine the effect of ASOD on accident occurrence and severity.

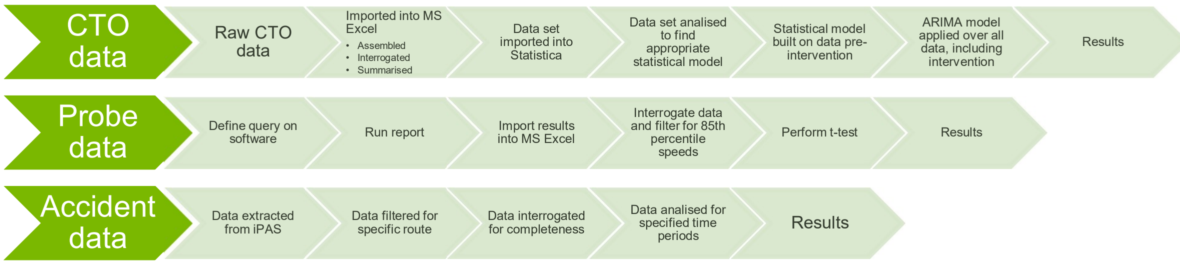


**Figure 4.1: Experimental flow**

In order to determine the effect of ASOD implementation, a statistical analysis was conducted on the data from the CTO's. The road and traffic environment was assumed constant, and the effect on crashes due to a change in speed is examined.

Specific focus was put on the fields for vehicles travelling in excess of 10 km/h of the posted speed limit. In terms of the Traffic Law Enforcement Offence Code Book, drivers have a 10 km/h over the speed limit grace before they are prosecuted (Western Cape Government Provincial Traffic, 2014). Thus, compliance is regarded as anything below 130 km/h. The speed limit varied for the different routes in this study:

- The N1 and the R27 routes both had speed limits of 120 km/h.
- The N2 over Sir Lowry's Pass had a speed limit of 80 km/h.
- The N2 between Sir Lowry's Pass and Houwhoek pass had a speed limit of 100 km/h.

Heavy vehicles have a speed limit of 80 km/h, whereas minibus taxis and buses are restricted to 100 km/h. This differentiation, however, was not accounted for in the analysis as the data did not differentiate between vehicle classes.

Additional to the above, a benefit-cost analysis was conducted on the implementation of ASOD on the N1-8 between Beaufort West and Three Sisters in December 2012. Several factors were included in this analysis. These included:

Costs:

- Initial costs such as the costs of construction, purchasing of the equipment and the installation and commissioning of the sites
- Recurring monthly costs to keep the sites running. These include routine maintenance, networking costs, electricity and monitoring costs
- Recurring annual costs for the running of the system

- Rehabilitation costs for the replacement of old and faulty equipment

The benefits that were investigated as regards their positive and negative effects were:

- Travel time
- Vehicle costs
- Safety and accidents
- Emissions
- Induced travel
- Travel time reliability
- Noise
- Construction disbenefits
- Economic effects
- Community impacts

The details of each of these factors are discussed in the next chapter.

The data collection exercise focused on the data obtained for the time series analysis, as well as the accident data that was used for the accident analysis, as part of this study. Supplementary information was obtained from the Western Cape Government and its implementing agent. The research was also informed by interviews with the relevant parties and the researcher's first-hand experiences.

### 4.3.1 CTO Data source and clean-up

The data was captured on Microsoft Excel spreadsheets. Each spreadsheet represented one direction of travel, with direction 1 being northbound and direction 2 being southbound. For each, the following fields were provided as in Table 4.1:

**Table 4.1: CTO Station data**

| Date Time | Duration | Total | Light | Heavy | Volume 0-60 | Volume 60-70 | Volume 70-80 | Volume 80-90 | Volume 90-100 | Volume 100-110 | Volume 110-120 | Volume 120-130 | Volume 130-140 | Volume 140 > |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Each line in the spreadsheet represented one calendar month. The data for both directions were then added together to give a total for the road.

The data was available in smaller intervals such as daily volumes (number of vehicles) or even 15-minute intervals. This detail, however, was not required for this study as the great variances between, for example, day-to-day volumes would have made it difficult to fit a time-series model to the data. The monthly data gave a much better reflection of the traffic volumes over time.

It was also possible to have the data provided for each class of vehicle. The four vehicle classes were:

- Class 1: Light motor vehicles. Typically with a GVM less than 3500 kilograms. This includes motorcycles, motor tricycles and motor vehicles.
- Class 2: Short heavy motor vehicles. Typically, heavy motor vehicles with a GVM between 3500 kilograms and 9000 kilograms, would be classified as Class 2. Light delivery vehicles and minibus taxis would also sometimes be classified as Class 2 because of their height. The inductive loops use the height of vehicles as an input to the classification.
- Class 3: Medium heavy motor vehicles: Typically, three- or four axle heavy motor vehicles with a GVM exceeding 9000 kilograms.
- Class 4: Long heavy motor vehicles: Typically double axle heavy motor vehicles (GVM exceeding 9000 kilograms) with semi-trailers. Five- or more axles.

The fact that some minibus taxis would be classified as Class 1 and other as Class 2 vehicles, as well as buses being classified as either Class 3 or Class 4 vehicles, it was not possible to make the differentiation between the classes for specific speed limits. Ideally, on a road with a GSL of 120 km/h, one would want Class 1 vehicles governed by a speed limit of 120 km/h, Class 2 vehicles 100 km/h and Classes 3 and 4 as 80 km/h. This is not possible with the current loop infrastructure and technology.

The data included the duration of the count. This duration is the length of time that the CTO-station was operational during that month. For purposes of completeness, all months that had recorded fewer than 600 hours of operational time were excluded from the study. The minimum of a 28-day month was taken as a benchmark. 28-days translated into 672 hours. A 31-day month has a total of 744 hours. The 600 hour minimum operational time would then reflect 80% of the total hours of a 31-day month.

After the data had been totalled as described above, it was scrutinised for inconsistencies. The further back the data went into history, the poorer the data became. The point at which complete data was captured is noted in the specific analysis of each CTO-station in Chapter 5. This point was used as the starting point of the statistical analysis.

Once all the data had been cleared up and the data for both of the two directions summed, a last field was added to each data set. This field reflected the total volume of vehicles exceeding the speed limit by 10 km/h. On the N1, for example, this was 130 km/h, i.e. the sum of the Volume 130-140 and Volume 140+ fields. The data was imported into the statistical model described in Chapter 4.3.3.

### 4.3.2 Probe data analysis

The probe data used in this study was obtained from the TomTom Traffic Stats portal. The queries were set up so that a before-and-after analysis of the data could be done. An analysis was done on the entire length of the section of the R27 West Coast Road covered by the ASOD-cameras. The analysis also included sections before and after the ASOD-sections, so that one could investigate whether the influence of the cameras went beyond the actual ASOD-sections.

Each dataset had three parameters that needed to be defined. These are:

- Routes
- Dates
- Time Sets

The portal has a limitation of a maximum route length of 15 kilometres. Five back-to-back segments were defined, covering 2.5 kilometres before the start of ASOD and 10 kilometres after the last ASOD-camera. These five segments were defined as the routes.

The dates were chosen so that trends before ASOD could be compared to trends post-ASOD implementation. The month of March was chosen, as the traffic counts indicated this was the month with the highest ADT. This would give the best probe penetration for more representative data.

The portal allows one to define a base time set, usually during free flow conditions. Additional to the base set, one can define six comparative time sets. As part of the results from the queries, comparative factors are given for travel times.

In this study the base set was chosen to be between 19h00 and 07h00 the next morning. The comparative sets were 07h00 – 09h00, 09h00 – 11h00, 11h00 – 13h00, 13h00 – 15h00, 15h00 – 17h00 and 17h00 – 19h00.

The TomTom Traffic Stats Portal generates four output formats for each submitted dataset. These are (1) a KML file, (2) a XLS file, (3) a shapefile and (4) charts that open in the portal. These outputs provide segment, speed and travel time information.

Information contained in these datasets includes:

- Route length
- Average travel time
- Median travel time
- Average speed
- 15th and 85th Percentile speeds
- Average travel time ratio (time set compared to base set's travel time)
- The data is also given, for each segment within the route, for average speed, median speed, percentile travel times, cumulative travel times, relative standard deviation, travel time ratios and percentile speeds. All the above for each comparative time set.

The datasets were defined for three different dates:

- March 2013: pre-ASOD implementation
- March 2014: post-ASOD implementation (ASOD was implemented in October 2013). The five month offset was chosen to allow for drivers to adapt to the new technology.
- March 2016: also post-ASOD implementation. This was used as an additional comparative dataset to March 2013. This dataset will also indicate whether there had been a permanent change in driver behaviour – if there had been a change at all.

The most important variable that was investigated, was the 85th percentile speeds of the different segments during the different data sets. The 85th percentile speed is used extensively in the field of traffic engineering and safety. Over time, the 85th percentile driver has been used to characterise reasonable and prudent behaviour (Donnell, et al., 2009). In the case of the R27, the posted speed limit is 120 km/h and ideally the 85th percentile speed should reflect this speed limit.

These datasets were analysed and compared. A time series analysis was not performed, as had been done with the CTO-data, as there were only three datasets. A statistical t-test for two independent samples was performed in order to test whether there was a significant change in the speeds on the R27. The statistical significance of the t-test indicates whether or not the difference between two groups' averages most probably reflects a significant difference in the population from which these groups were sampled. In this case the population would be all vehicles on the road, whereas the probe data would be the group out of the population tested in the t-test. The results are discussed in Chapter 5.2.

### 4.3.3 Statistical models used in the analysis

A time series analysis was used to analyse the data from the CTO stations as the data was presented sequentially over a long period of time. This allowed for seasonality and long term trends to be built into the model so as to limit the influence of the regression to the mean.

The probe data was analysed by means of a paired t-test. The data was presented in pairs – 85$^{th}$ percentile speeds for March 2013 versus March 2014 for each sub segment along the route.

#### *4.3.3.1 Statistical model – Time Series Analysis*

The data, as presented, from the CTO's is regarded as a univariate time series. The data consists of single observations (month totals) recorded sequentially (monthly) over time.

Univariate refers to the dataset having only one variable. In this case the variable is the total number of vehicles exceeding the 130 km/h threshold (on a road with a speed limit of 120 km/h) accumulated over a month. The monthly totals are the values in the dataset.

The dataset is regarded as a time series model as it is a series of data listed in time order. In this case it is in a monthly order. A time series requires the data to be equi-spaced. This is the case in the analysis as the data is presented on a monthly basis. If a specific month's data was incomplete, it was not used in the time series, else the data would not be equi-spaced.

Cameron *et al.* (2010) concluded that in order to establish a relationship between speed and crashes, a time series study should be undertaken (Cameron, *et al*, 2010).

A time series analysis was deemed an appropriate analytic tool as it accounts for the fact that data points over time, in this case months, have an internal structure that should be accounted for. This structure may reveal itself in forms such as autocorrelations, trends or seasonal variations. (NIST/SEMATECH, 2003). A first look at the vehicular volumes will confirm this motion where one can clearly see seasonal peaks, such as December holidays and Easter weekend traffic.

The seasonal trends only become clear if a long time series is analysed. A five year period will show trends and seasonality clearly. As the data is presented in a monthly format, five years equals to 60 months. Although not all the data sources had such historical data, all usable data was used in this study.

Once the data is modelled in a time series analysis, one can investigate the effects of interventions at specific points in time.

There are various methods of fitting the appropriate time series models to the data, amongst others, the Box-Jenkins ARIMA models, the Box-Jenkins Multivariate models and the Holt-

Winters Exponential Smoothing models. Since the data in this analysis is a univariate data set, the Box-Jenkins ARIMA model was used.

According to Cameron *et al.* 2010, the data set was introduced into Statistica 13® for a time series analysis. Each month was regarded as a ***case*** in the analysis. One year would therefore be represented by twelve cases.

The first step was to plot the monthly volume for the analysed speed (such as 130-140 km/h field) over time for all cases before the intervention. After this the time series was differenced by a factor of one. Differencing makes the time series stationary-the process of eliminating trends and seasonality and stabilising the mean of the time series. This is done by computing the difference between consecutive observations:

$$y'_t = y_{t-} y'_{t-1}$$

A common approach to model a univariate time series such as in this study, is the autoregressive model (AR model). An autoregressive model is a linear regression of the current value of the data set against one or more prior values in the data set. Another common approach for modelling a univariate time series is the moving average model (MA model). The moving average model is a linear regression of the current value of the data set against the white noise of one or more prior values in the data set. Fitting a MA model is more complicated than with an AR model as the error terms are not observable. For this reason the researcher consulted the university's Centre of Statistics to aid in the analysis of the models.

An autoregressive integrated moving average (ARIMA) model is fitted to the data to understand the data using the Box-Jenkins approach.

The autocorrelation function is a tool for finding repeating patterns in the time series within the time lag. The autocorrelation plot shows spikes at lags equal to the seasonal periods. In the case of monthly data, where there is a seasonality effect, one would expect to see spikes at lags 12, 24 and so on (NIST/SEMATECH, 2003). The partial autocorrelation function (PACF) give the partial correlation with its own lagged values. This function aids in determining the appropriate lags for **p** in the ARIMA (**p,d,q**) model.

The Autocorrelation- and Partial Autocorrelation functions were drawn for a total of 24 lags (in this case covering 24-months). These functions were used to determine what kind of ARIMA-model could be fitted to the data. Once this had been determined, the proposed model was fitted on the data and tested for statistical significance.

Box and Jenkins developed an approach where the moving average (MA) and autoregressive (AR) models are incorporated in their book titled "Time Series Analysis: Forecasting and Control"

(Box, Jenkins, and Reinsel, 1994). The systematic methodology suggested by Box and Jenkins made for a powerful class of models. This approach was used in the analysis.

The Box-Jenkins approach suggest the following for model identification:

**Table 4.2: Table for the determination of the ARIMA model (NIST/SEMATECH, 2003)**

| **Shape** | **Indicated Model** |
|---|---|
| **Exponential, decaying to zero** | Autoregressive model. Use the partial autocorrelation plot to identify the order of the autoregressive model. |
| **Alternating positive and negative, decaying to zero** | Autoregressive model. Use the partial autocorrelation plot to help identify the order. |
| **One or more spikes, rest are essentially zero** | Moving average model, order identified by where plot becomes zero. |
| **Decay, starting after a few lags** | Mixed autoregressive and moving average (ARMA) model. |
| **All zero or close to zero** | Data are essentially random. |
| **High values at fixed intervals** | Include seasonal autoregressive term. |
| **No decay to zero** | Series is not stationary. |

The Box-Jenkins model assumes that the time series is stationary, hence the step mentioned above where the difference of one is calculated on the time series.

If the model fitted, the Autocorrelation and Partial Autocorrelation functions were drawn again, so as to verify that the model fell within the confidence limits.

Forecasts were calculated based on the determined model and were drawn graphically.

The implementation of the ASOD was regarded as an intervention on the time-series. The month of implementation was taken as the intervention case in the model. The intervention was tested against three models:

- An Abrupt/Permanent intervention. This type of intervention had an immediate effect on the time series. The effect was also permanent. Statistically this implied that the overall mean of the time series shifted after the intervention, denoted by $\omega$ (Omega).
- A Gradual/Permanent intervention. This type of intervention implied that the intervention resulted in a gradual increase or decrease in the pattern, which became evident only after time.

- An Abrupt/Temporary intervention. This type of intervention implied that there was an abrupt increase or decrease due to the intervention, but that this effect slowly decayed without permanently changing the mean of the series.

The above three models were tested for significance and the outcomes of these findings discussed within each section in Chapter 5.

#### *4.3.3.2 Paired t-test*

The probe data was presented for three periods – March 2013 (pre-ASOD implementation), March 2014 (post-ASOD implementation) and March 2016 (control period for post-ASOD implementation). For each sub segment of road as described in Chapter 4.3.2, values for average speed and 85$^{th}$ percentile speed are given.

The value of the t-test is that it can indicate whether a difference in two measurements are statistically significant or just random. The t-test compares two population means where the observations in one sample can be paired with observations in the other sample. In this analysis the March 2013 sample is compared to the March 2014 and March 2016 samples respectively, with each observation being the 85$^{th}$ percentile speed for the sub segment of the route. The confidence level was set at 95%.

## 4.4 Site specific factors

Any study pertaining to speed-related analyses requires a thorough understanding of all the factors that play a role in the specific focus area. Aarts *et al*. (2006) noted in the summary of their review that it is important for researchers to be explicit about the external factors that can influence the study (Aarts & van Schagen, 2006). The following are factors that could have an influence on this study:

### 4.4.1 All sites

There are some factors that have an impact on the data, irrespective of the exact location of the study.

#### *4.4.1.1 Extreme weather*

Extreme weather conditions play a significant role in driver behaviour and the risk of an accident. Drivers tend to drive more cautiously during heavy rains, fog, high winds, hail storms and dust storms (especially applicable in the Karoo-area of the Western Cape). These conditions have an effect of the handling capability of vehicles, thus forcing drivers to drive more slowly in order to keep control of their vehicles.

These extreme weather conditions occur at random times and could therefore not be built into the time-series analysis model. However, these conditions do tend to occur more in specific seasons of the year. Seasonality was built into the model, thereby addressing this factor to some measure.

#### *4.4.1.2 Road works*

Temporary and permanent road works also play a major role in the speed behaviour of motorists. A Stop-Go operation within an ASOD section would mean that the average speed of all motorists would be very low, as there were times within the ASOD section where the vehicles were stationary. Contrary to this, the CTO-stations used for the data are placed at a fixed location. Recording of data is done by these CTO-stations- which may be outside the roadworks. If motorists were forced to stop at the Stop-Go operation, many would have wanted to make up their time, thereby increasing their speed. These higher speeds could then have been recorded at the CTO-station location.

#### *4.4.1.3 Law enforcement*

Law enforcement plays a role in the behaviour of drivers. Visible policing in the forms of patrol vehicles or vehicle check points has an effect on driver behaviour. If drivers know that there are traffic officers at the end of an ASOD-section, they will change their behaviour so as not to speed because they do not want to be fined.

Irrespective of real time law enforcement, if the back-office process of issuing Section 341 works well, drivers will also change their behaviour. But if this process is not administered properly, drivers will quickly learn that their behaviour is not condemned and then they will go back to speeding.

#### *4.4.1.4 Other factors*

Other factors that could play a role in the speed characteristics of the road include major accidents, when they cause traffic to back up on the road. Although this seems significant, the effect of such an incident is small compared to a month's data. If an incident had caused a major disruption over more than one day, this exception was eliminated in the statistical model.

High volumes of traffic, especially during holiday periods such as the Easter weekend and the December holiday period, could also influence the speeds on the road. Heavy volumes do not give drivers the opportunity to pass slower vehicles easily. Thus the speed of the entire route slows down. This factor, however, is taken into account in the seasonality that is built into the statistical model.

### 4.4.2 R27 West Coast – CTO-station 5050

The R27 between Langebaan and Cape Town is used mainly for daily commuting between the towns of Velddrif, Langebaan, Vredenburg and Saldanha and the Cape Town Metro. The secondary use of this route is recreational travel over weekends, when residents from the Metro visit the coastal towns. A small percentage of use entails a freight link between the Saldanha – and Cape Town harbours. According to the SANRAL 2013 Yearbook, only 8.8% of the total vehicles were heavy vehicles (Botha, 2013).

The daily counts obtained from the Western Cape Government's RNIS website suggest strong trends in terms of daily volumes. The volumes for Mondays through to Thursdays and Saturdays are consistent. Fridays and Sundays show much higher peaks, due to the recreational travel referred to above. These drastic variations on a weekly basis are difficult to model properly. The monthly data gives a much better overall representation of volumes on this route.

### 4.4.3 National Route 1 – CTO-stations 480 and 064

The N1 carries many more heavy vehicles than the R27. These heavy vehicles are long haul vehicles carrying freight between Gauteng and Cape Town. Station 480 at Beaufort West recorded 46% heavy vehicles, and 064 Hanover Road recorded 47.3% heavy vehicles, in 2013 (Botha, 2013).

CTO-station 480 is situated at the start of the ASOD-section, close to the town of Beaufort West. This could have an effect of the speeds calculated at the CTO-station, as some vehicles, especially heavy vehicles, might not yet have accelerated to their cruise speed.

The fact that heavy vehicles make up a large percentage of the total traffic on the N1, and the fact that their speed limit is 80 km/h, could have an influence on the time series analysis, as the average speeds of light motor vehicles, which cannot easily pass them, is thereby reduced.

### 4.4.4 National Route 2 – CTO-station 1243

The N2 across Sir Lowry's Pass carries mostly daily commuters between the Cape Town metropole and Grabouw and the surrounding areas. The road users therefore differ in their use, as they are daily commuters, whereas on the N1 one would find long-distance travellers, some using the N1 only once a year for vacation purposes.

## 4.5 Summary

In this chapter the research approach was discussed. Three types of data were to be analysed: CTO-station data, probe data and accident data. The CTO data was to be analysed as a time series within an ARIMA model. The probe data was analysed with a paired t-test. The accident data was to be analysed numerically. The different factors necessary to take into account for each of the sites were also discussed. A benefit-cost analysis was also setup for this study. The next chapter will report on this approach.

# 5 Data analysis

Chapter 4 described the research methodology. This chapter aims at following the methodology for each of the sites described in Chapter 3.

## 5.1 CTO-station data analysis for speed and import into a time-series analysis

The data from CTO-stations were processed in MS Excel as described in Chapter 4 and imported into Statistica for the time series analysis.

### 5.1.1 R27 West Coast Road

The data for this time series analysis ran from January 2011 to September 2015, a total of 56 months (cases). The implementation of ASOD was in October 2013, case number 33. Hence a model was developed for cases 1-32. Once the model fit the data, the effect of the intervention was analysed.

#### *5.1.1.1 Time Series transformations dialog*

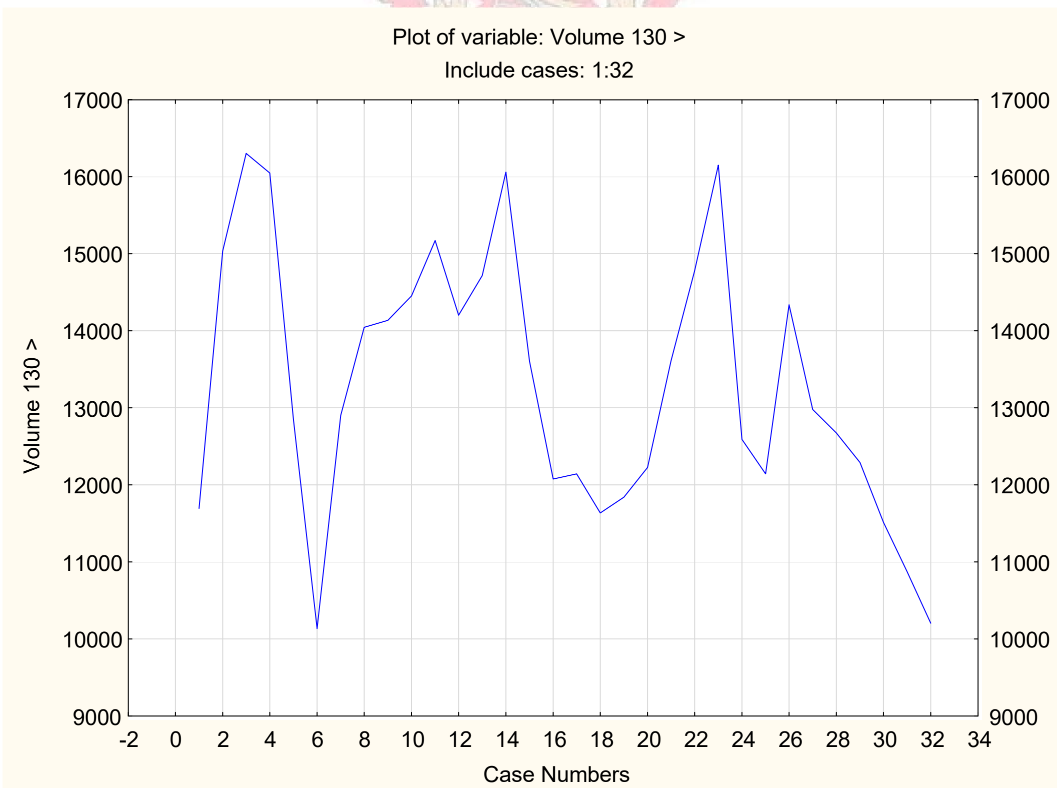


**Figure 5.1: CTO 5050 Plot of variable: Volume >130 km/h pre-intervention**

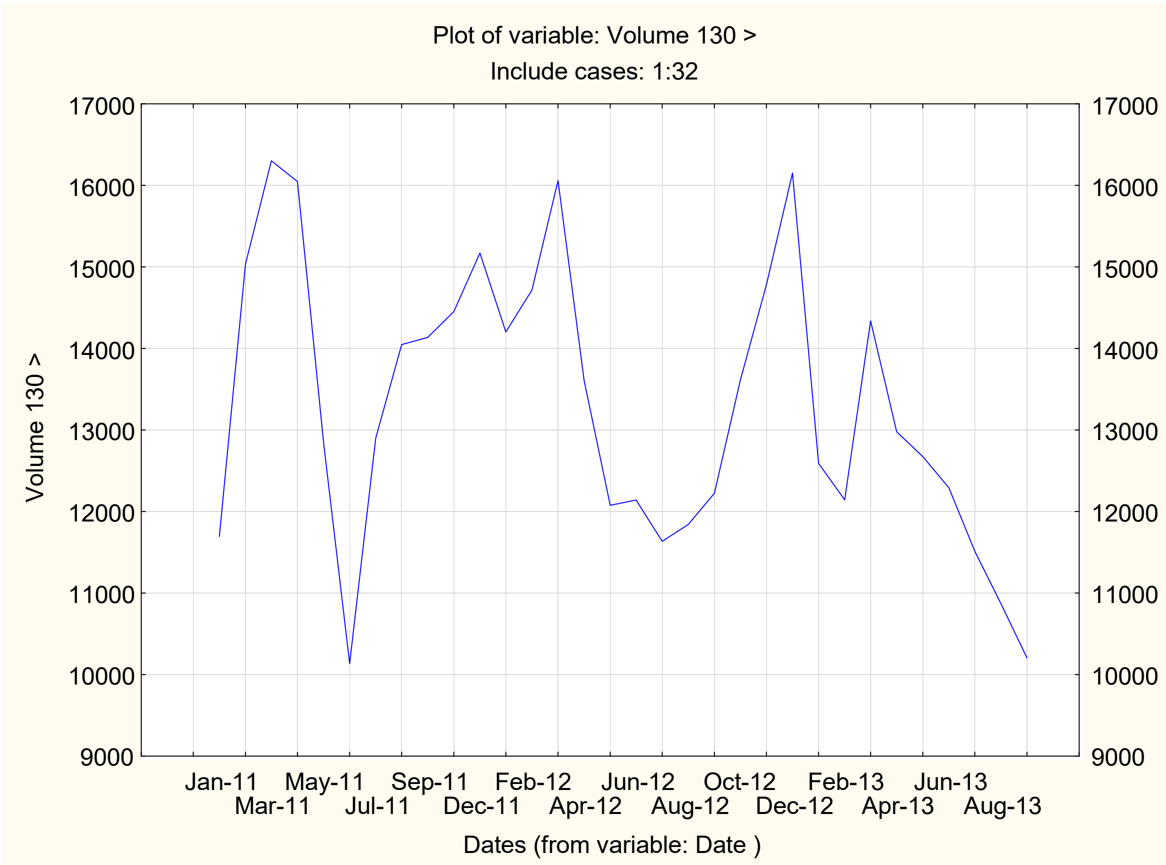


**Figure 5.2: CS5050 Plot of variable: Volume >130 km/h pre-intervention with dates**

The two graphs above plot the number of vehicles exceeding the speed of 130 km/h for each month. Figure 5.1 shows the plot of the data for each of the cases before the intervention. Figure 5.2 shows exactly the same data, only the cases are now displayed as the actual months on the horizontal axis. This also clearly shows that there is some form of seasonality to the volumes. The lower limits correspond with winter months and the higher limits with summer months. This is explained by the fact that one of the main uses of this route is for recreational purposes. People tend not to go up the coast during the cold and wet winter months, but rather during the warm and dry summer months.

It is important to note that the range of 10 000-16 500 vehicles exceeding 130 km/h is part of an average of 140 000 vehicles per month.

A one-order difference (refer paragraph 4.3.2) was done on the data to make the time series stationary. The stationary time series would be used in the Box-Jenkins approach to determine the ARIMA model. The plot of the differentiated data is shown in Figure 5.3.

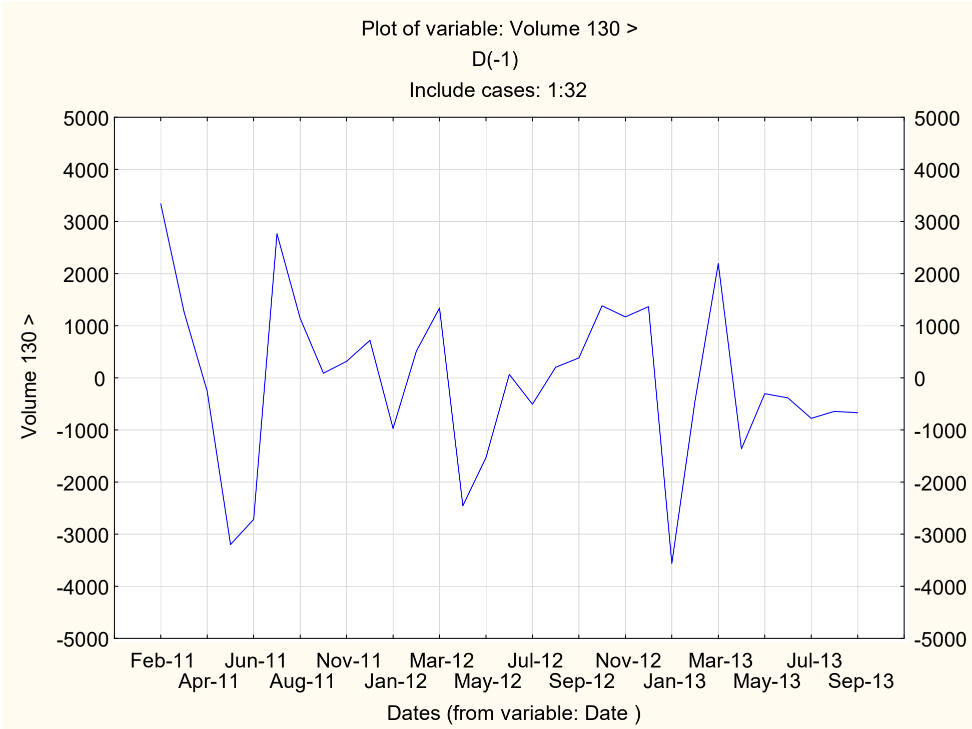


**Figure 5.3: CTO 5050 Plot of variable: Volume >130 km/h pre-intervention with 1 Order Difference**

Both the Autocorrelation (ACF) Figure 5.4 and Partial Autocorrelation Function (PACF) Figure 5.5 have a few spikes, with the other lags essentially zero. As in Table 4.2, the shape of the models suggest that this is a moving average model. The PACF gives the order of the ARIMA-model, in this case an order of 2. A moving average model is essentially a model which regresses linearly against the white noise of one or more of the prior values in the series.

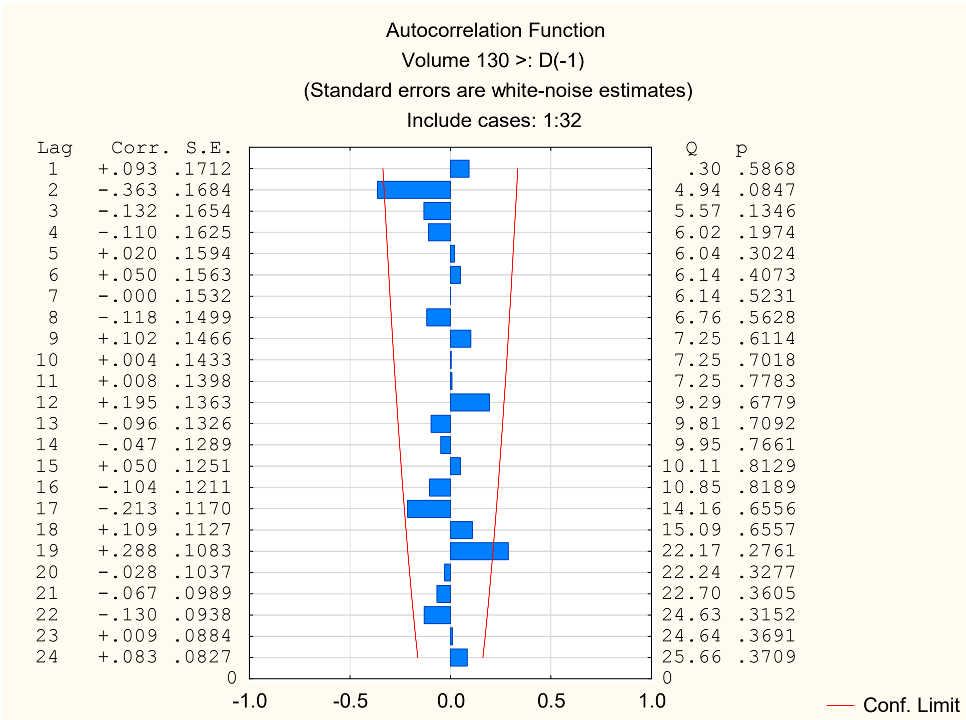


**Figure 5.4: Autocorrelation function for Volume >130 km/h with D(-1) pre-intervention**

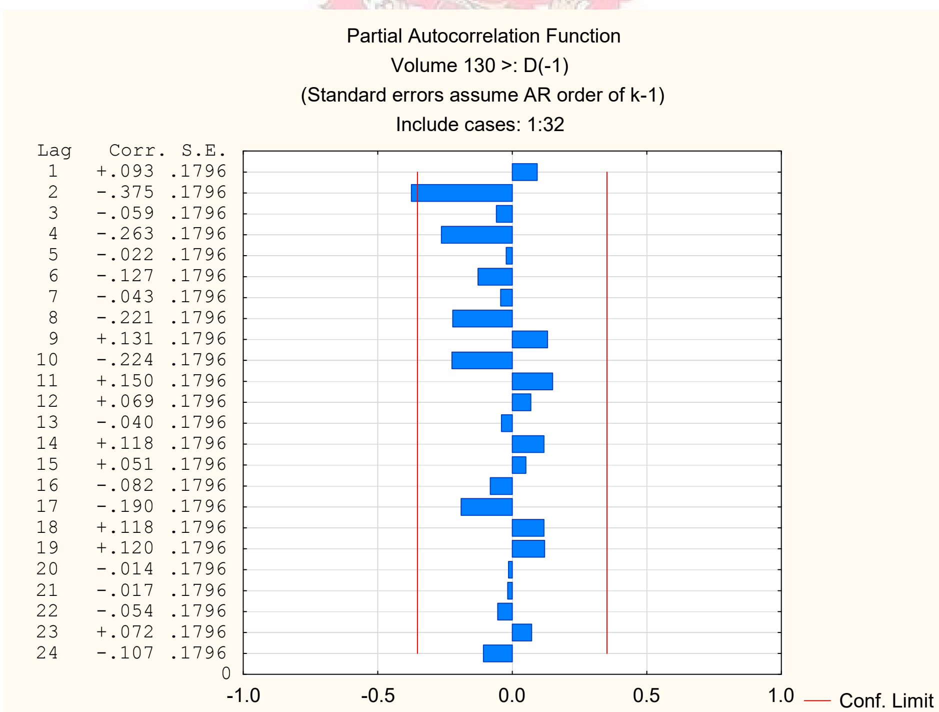


**Figure 5.5: Partial Autocorrelation function for Volume >130 km/h with D(-1) pre-intervention**

### *5.1.1.2 Time Series ARIMA results dialog*

**Table 5.1: MA(2) model for Volume >130km/h with (D-1) pre-intervention**

| | 1<br>Var1 | 2<br>Var2 | 3<br>Var3 | 4<br>Var4 | 5<br>Var5 | 6<br>Var6 | 7<br>Var7 | 8<br>Var8 | 9<br>Var9 | 10<br>Var10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |

A moving average model (MA(2)) was fitted and tested for significance and found to be significant as per the q(2) parameter in Table 5.1.

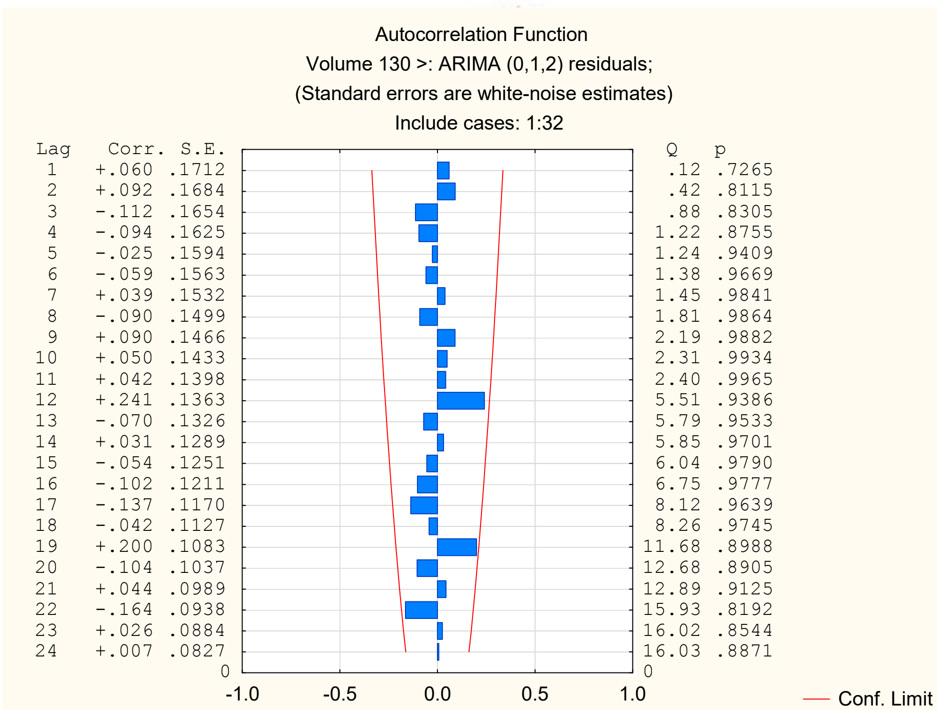


**Figure 5.6: Autocorrelation Function for MA(2) model D(-1)**

Figure 5.6 shows that all the lags fall within the 95% confidence limit – thereby following the suggested model.

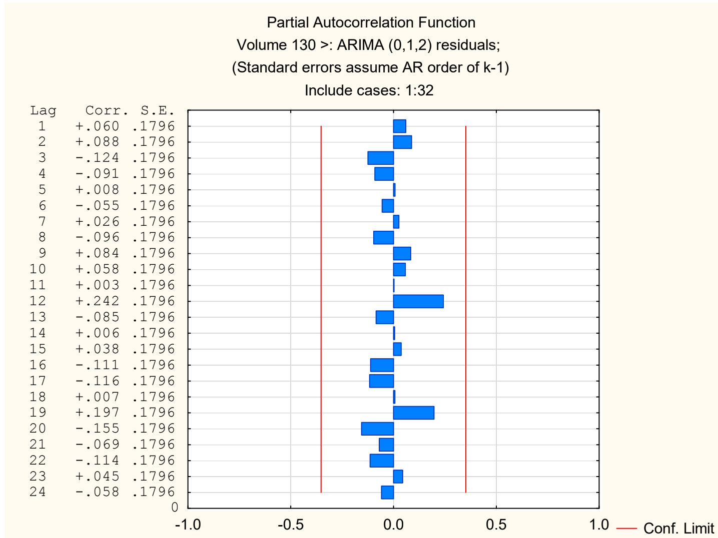


**Figure 5.7: Partial Autocorrelation Function for MA(2) model D(-1)**

The autocorrelation (Figure 5.6) and partial autocorrelation functions (Figure 5.7) both showed that this model falls within the confidence limits, thereby confirming that this (0,1,2) model fits on the time series.

#### *5.1.1.3 Interrupted ARIMA at case 33 (October 2013)*

An interrupted time series analysis was performed on the entire data set in order to determine the effect of the ASOD intervention. In this case, the intervention was in the month of October 2013, Case number 33.

The model was tested for all three types of interventions described in Section 4.3.3.1. The Abrupt-Permanent intervention was found to be significant.

**Table 5.2: Interrupted ARIMA model - Abrupt/Permanent intervention**

| | Input: Volume 130 > (5050_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(0,1,2) MS Residual= 1425E3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 52) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| q(1) | 0.05 | 0.170 | 0.30981 | 0.757942 | -0.29 | 0.39 | | |
| q(2) | 0.5558 | 0.1380 | 4.0286 | 0.0002 | 0.2789 | 0.8326 | | |
| Omega(1) | -3933.4458 | 1343.4119 | -2.9280 | 0.0051 | -6629.1990 | -1237.6925 | 33 | Abr/Perm |

The resultant significant Abrupt/Permanent intervention suggests that the implementation of ASOD had an immediate and lasting effect on the reduction of speed on the R27 West Coast Road. The model reflected a drop of 3 933.45 vehicles in the >130 km/h category. At the Lower 95% confidence level, the number of vehicles reduced by 6 629.20, on average a reduction of 50% after ASOD implementation.

#### *5.1.1.4 Forecasts; Model:(0,1,2) Seasonal lag: 12*

A forecast model for the next 12 months (or cases) was also built to establish what the time series would look like into the future. The following forecast was determined:

**Table 5.3: Forecasts Model MA(2) for CTO 5050**

| | Forecasts; Model:(0,1,2) 1 Interventions (5050_Spee<br>Input: Volume 130 ><br>Start of origin: 1 End of origin: 56 | | | |
|---|---|---|---|---|
| CaseNo. | Forecast | Lower 95.0000% | Upper 95.0000% | Std.Err. |
| 57 | 7368.428 | 4973.055 | 9763.80 | 1193.719 |
| 58 | 7140.730 | 3840.924 | 10440.54 | 1644.438 |
| 59 | 7140.730 | 3710.126 | 10571.33 | 1709.621 |
| 60 | 7140.730 | 3584.134 | 10697.33 | 1772.408 |
| 61 | 7140.730 | 3462.455 | 10819.01 | 1833.046 |
| 62 | 7140.730 | 3344.675 | 10936.79 | 1891.741 |
| 63 | 7140.730 | 3230.440 | 11051.02 | 1948.669 |
| 64 | 7140.730 | 3119.450 | 11162.01 | 2003.980 |
| 65 | 7140.730 | 3011.441 | 11270.02 | 2057.805 |
| 66 | 7140.730 | 2906.187 | 11375.27 | 2110.258 |

Table 5.3 shows the forecasted number of vehicles exceeding 130 km/h for the 12 months following the intervention.

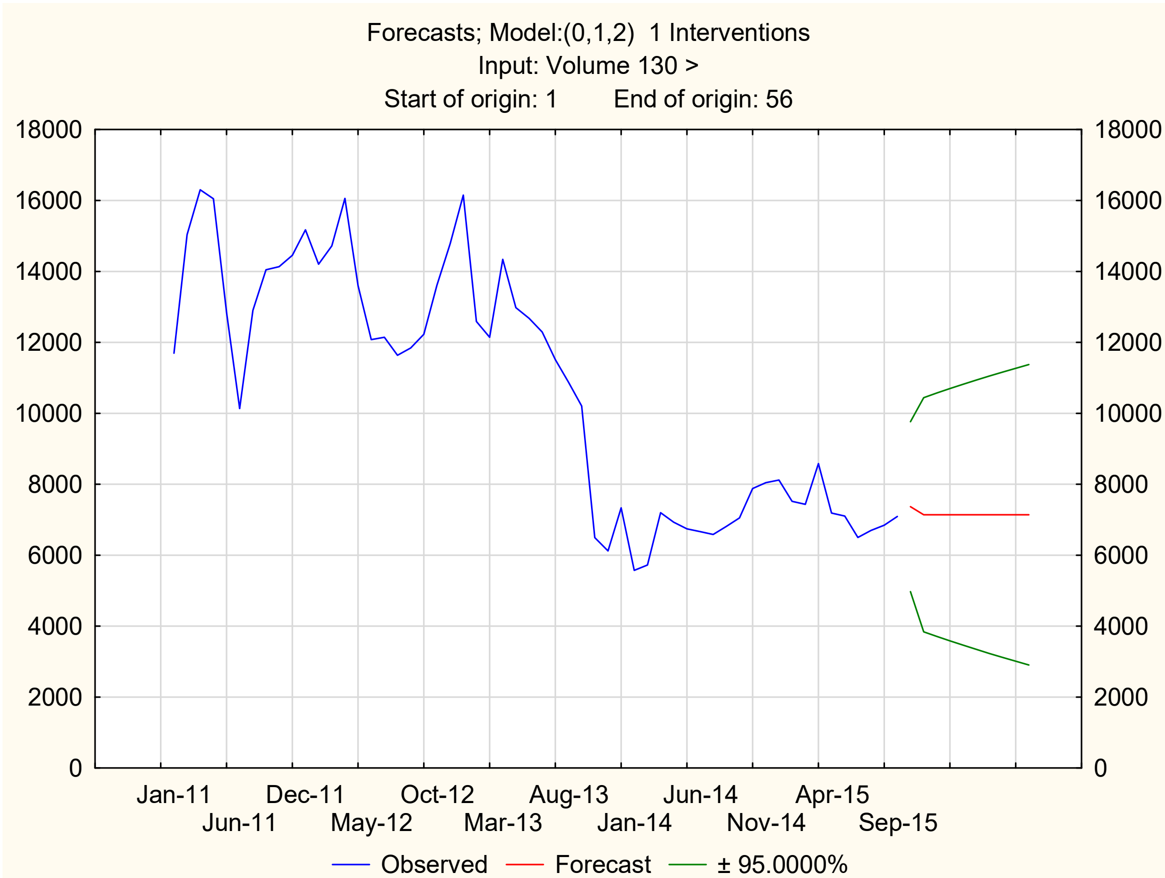


**Figure 5.8: Forecasts model MA(2) for CS5050**

The forecast model, displayed in Figure 5.8, estimated the volume of vehicles travelling at speeds greater than 130 km/h to be around 7140 per month. It is interesting to note that this trend settles at the 7140 vehicles per month mark.

The findings of the above analysis are confirmed by the numerical analysis of the 85th percentile speeds in Figure 5.9. The figure shows that in the months before implementation, the 85th percentile speed was approximately 128 km/h. This measure came down to approximately 122 km/h after the implementation of ASOD. There was a slight increase again, as there was no enforcement. This, however, changed again as enforcement started again in May 2015.

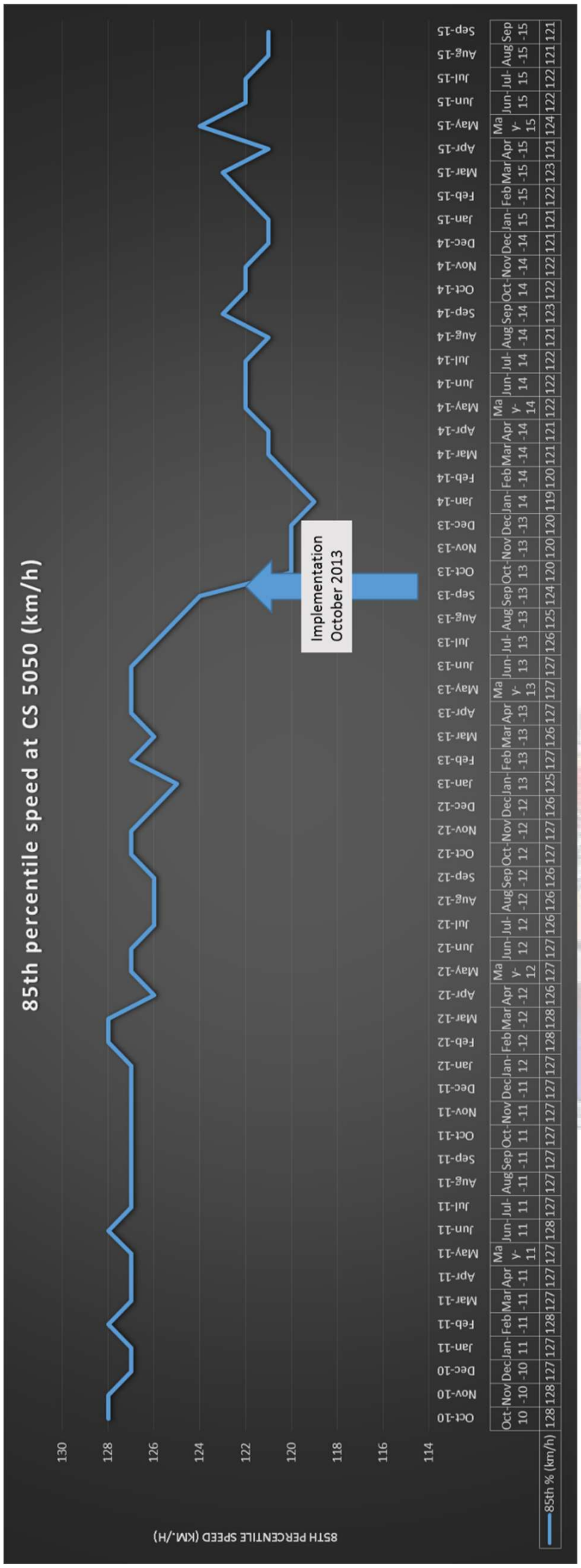


**Figure 5.9: 85th percentile speeds on the R27 at CTO 5050**

### 5.1.2 N1 – CTO-station 306 between Touwsriver and Laingsburg

The data analysed ran from January 2002 to September 2015. The year 2005 was omitted from the data set due to the fact that the data was incomplete. This CTO-station is located within an ASOD stretch that was implemented in October 2014 (case number 133). This was Phase 5 of the Western Cape Government's ASOD roll-out.

#### *5.1.2.1 Time Series transformations dialog*

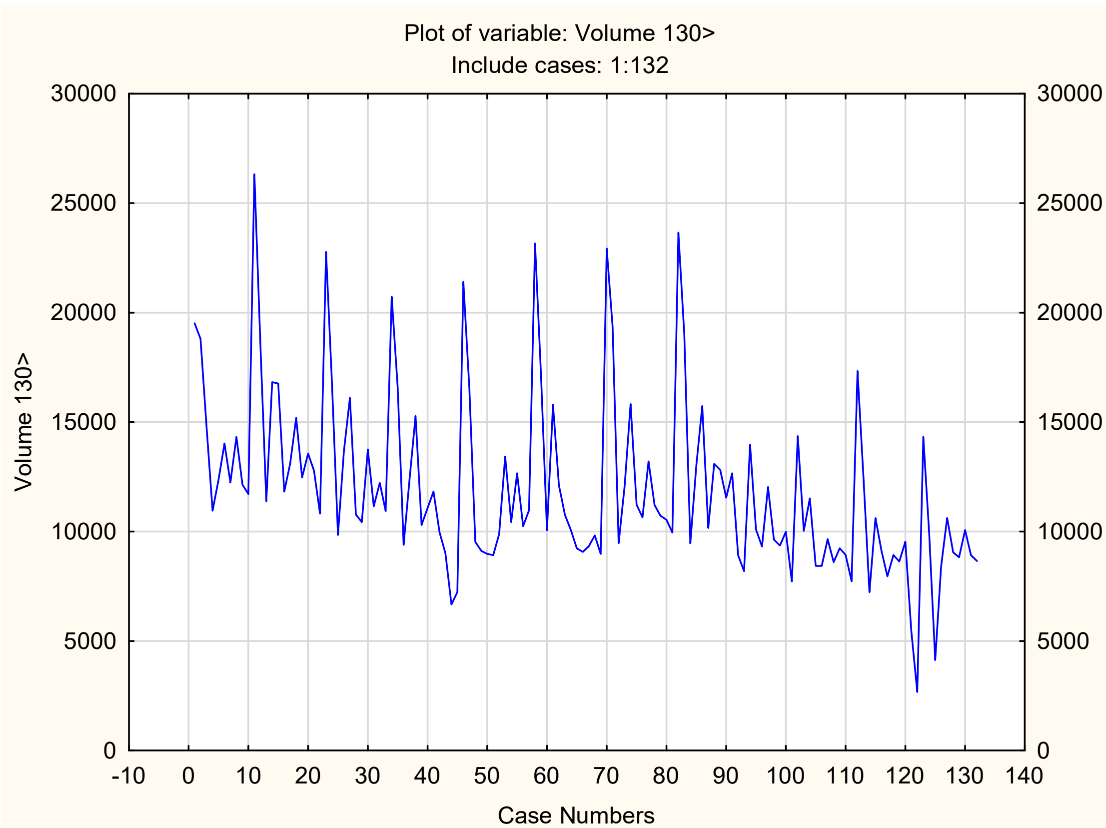


**Figure 5.10: CTO 306 Plot of variable: Volume >130 km/h pre-intervention**

Figure 5.10 shows the plot of the monthly volumes of vehicles exceeding 130 km/h. The peaks in the figure represent the increased volumes over the December holiday periods. This gives a strong seasonality to the time series. The peaks are 12 cases apart, hence 12 months.

Taking the difference of 1 on the time series makes the time series stationery as shown in Figure 5.11.

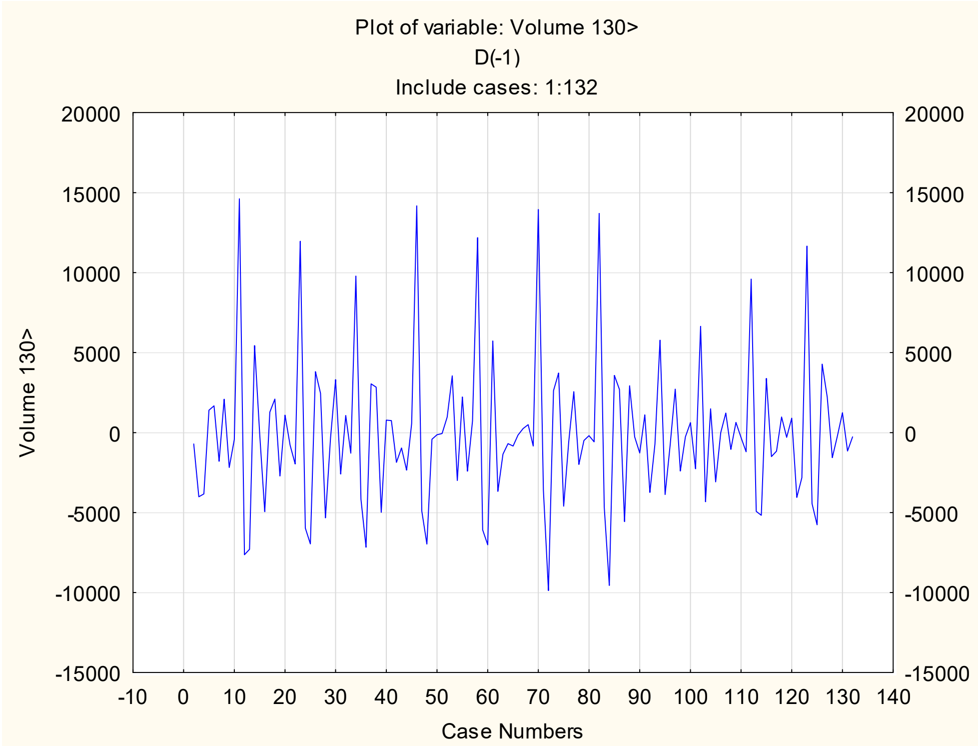


**Figure 5.11: CTO 306: Plot of variable: Volume <130 km/h pre-intervention with 1 Order Difference**

The ACF, Figure 5.12, and PACF, Figure 5.13, both confirm a strong seasonality around the point of 12 months, with an autoregressive nature around the first two lags. With reference to the Box-Jenkins approach, one can deduce that this is an autoregressive model with an order of two (2), as well as a seasonality component every 12 months. Because a seasonal lag of 12 is chosen for the model, the value for P in the ARIMA(p,d,q)(P,D,Q) becomes 1. The figures are found below:

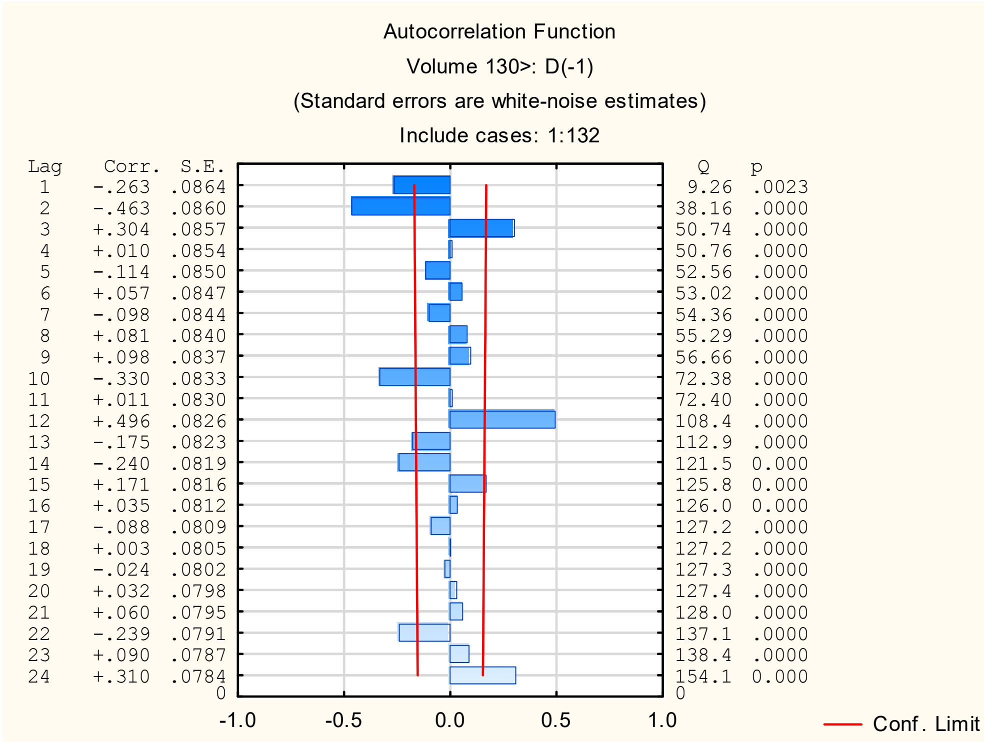


**Figure 5.12: CTO 306: Autocorrelation function for Volume >130 km/h pre-intervention**

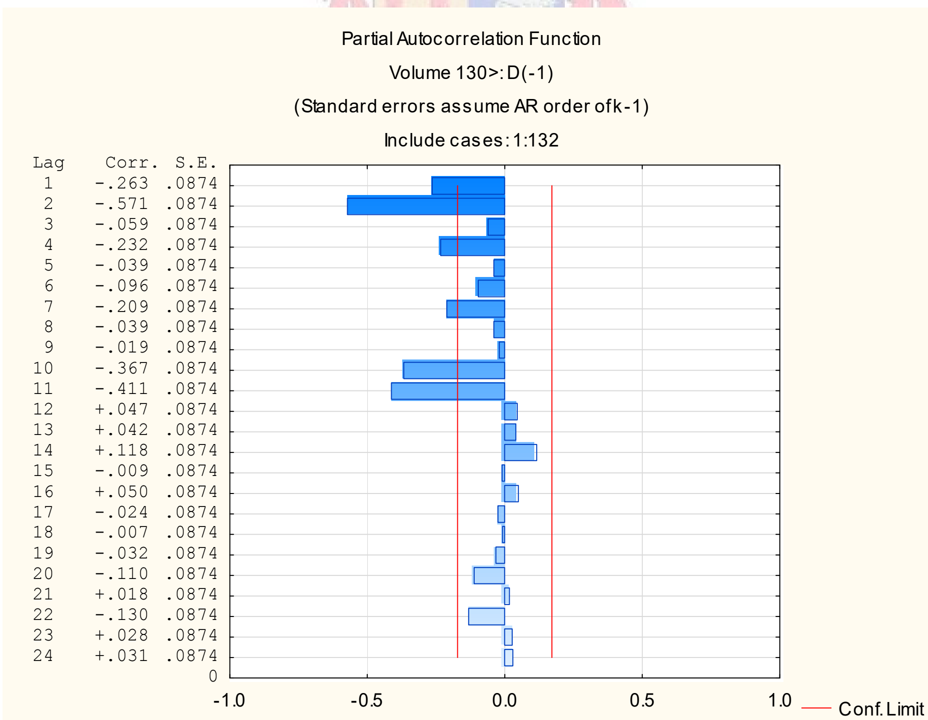


**Figure 5.13: Partial Autocorrelation function for volume >130 km/h pre-intervention**

#### *5.1.2.2 Time Series ARIMA results dialog*

With the above in mind, an ARIMA(2,1,0)(1,0,0) model was developed.

**Table 5.4: ARIMA model for CTO 306 pre-intervention**

| | Input: Volume 130> (306_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1)<br>Model:(2,1,0)(1,0,0) Seasonal lag: 12 MS Residual= 1013E4<br>Include cases: 1:132 | | | | | |
|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 128) | p | Lower 95% Conf | Upper 95% Conf |
| p(1) | -0.516040 | 0.075757 | -6.81177 | 0.000000 | -0.665938 | -0.366141 |
| p(2) | -0.545463 | 0.074512 | -7.32046 | 0.000000 | -0.692898 | -0.398028 |
| Ps(1) | 0.551960 | 0.079173 | 6.97154 | 0.000000 | 0.395302 | 0.708617 |

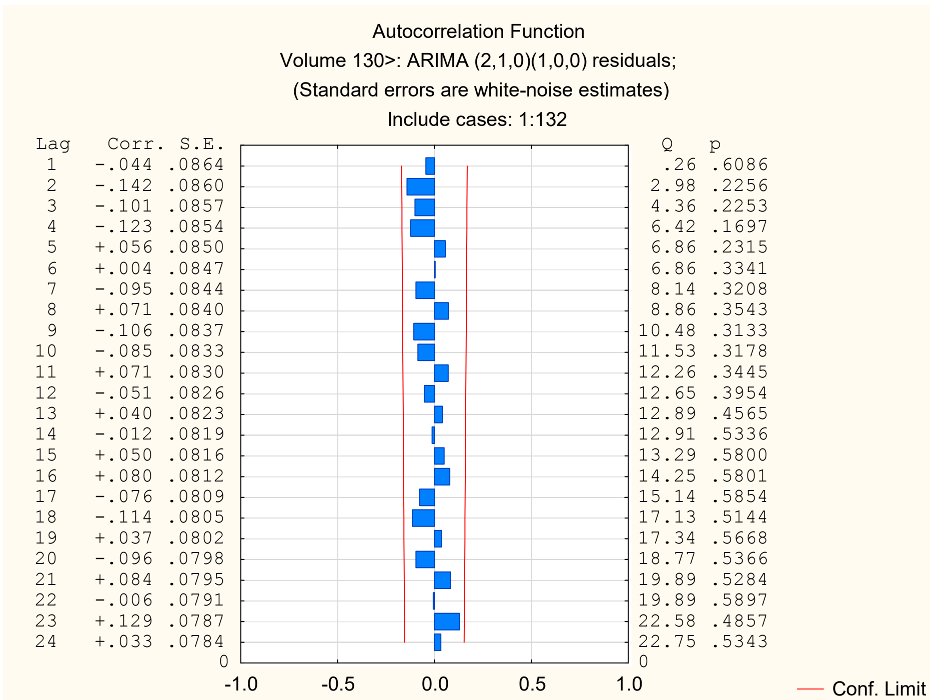


**Figure 5.14: Autocorrelation function for ARIMA (2,1,0)(1,0,0) model for CTO 306**

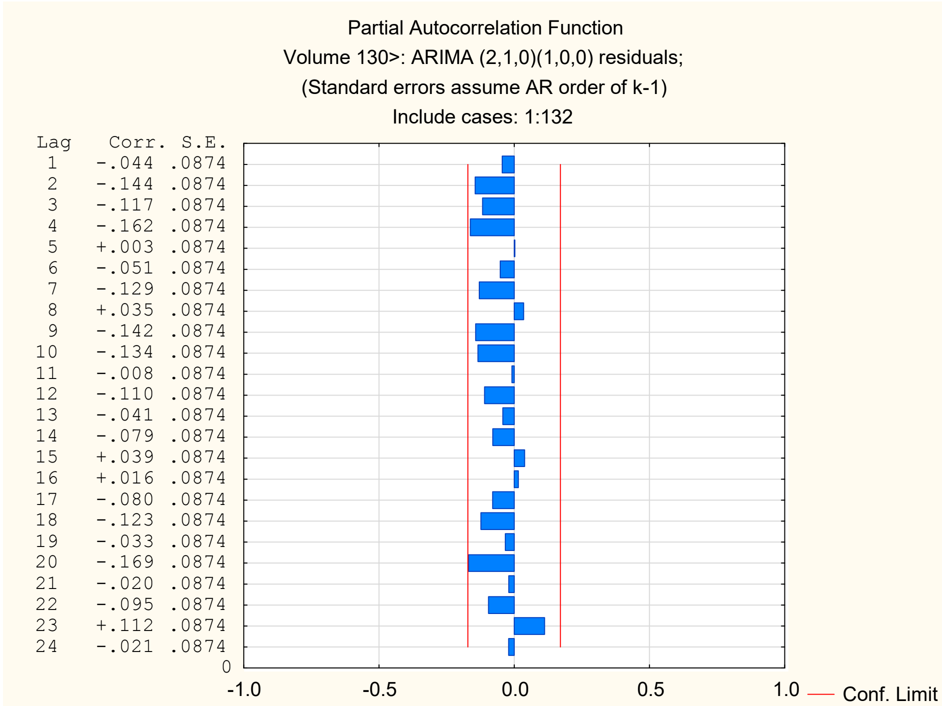


**Figure 5.15: Partial autocorrelation function for ARIMA (2,1,0)(1,0,0) model for CTO 306**

The ACF and PACF (Figure 5.14 and Figure 5.15) confirmed that the model (2,1,0)(1,0,0) fits.

#### *5.1.2.3 Interrupted ARIMA at case 133 (October 2014)*

The implementation of ASOD occurred in October 2014, case number 133. The intervention was tested against the three possible intervention types and found not to be significant for any of the three.

**Table 5.5: Interrupted time series analysis on CTO 306 - Abrupt/Permanent Intervention**

| Paramet. | Input: Volume 130> (306_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(2,1,0)(1,0,0) Seasonal lag: 12 MS Residual= 9383E3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Param. | Asympt. Std.Err. | Asympt. t( 139) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| p(1) | -0.516 | 0.073 | -7.10577 | 0.000000 | -0.66 | -0.372 | | |
| p(2) | -0.545 | 0.071 | -7.62389 | 0.000000 | -0.69 | -0.404 | | |
| Ps(1) | 0.555 | 0.074 | 7.51772 | 0.000000 | 0.41 | 0.701 | | |
| Omega(1) | -262.995 | 2460.715 | -0.10688 | 0.915040 | -5128.26 | 4602.276 | 133 | Abr/Perm |

The Abrupt/Permanent model was not significant for the intervention at case 133, as indicated on the Omega(1) variable in Table 5.5.

The Gradual/Permanent model could not be computed, because of an ill-conditioned matrix. An ill-conditioned matrix is a general term describing a rectangular matrix of values which are unsuitable for use in the analysis. In this case the matrix inverse cannot be computed.

The Abrupt/Temporary model also was not significant, as indicated in Table 5.6.

**Table 5.6: Interrupted time series analysis on CTO 306 - Abrupt/Temporary Intervention**

| Paramet. | Input: Volume 130> (306_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(2,1,0)(1,0,0) Seasonal lag: 12 MS Residual= 9438E3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Param. | Asympt. Std.Err. | Asympt. t( 138) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| p(1) | -0.5160 | 0.073 | -7.08057 | 0.000000 | -0.66 | -0.372 | | |
| p(2) | -0.5450 | 0.072 | -7.59864 | 0.000000 | -0.69 | -0.403 | | |
| Ps(1) | 0.5566 | 0.074 | 7.50216 | 0.000000 | 0.41 | 0.703 | | |
| Omega(1) | 882.7646 | 2540.412 | 0.34749 | 0.728754 | -4140.40 | 5905.930 | 133 | Abr/Temp |
| Delta(1) | 0.8660 | 0.646 | 1.33959 | 0.182580 | -0.41 | 2.144 | 133 | Abr/Temp |

The results above show that there was no significant change in the number of vehicles exceeding the 130 km/h speed threshold on the N1-4 section between Touwsriver and Laingsburg.

### 5.1.3 N1 – CTO-station 480 between Beaufort West and Riemhoogte

CTO-station 480 is located within Phase 2 of the Western Cape Government's ASOD roll-out. It was also the first ASOD-section implemented on the N1. The data goes back as far as the year 1999. Not all years' data was included, because of gaps in the data. Only in years where data was available for the full year, was the data used. This resulted in the following years of data:

- January 1999 – December 2001
- January 2008 – September 2015

The fact that full years' data is used allowed the researcher to model seasonal trends in the data.

ASOD was implemented in December 2012, case number 92.

#### 5.1.3.1 Time Series transformations dialog

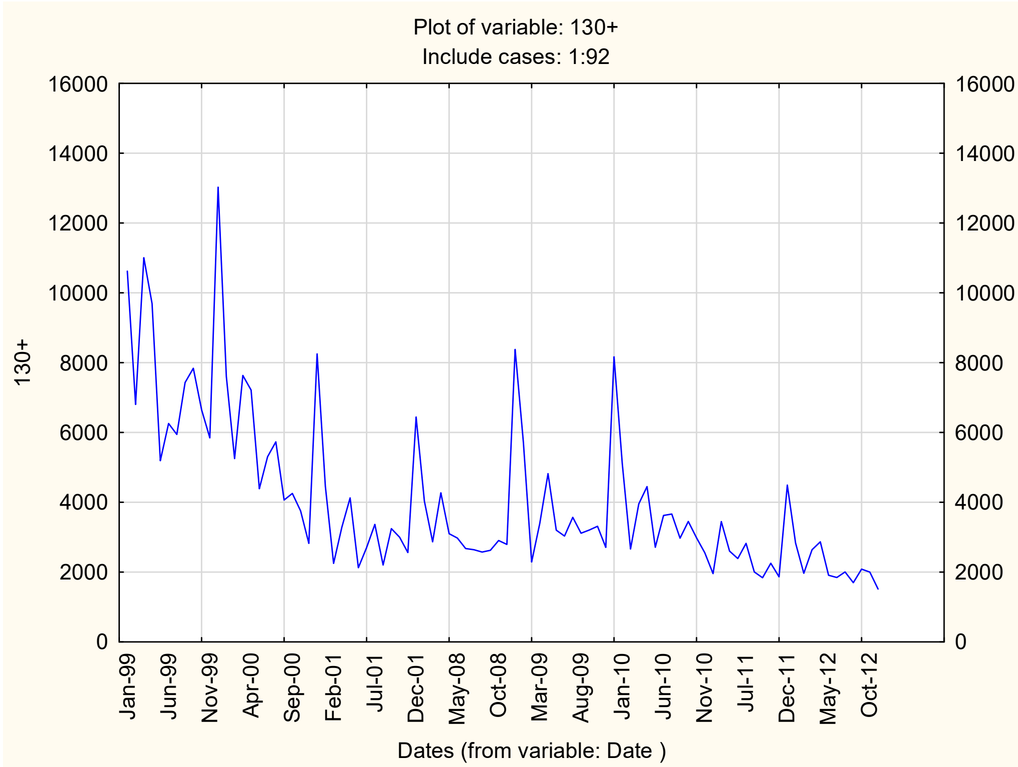


**Figure 5.16: CTO 480 Plot of variable: Volume >130 km/h pre-intervention**

The peaks in the data were for the December holiday periods, the same as with CTO-station number 306.

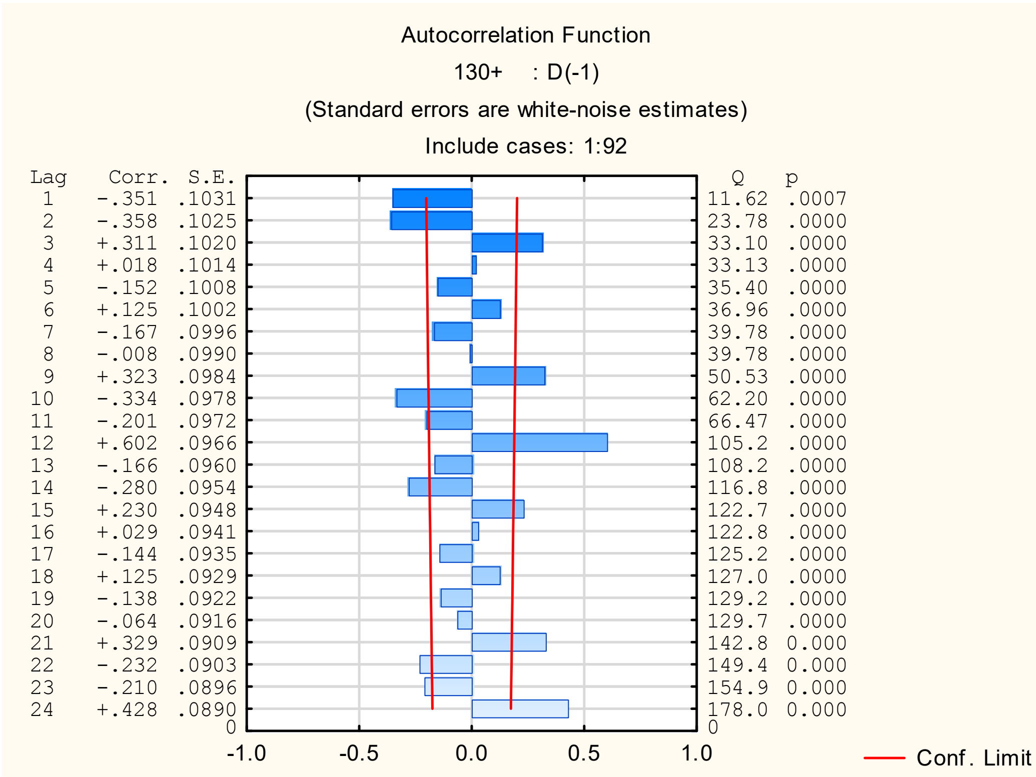


**Figure 5.17: Autocorrelation function for Volume >130 km/h with D(-1) pre-intervention**

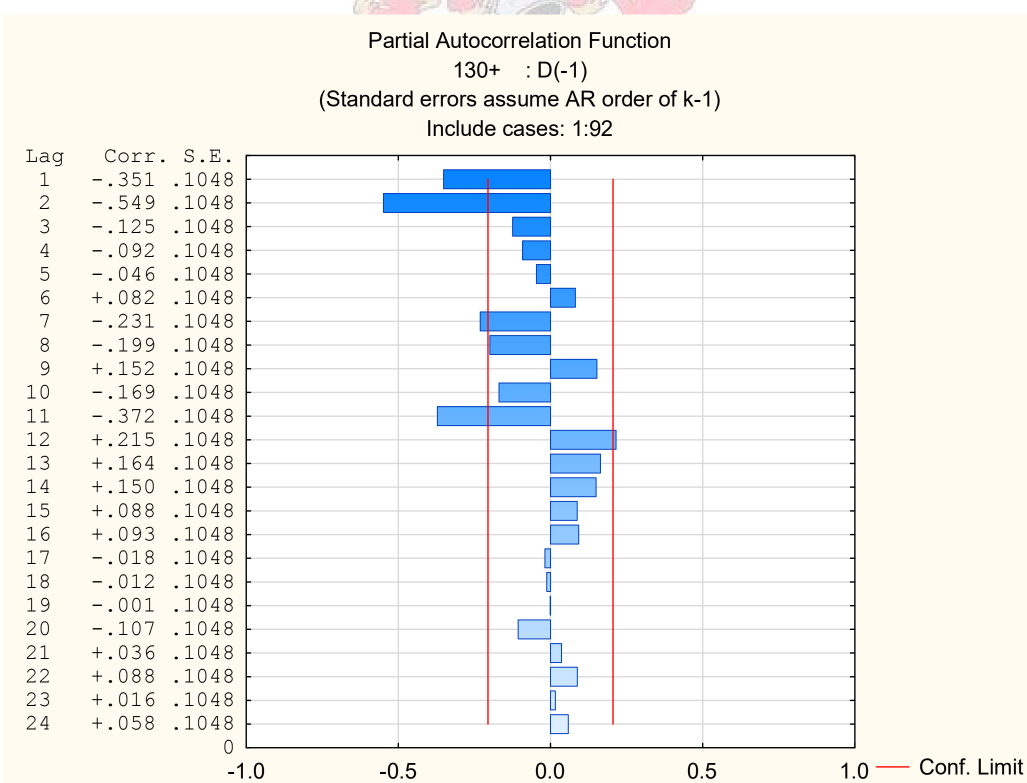


**Figure 5.18: Partial autocorrelation function for Volume >130 km/h with D(-1) pre-intervention**

The ACF, Figure 5.17, has alternating positive and negative lags and PACF, Figure 5.18, both confirm a strong seasonality around the point of 12 months, with an autoregressive nature around the first two lags. Based on the above with the Box-Jenkins approach, an ARIMA (2,1,0)(1,0,0) model was chosen.

#### *5.1.3.2 Time Series ARIMA results dialog*

An ARIMA (2,1,0)(1,0,0) model was constructed on the pre-intervention data and found to be significant.

**Table 5.7: ARIMA model for CTO 480 pre-intervention**

| | Input: 130+ (480_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1)<br>Model:(2,1,0)(1,0,0) Seasonal lag: 12 MS Residual= 1835E3<br>Include cases: 1:92 | | | | | |
|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 88) | p | Lower 95% Conf | Upper 95% Conf |
| p(1) | -0.576886 | 0.097463 | -5.91905 | 0.000000 | -0.770572 | -0.383200 |
| p(2) | -0.420424 | 0.099578 | -4.22205 | 0.000059 | -0.618315 | -0.222534 |
| Ps(1) | 0.580444 | 0.092779 | 6.25622 | 0.000000 | 0.396066 | 0.764822 |

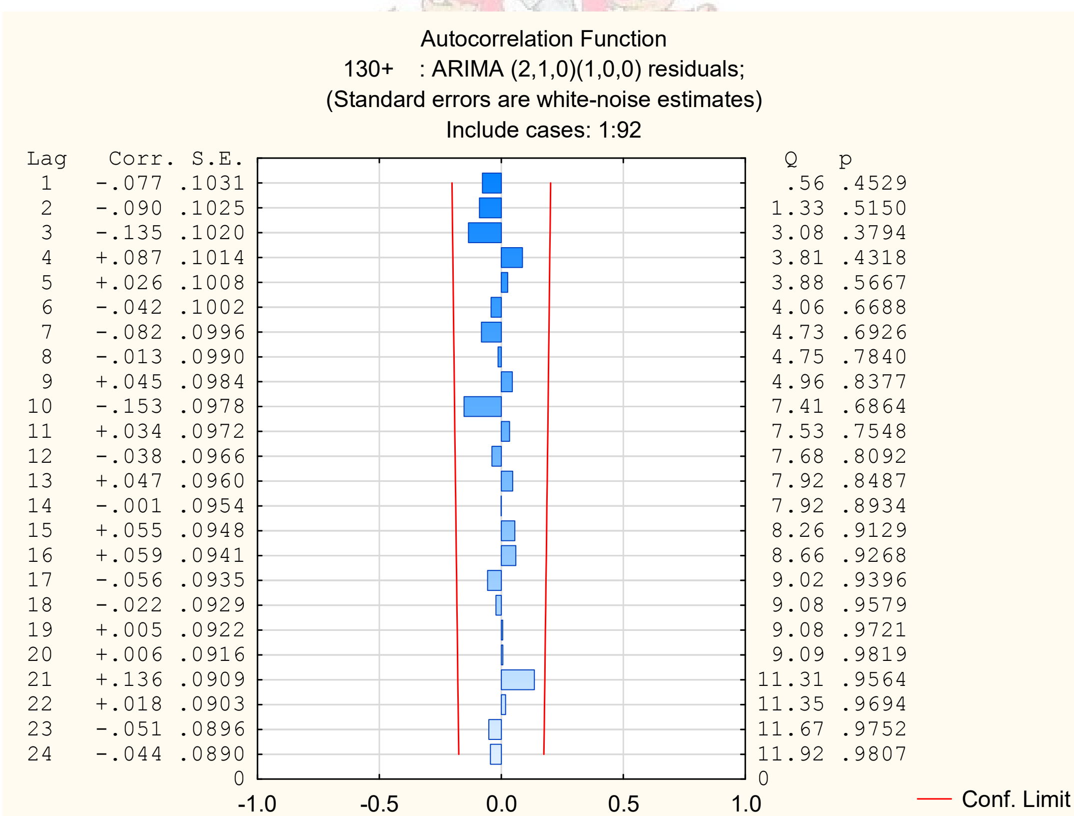


**Figure 5.19: Autocorrelation function for Volume >130 km/h pre-intervention**

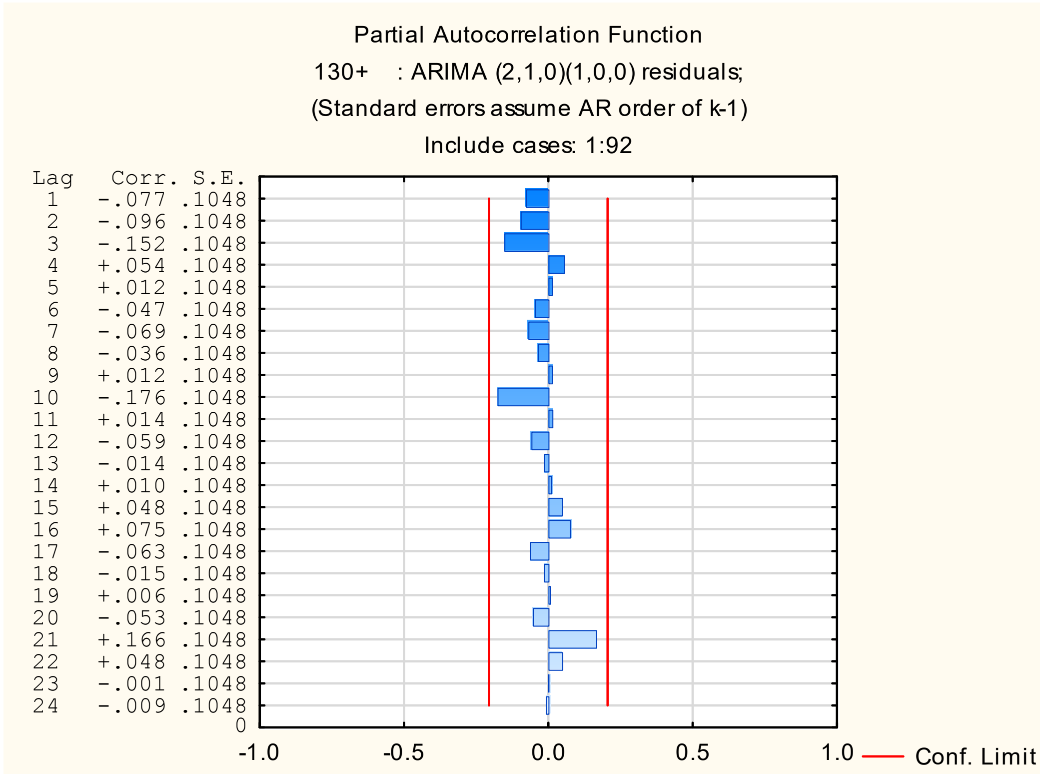


**Figure 5.20: Partial autocorrelation function for Volume >130 km/h pre-intervention**

Figure 5.19 and Figure 5.20 for the ARIMA (2,1,0)(1,0,0) model confirmed that the model fell within the confidence limits.

#### *5.1.3.3 Interrupted ARIMA at case 93 (December 2012)*

An interrupted time series analysis was performed on the entire data set in order to determine the effect of the ASOD intervention. In this case, the intervention was in the month of December 2012, Case number 33.

The model was tested for all three types of intervention described in Chapter 4.3.3.1. None of the three types of interventions were found to be significant.

A numerical analysis of the percentage of vehicles exceeding the speed of 130 km/h confirmed the above. The results of this analysis are shown in Figure 5.21:

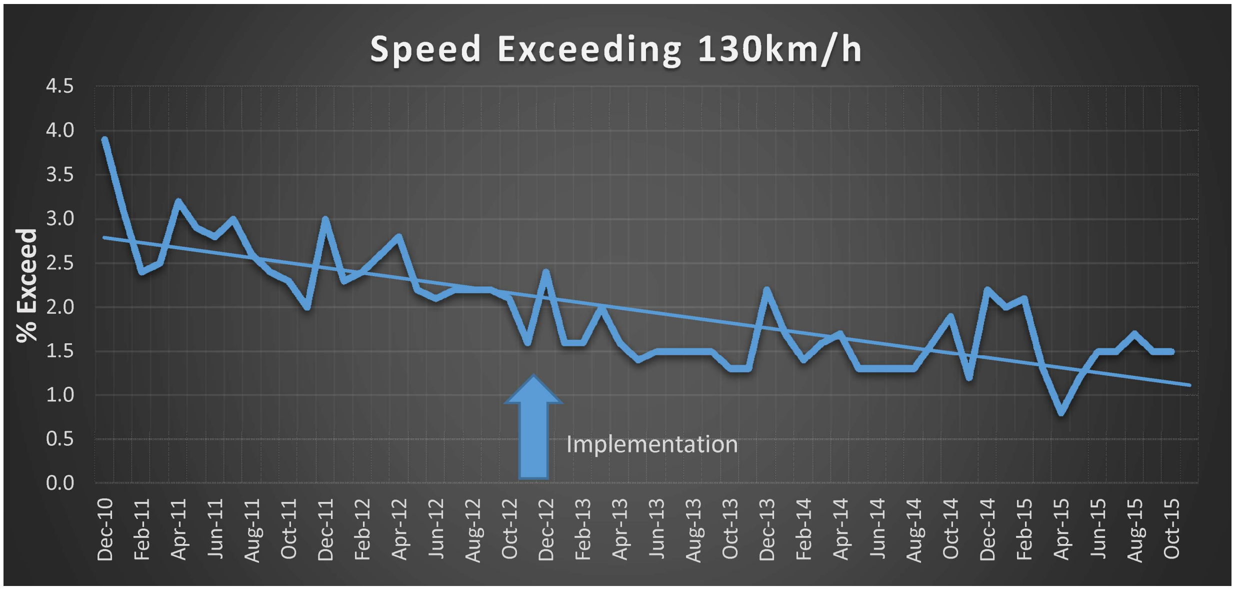


**Figure 5.21: Numerical analysis of percentage of vehicles exceeding 130 km/h at CTO-station 480**

The trend line in Figure 5.21 shows that the percentage of vehicles exceeding the 130 km/h speed had demonstrated a downward trend, even before the implementation of ASOD. From the graph it seems as if that trend only continued to go down. This trend is observed over the whole province. A possible reason for the decrease in speeds is the increase in the volume of traffic, especially heavy vehicles, leading to the road operating at higher capacity. With more vehicles on the road, passing opportunities for fast drivers become fewer, thereby reducing their speed. The graph actually showed an increase in the percentage for the implementation month.

The above could be explained by the fact that this CTO-station lies at the start of the ASOD section, as mentioned in Section 4.4.3. There is no opportunity for vehicles to accelerate to excessive speeds, due to the close proximity to the town of Beaufort West.

### 5.1.4 N2 – CTO-station 1243 in Sir Lowry's Pass

The speed limit at this site was set at 80 km/h. ASOD implementation was in April 2015, case number 106.

#### *5.1.4.1 Time Series transformations dialog*

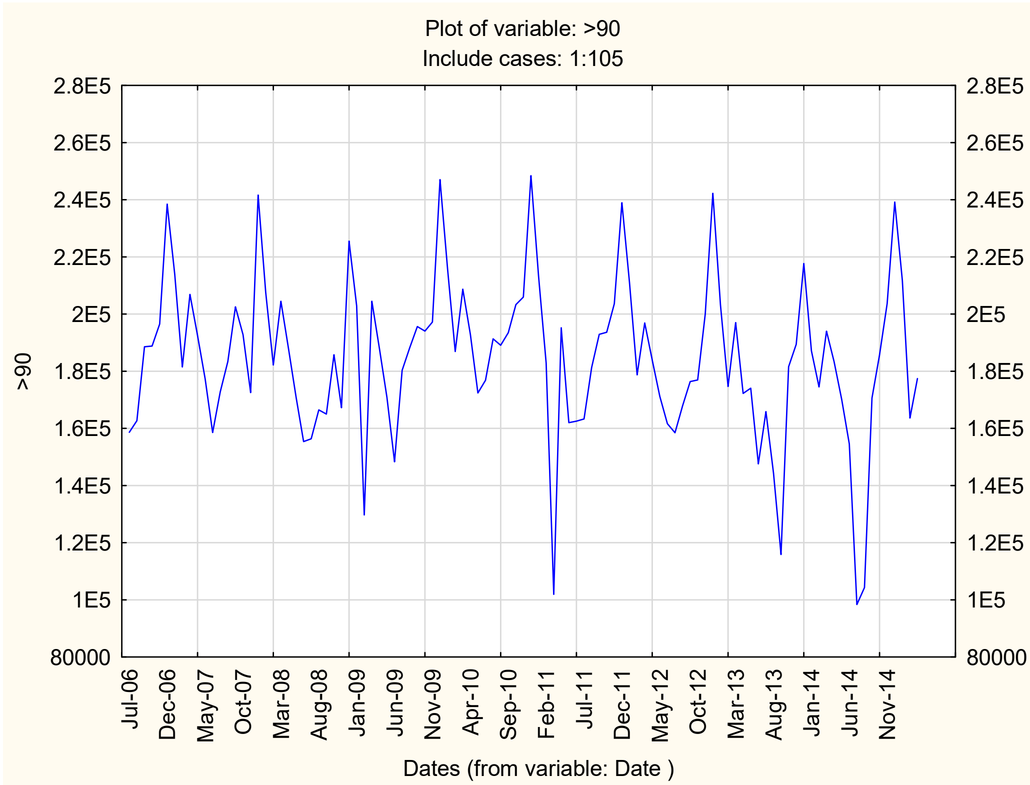


**Figure 5.22: Plot of variable: Volume >90 km/h pre-implementation**

The peaks in the data in Figure 5.22 were for the December holiday periods, the same as with CTO-stations on the N1.

The same process was followed as in the analyses for CTOs 5050 and 480. The autocorrelation and partial autocorrelation functions both confirmed a strong seasonality around the 12-month point with a moving average nature around the first two lags, as seen in Table 4.2. An ARIMA (1,1,1)(1,0,0) model was constructed, tested for significance and found to be significant, and fell within the confidence limits.

#### *5.1.4.2 Interrupted ARIMA at case 106 (April 2015)*

An interrupted time series analysis was performed on the entire data set in order to determine the effect of the ASOD intervention. In this case, the intervention was in the month of April 2015, case 106.

The model was tested for all three types of intervention described in Chapter 4.3.24.3.3.1. It was found that there was an abrupt and permanent change in the number of vehicles exceeding 90 km/h. Table 5.8 shows the result of this analysis.

**Table 5.8: Interrupted time series analysis on CTO 1243 for vehicles exceeding 90 km/h: Abrupt/Permanent Intervention**

| | Input: >90 (1243 combined)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(1,1,1)(1,0,0) Seasonal lag: 12 MS Residual= 4817E5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 119) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| p(1) | 0.4 | 0.10 | 3.93527 | 0.000140 | 0.2 | 0.6 | | |
| q(1) | 1.0 | 0.04 | 27.06729 | 0.000000 | 0.9 | 1.0 | | |
| Ps(1) | 0.5 | 0.09 | 5.86799 | 0.000000 | 0.3 | 0.7 | | |
| Omega(1) | -49086.0 | 12587.27 | -3.89965 | 0.000160 | -74010.1 | -24162.0 | 106 | Abr/Perm |

Figure 5.23 below shows the plot of the percentage of vehicles exceeding the speed of 90 km/h in Sir Lowry's Pass. The abrupt change can clearly be seen in the plot. The downward trend just before implementation is explained by the apparent effect of the ASOD cameras while they were still being constructed and not yet commissioned.

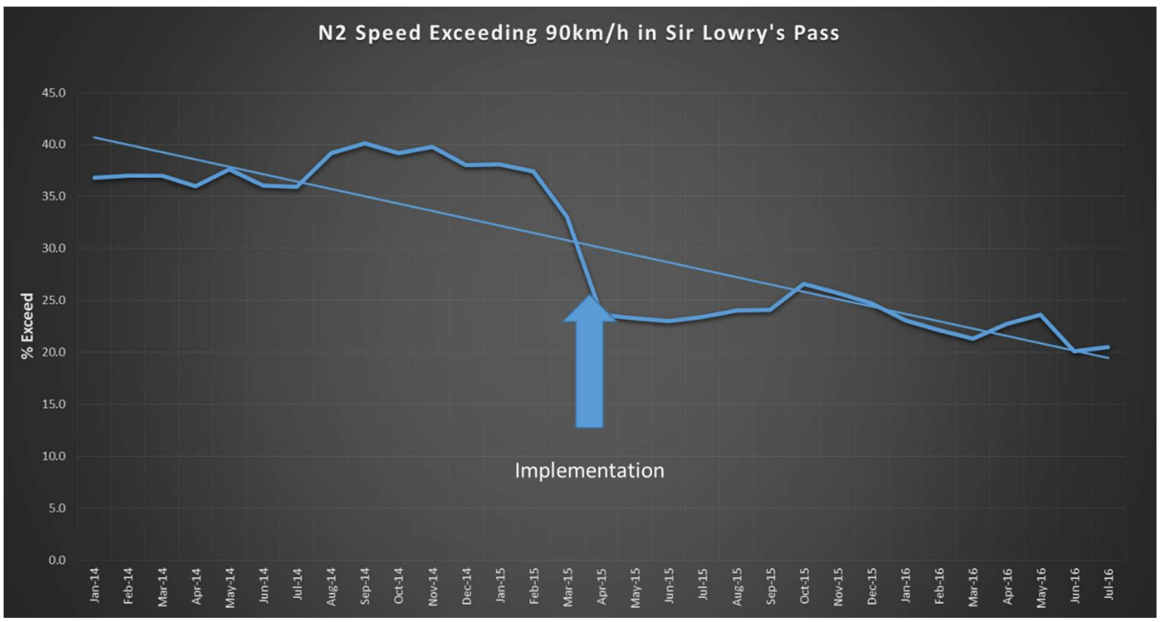


**Figure 5.23: Percentage of vehicles exceeding 90 km/h in Sir Lowry's Pass on the N2**

### 5.1.5 Control Set: 064 Hanover

The same process as with the other CTO stations was followed for CTO station 064, close to Hanover on the N1. This CTO station's data was included as a measure to determine whether there were perhaps other factors picked up at CTO 480 that were influencing the trends, although they were not ASOD related.

### 5.1.5.1 Time Series transformations dialog

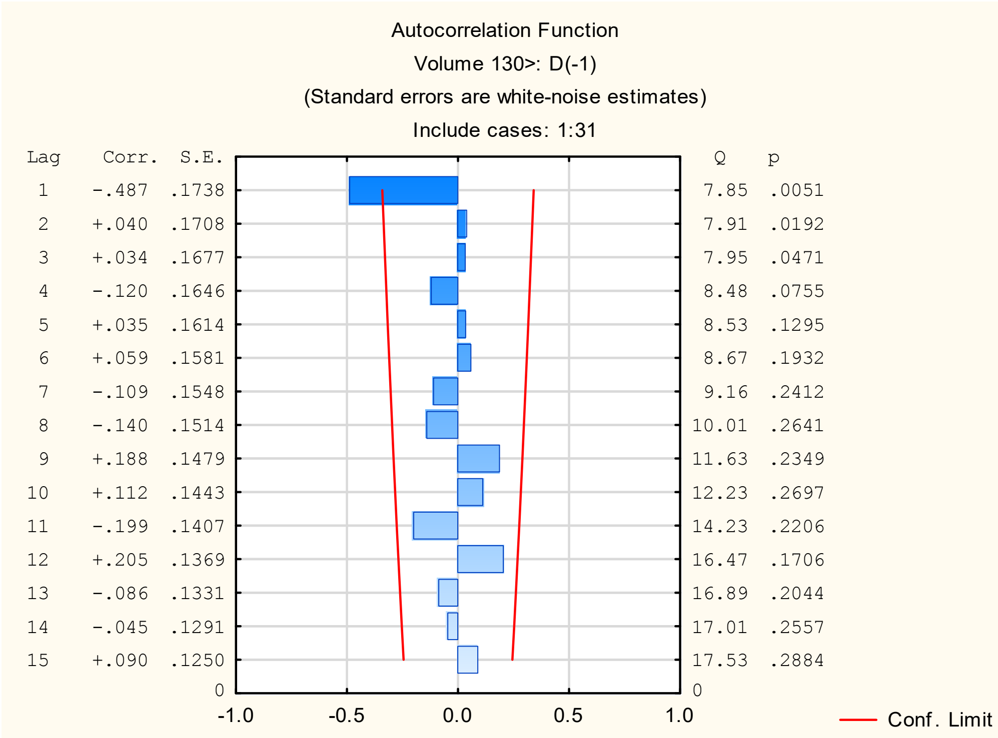


**Figure 5.24: Autocorrelation function for Volume >130 km/h pre-intervention**

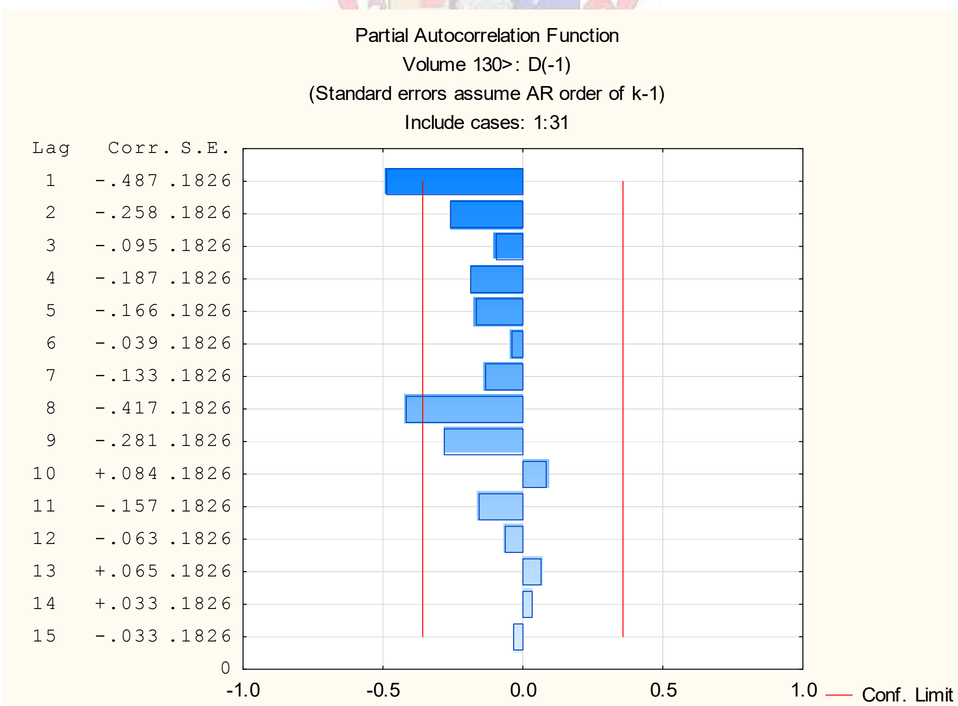


**Figure 5.25: Partial autocorrelation function for Volume >130 km/h pre-intervention**

The ACF in Figure 5.24 and PACF in Figure 5.25 pointed to a MA(1) model. The one spike and essentially zero other spikes in the ACF confirmed the model.

#### *5.1.5.2 Time Series ARIMA results dialog*

The MA(1) model was built and tested for significance, as shown in Table 5.9.

**Table 5.9: ARIMA moving average model for CTO 064 pre-intervention**

| | Input: Volume 130> (DATA 064_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1)<br>Model:(0,1,1) MS Residual= 1459E4<br>Include cases: 1:31 | | | | | |
|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 29) | p | Lower 95% Conf | Upper 95% Conf |
| q(1) | 0.787711 | 0.137112 | 5.745010 | 0.000003 | 0.507285 | 1.068136 |

#### *5.1.5.3 Interrupted ARIMA at case 32 (December 2012)*

An interrupted time series analysis was performed on the entire data set in order to determine the effect of the ASOD intervention. In this case, the intervention was in the month of December 2012, Case number 32.

The model was tested for all three types of interventions described in Section 4.3.3.1. None of the three types of interventions were found to be significant. The results of these analyses are shown in Table 5.10, Table 5.11 and Table 5.12.

**Table 5.10: Interrupted time series analysis for CTO 064: Abrupt/Permanent intervention**

| | Input: Volume 130> (DATA 064_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(0,1,1) MS Residual= 8541E3 ABRUPT PERMANENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Paramet. | Param. | Asympt. Std.Err. | Asympt. t( 60) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| q(1) | 0.80 | 0.097 | 8.220808 | 0.000000 | 0.60 | 0.992 | | |
| Omega(1) | -1896.02 | 2018.168 | -0.939473 | 0.351255 | -5932.95 | 2140.923 | 32 | Abr/Perm |

In Table 5.10, the variable Omega(1) fell outside of the confidence limits – thereby indicating that no abrupt and permanent change occurred due to the intervention. The same could be said for the Omega(1) and Delta(1) parameters in Table 5.11 and Table 5.12.

**Table 5.11: Interrupted time series analysis for CTO 064: Gradual/Permanent intervention**

| Paramet. | Input: Volume 130> (DATA 064_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(0,1,1) MS Residual= 8645E3 GRADUAL PERMANENT | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Param. | Asympt. Std.Err. | Asympt. t( 59) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| q(1) | 0.80 | 0.096 | 8.333560 | 0.000000 | 0.61 | 0.992 | | |
| Omega(1) | -1122.37 | 1686.402 | -0.665543 | 0.508297 | -4496.86 | 2252.110 | 32 | Grd/Perm |
| Delta(1) | 0.54 | 0.664 | 0.819176 | 0.415983 | -0.79 | 1.874 | 32 | Grd/Perm |

**Table 5.12: Interrupted time series analysis for CTO 064: Abrupt/Temporary intervention**

| Paramet. | Input: Volume 130> (DATA 064_Speed_Distribution_Both Monthly.sta)<br>Transformations: D(1) (Interrupted ARIMA)<br>Model:(0,1,1) MS Residual= 8613E3 ABRUPT TEMPORARY | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Param. | Asympt. Std.Err. | Asympt. t( 59) | p | Lower 95% Conf | Upper 95% Conf | Interv. Case No. | Interv. Type |
| q(1) | 0.80 | 0.097 | 8.22266 | 0.000000 | 0.61 | 0.996 | | |
| Omega(1) | -1602.13 | 2027.286 | -0.79028 | 0.432528 | -5658.72 | 2454.463 | 32 | Abr/Temp |
| Delta(1) | 1.03 | 0.046 | 22.61101 | 0.000000 | 0.94 | 1.125 | 32 | Abr/Temp |

The above results indicate that the implementation of ASOD on the N1 between Beaufort West and Riemhoogte did not have a knock-on effect on the areas not covered by ASOD. The comparison of the analysis for the control set with CTO 480 at Beaufort West shows that the same trends occur at both these locations, and at both these locations the analysis indicated that no significant change in excessive speeds occurred after ASOD implementation.



## 5.2 Probe data analysis

As discussed in Chapter 4.3.2, three time periods were chosen on which an analysis was done for a total of just under 70 kilometres on the R27 West Coast Road. These time periods were March 2013, March 2014 and March 2016, respectively. The analysis was based on all vehicles travelling in a Northbound (outbound) direction.

The query was set up so that the route started at km 48.1 and ended at km 117.2, a total of 69.1 kilometres. The distance covered under ASOD on this road totals 57.5 kilometres.

It is important to note that the route start point, as defined in the query, does not correlate with the start point of the R27. For the purpose of the analysis, the ASOD cameras are located along the defined route:

- Ganzekraal at 2 454 m

- Yzerfontein at 24 655 m
- Buffelsfontein at 39 729 m
- Waschklip at 59 977 m

The route of 69.1 kilometres was divided into five segments, as the traffic stats portal allowed for a maximum route distance of 15 kilometres at a time. Each of these five segments was made up of sub-segments with unique identifiers. These segments are usually divided to occur at changes in road alignment, intersections, speed limit changes and other factors that might influence driver behaviour. The locality of the analysis is shown below:

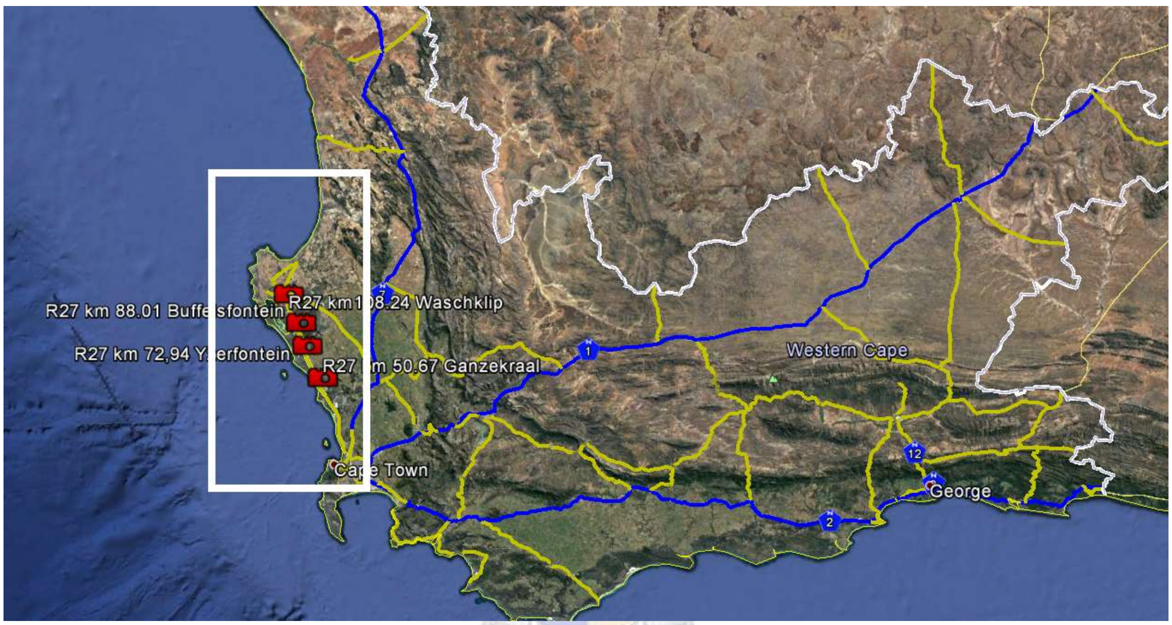


**Figure 5.26: Locality of probe data analysis**

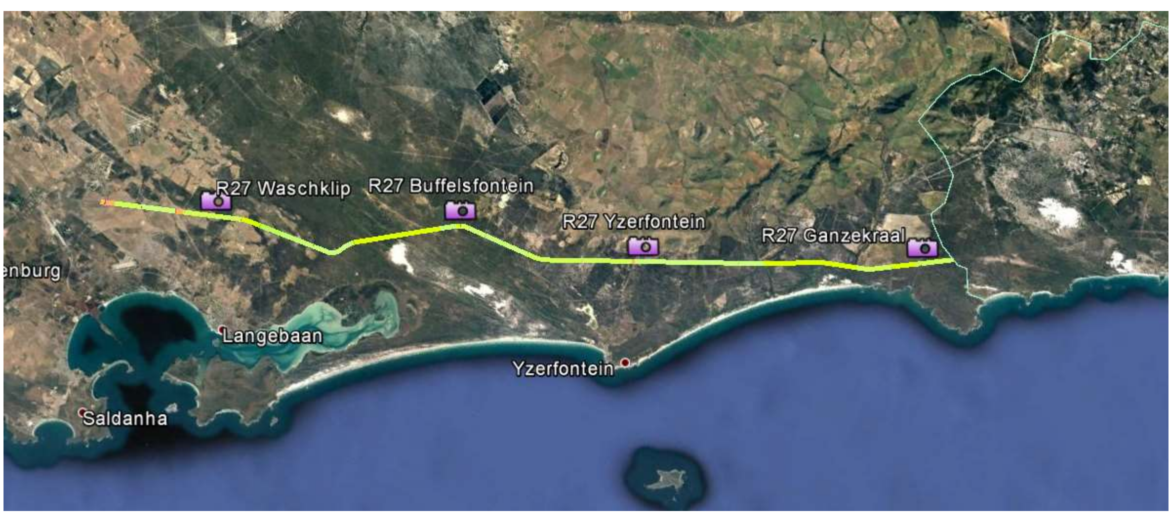


**Figure 5.27: Probe data analysis segments with ASOD cameras**

Figure 5.27 shows the probe data analysis route with the ASOD cameras along this route. The analysis started approximately 2 kilometers before the first camera, at Ganzekraal, and ended approximately 10 kilometers after the last camera, at Waschklip. The five segments run consecutively along the route.

Since the R27 is a rural road with no major changes in the factors mentioned above, most of the sub-segments are quite long. Table 5.13 below gives a breakdown of the segment lengths:

**Table 5.13: Probe data analysis subsegment and ASOD camera details**

| Segment | Sub segment | Length (m) | Speed Limit (km/h) | Cumulative Distance (m) | Camera name | Camera location on route |
|---|---|---|---|---|---|---|
| START | | | | 0 | **Ganzekraal** | **2454.03** |
| 1 | 1 | 2621.03 | 120 | 2621 | | |
| 1 | 2 | 408.94 | 120 | 3030 | | |
| 1 | 3 | 1910.93 | 120 | 4941 | | |
| 1 | 4 | 2847.80 | 120 | 7789 | | |
| 1 | 5 | 13.96 | 120 | 7803 | | |
| 1 | 6 | 7354.16 | 120 | 15157 | | |
| 2 | 1 | 6.19 | 120 | 15163 | | |
| 2 | 2 | 1950.58 | 120 | 17114 | | |
| 2 | 3 | 3122.29 | 120 | 20236 | | |
| 2 | 4 | 796.09 | 120 | 21032 | **Yzerfontein** | **24655** |
| 2 | 5 | 4328.27 | 120 | 25360 | | |
| 2 | 6 | 225.53 | 120 | 25586 | | |
| 2 | 7 | 3872.06 | 120 | 29458 | | |
| 2 | 8 | 50.35 | 120 | 29508 | | |
| 3 | 1 | 50.35 | 120 | 29559 | | |
| 3 | 2 | 4372.05 | 120 | 33931 | | |
| 3 | 3 | 1207.28 | 120 | 35138 | | |
| 3 | 4 | 573.70 | 120 | 35712 | | |

| Segment | Sub segment | Length (m) | Speed Limit (km/h) | Cumulative Distance (m) | Camera name | Camera location on route |
|---|---|---|---|---|---|---|
| 3 | 5 | 406.12 | 120 | 36118 | | |
| 3 | 6 | 1510.54 | 120 | 37628 | | |
| 3 | 7 | 1335.10 | 120 | 38963 | | |
| 3 | 8 | 765.40 | 120 | 39729 | **Buffelsfontein** | **39729** |
| 3 | 9 | 267.12 | 120 | 39996 | | |
| 3 | 10 | 1336.95 | 120 | 41333 | | |
| 4 | 1 | 6969.23 | 120 | 48302 | | |
| 4 | 2 | 3496.83 | 120 | 51799 | | |
| 4 | 3 | 2687.79 | 120 | 54487 | | |
| 4 | 4 | 1830.08 | 120 | 56317 | | |
| 5 | 1 | 4.51 | 120 | 56321 | | |
| 5 | 2 | 1598.20 | 120 | 57919 | **Waschklip** | **59977** |
| 5 | 3 | 4524.92 | 120 | 62444 | | |
| 5 | 4 | 145.22 | 120 | 62590 | | |
| 5 | 5 | 101.56 | 120 | 62691 | | |
| 5 | 6 | 401.56 | 120 | 63093 | | |
| 5 | 7 | 89.67 | 120 | 63182 | | |
| 5 | 8 | 2690.06 | 120 | 65872 | | |
| 5 | 9 | 85.86 | 120 | 65958 | | |
| 5 | 10 | 2059.15 | 120 | 68017 | | |
| 5 | 11 | 726.35 | 120 | 68744 | | |
| 5 | 12 | 85.18 | 120 | 68829 | | |
| 5 | 13 | 300.08 | 120 | 69129 | | |
| **END** | | | | | | |

As can be seen in Table 5.13, some segments are longer than four kilometres, while some segments are shorter than 100 metres. The average segment length is 1720 metres. This is what one would typically find in terms of segment lengths in rural areas. In urban areas segment lengths can be as short as five metres. The total number of sub segments is 41.

The data was studied and it was found that the base time set, between 19h00 and 07h00, had the highest 85th percentile speeds. The analysis was conducted on sub segment level to ensure that all variances in speed could be accounted for. Averaging the speeds over 15 kilometre distances would not give an accurate reflection of the true speed characteristics of the route.

The average speeds and 85th percentile speeds are summarised in Table 5.14 below.

**Table 5.14: Average and 85th Percentile Speeds for Probe data on R27**

| | | March 2013 | | March 2014 | | March 2016 | |
|---|---|---|---|---|---|---|---|
| Segment | Sub segment | Average Speed | 85th Percentile Speed | Average Speed | 85th Percentile Speed | Average Speed | 85th Percentile Speed |
| 1 | 1 | 98.89 | 126 | 91.77 | 120 | 96.07 | 118 |
| 1 | 2 | 88.68 | 131 | 94.99 | 120 | 97.68 | 117 |
| 1 | 3 | 98.10 | 130 | 95.33 | 122 | 99.87 | 122 |
| 1 | 4 | 98.97 | 130 | 95.42 | 121 | 99.23 | 121 |
| 1 | 5 | 101.17 | 129 | 95.93 | 121 | 101.65 | 126 |
| 1 | 6 | 97.88 | 128 | 93.07 | 119 | 97.63 | 120 |
| 2 | 1 | 103.55 | 135 | 96.96 | 123 | 102.56 | 125 |
| 2 | 2 | 96.80 | 129 | 90.53 | 117 | 94.96 | 119 |
| 2 | 3 | 98.70 | 127 | 93.12 | 121 | 96.01 | 120 |
| 2 | 4 | 98.36 | 127 | 93.14 | 118 | 94.35 | 119 |
| 2 | 5 | 96.08 | 125 | 92.40 | 117 | 88.13 | 111 |
| 2 | 6 | 81.33 | 115 | 79.45 | 114 | 76.40 | 103 |
| 2 | 7 | 98.62 | 127 | 93.90 | 118 | 95.42 | 121 |
| 2 | 8 | 101.44 | 133 | 94.50 | 120 | 96.49 | 121 |
| 3 | 1 | 101.44 | 133 | 94.50 | 120 | 96.49 | 121 |
| 3 | 2 | 99.74 | 130 | 93.37 | 120 | 95.40 | 119 |
| 3 | 3 | 89.40 | 121 | 84.38 | 116 | 85.18 | 115 |
| 3 | 4 | 94.00 | 125 | 88.70 | 118 | 86.19 | 114 |

| | | March 2013 | | March 2014 | | March 2016 | |
|---|---|---|---|---|---|---|---|
| **Segment** | **Sub segment** | **Average Speed** | **85th Percentile Speed** | **Average Speed** | **85th Percentile Speed** | **Average Speed** | **85th Percentile Speed** |
| 3 | 5 | 98.35 | 129 | 92.13 | 121 | 66.15 | 119 |
| 3 | 6 | 89.66 | 125 | 82.71 | 117 | 59.39 | 116 |
| 3 | 7 | 91.22 | 125 | 84.32 | 118 | 87.32 | 117 |
| 3 | 8 | 98.75 | 130 | 91.40 | 119 | 89.76 | 115 |
| 3 | 9 | 98.83 | 132 | 92.50 | 118 | 82.49 | 116 |
| 3 | 10 | 100.53 | 133 | 93.82 | 121 | 94.57 | 121 |
| 4 | 1 | 97.69 | 128 | 91.98 | 118 | 81.06 | 117 |
| 4 | 2 | 97.00 | 125 | 90.51 | 118 | 64.10 | 119 |
| 4 | 3 | 100.64 | 132 | 92.35 | 122 | 90.95 | 120 |
| 4 | 4 | 100.42 | 131 | 93.22 | 121 | 51.35 | 112 |
| 5 | 1 | 102.01 | 133 | 93.47 | 119 | 74.82 | 117 |
| 5 | 2 | 99.88 | 130 | 92.74 | 118 | 86.06 | 113 |
| 5 | 3 | 99.22 | 126 | 92.04 | 117 | 86.06 | 108 |
| 5 | 4 | 78.38 | 112 | 84.09 | 106 | 77.30 | 101 |
| 5 | 5 | 80.57 | 112 | 82.08 | 106 | 71.44 | 101 |
| 5 | 6 | 72.27 | 103 | 76.80 | 101 | 70.56 | 101 |
| 5 | 7 | 56.02 | 111 | 58.94 | 106 | 45.92 | 99 |
| 5 | 8 | 92.40 | 121 | 90.40 | 115 | 94.02 | 116 |
| 5 | 9 | 80.73 | 126 | 92.22 | 116 | 100.32 | 125 |
| 5 | 10 | 93.75 | 126 | 91.56 | 117 | 98.76 | 124 |
| 5 | 11 | 80.34 | 115 | 82.82 | 105 | 80.57 | 100 |
| 5 | 12 | 45.66 | 119 | 57.68 | 102 | 54.55 | 107 |
| 5 | 13 | 78.95 | 122 | 80.01 | 106 | 78.75 | 107 |
| | **Averages** | **92.11** | **125.54** | **88.81** | **116.39** | **85.02** | **115.20** |

The data from Table 5.14 is shown on Figure 5.28 and Figure 5.29 below:

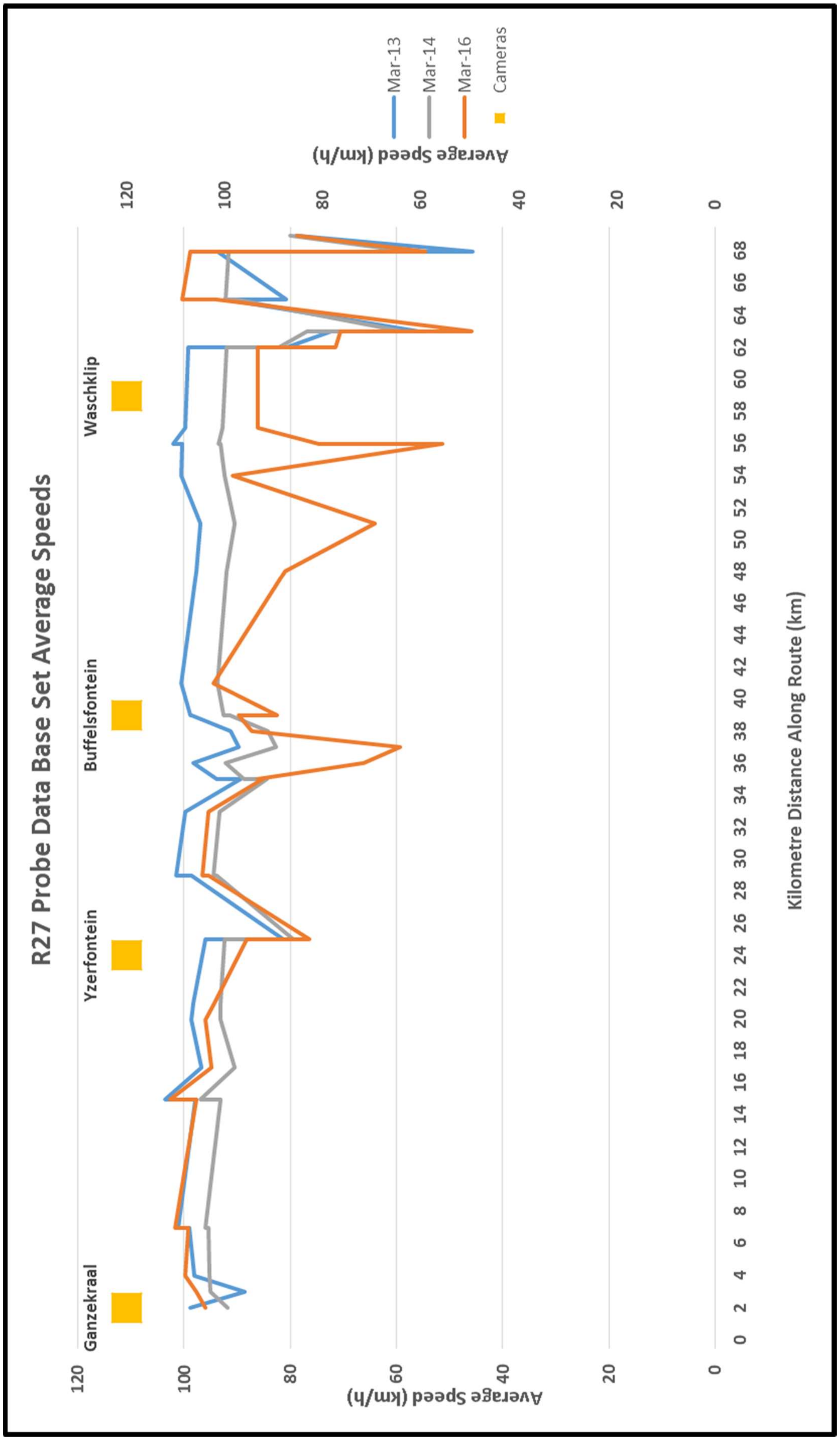


**Figure 5.28: R27 Probe Data Base Set Average Speeds**

The use of the figures assists in analysing the data relative to the cameras. Due to the short distance before the first camera, Ganzekraal, it is not possible to draw conclusions from the data for the road before the ASOD section. The 10 kilometres after the last camera, Waschklip, can, however, be used to analyse trends for sections not covered by ASOD cameras.

It is important to note that the only camera site where there is a break in sub segments is Buffelsfontein. At all three other sites, there is not break in the sub segment, so it is not possible to know details of trends at the exact points of the cameras.

Figure 5.28 shows the average speeds along the route as set up in the TomTom Traffic Stats Portal. The major drop in speeds just after the Yzerfontein camera (at approximately kilometre 25) is explained by the fact that there is a major intersection at that point. The posted speed limit for the approaches to the intersection is 100 km/h. There are also traffic calming measures such as rumble strips and painted islands with vuka studs. All of these factors contribute to the drop in speeds at the intersection.

The major variations in average speed for the section between Buffelsfontein and Waschklip for March 2016 is attributed to road works that took place on that section of road during March 2016. There was a reseal project which required ‘stop-go’ controls. Vehicles waiting at these points would bring the average speeds down.

The major drop in speeds just after the Waschklip camera is attributed to another major intersection, as well as a petrol filling station, convenience store and restaurant. The intersection is the turn-off to the town of Langebaan, a popular weekend and holiday destination. It is interesting to note that the average speeds after this intersection (from approximately kilometre 64 onwards) is higher for March 2016, whereas everywhere else along the road, the March 2016 line is below the other previous years’ lines. This could be explained by the motorists being aware that they are then no longer enforced by the ASOD system to comply with the legal speed limit and therefore pick up speed again.

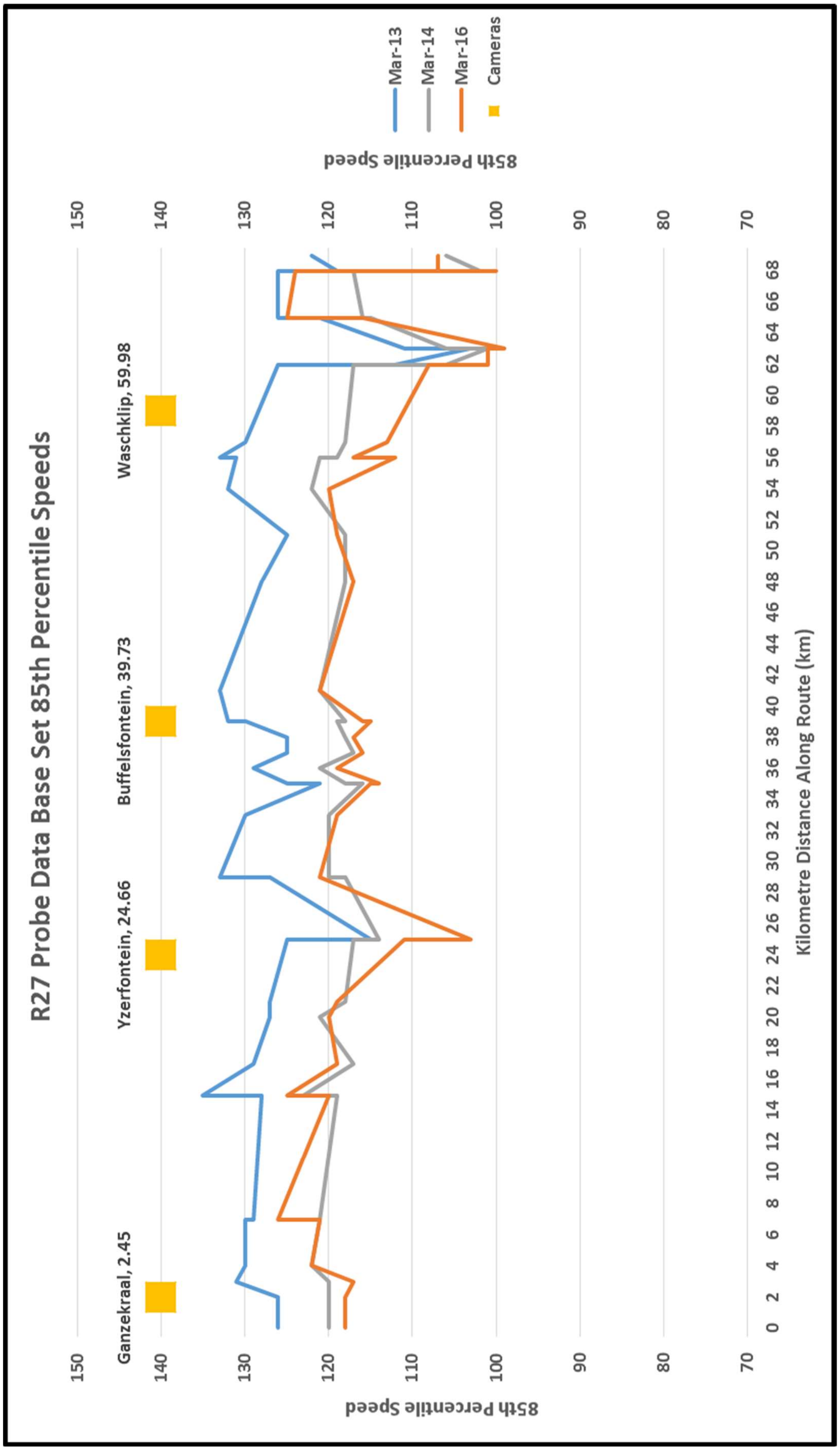


**Figure 5.29: R27 Probe Data Base Set 85th Percentile Speeds**

Figure 5.29 shows the 85th percentile trends over the analysis for the three time periods. With a design speed and posted speed limit of 120 km/h, one would expect to see the 85th percentile speeds to be at 120 km/h.

In March 2013, the 85th percentile speed in some segments was at 135 km/h. The only locations where the 85th percentile speed was below 120 km/h, were at the major intersections of Yzerfontein and the Langebaan/Filling station intersection.

The average 85th percentile speed for March 2013 over the entire analysed route was 125.5 km/h. It was for these reasons that ASOD enforcement was rolled out on the R27 route.

Plots in Figure 5.29 clearly show a reduction in 85th percentile speeds from March 2013 to March 2014 and March 2016. The March 2014 plot hovers around the 120 km/h 85th percentile speed. This reduction in speed is attributed to the presence of the ASOD cameras.

The reduced speeds, compared to March 2013, after the last camera, Waschklip, are indicative of the calming effect of the ASOD cameras on the road users. In March 2014, the 85th percentile speed did not exceed 120 km/h for the 10 kilometres after the Waschklip camera.

The average 85th percentile speed of 125.5 km/h for March 2013 dropped to 116.4 km/h in March 2014, and further to 115.2 km/h in March 2016.

The significance of the change in percentile speeds was analysed by means of a paired t-test with a 95% confidence level.

A one-tailed p-value was tested, as it was predicted that one mean would be higher than the other.

The t-test analysis was performed on the 85th percentile data and the results are shown in Table 5.15 and Table 5.16 below.

**Table 5.15: t-test for March 2013 vs March 2014**

| **Parameter** | **Value** |
|---|---|
| **Mean of Difference** | -9.146341 |
| **N:** | 41 |
| **Degrees of freedom** | 40 |
| **t-value** | 17.439031 |
| **P-value (one-tailed)** | 1.348E-20 |

**Table 5.16: t-test for March 2013 vs March 2016**

| **Parameter** | **Value** |
|---|---|
| **Mean of Difference** | -10.341463 |
| **N:** | 41 |
| **Degrees of freedom** | 40 |

| | |
|---|---|
| **t-value** | 15.159302 |
| **P-value (one-tailed)** | 1.78E-18 |

In both the cases, the p-value is significantly smaller than 0.05 thereby it may be accepted that there is a statistically significant change in the 85$^{th}$ percentile speeds between March 2013 and March 2014 and March 2016, respectively.

The output of the queries also gives the travel time ratios of the base time set (between 19h00 and 07h00). These ratios are shown in the following tables:

**Table 5.17: R27 Probe analysis Comparative Time Set Travel Times - March 2013**

| **March 2013** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Segment** | **Base Set** | **07h00-09h00** | **09h00-11h00** | **11h00-13h00** | **13h00-15h00** | **15h00-17h00** | **17h00-19h00** | **Min. ratio** | **Time Set** |
| **1** | 1.00 | 0.88 | 0.89 | 0.88 | 0.87 | 0.85 | 0.83 | 0.83 | 17h00 - 19h00 |
| **2** | 1.00 | 0.89 | 0.92 | 0.90 | 0.92 | 0.89 | 0.87 | 0.87 | 17h00 - 19h00 |
| **3** | 1.00 | 0.82 | 0.90 | 0.87 | 0.86 | 0.85 | 0.81 | 0.81 | 17h00 - 19h00 |
| **4** | 1.00 | 0.87 | 0.88 | 0.87 | 0.87 | 0.88 | 0.84 | 0.84 | 17h00 - 19h00 |
| **5** | 1.00 | 0.87 | 0.89 | 0.88 | 0.86 | 0.87 | 0.82 | 0.82 | 17h00 - 19h00 |

In Table 5.17, the 17h00 – 19h00 time set has the smallest travel time ratio. This means that it took motorist the least amount of time to travel the route during that time set.

Table 5.18: R27 Probe analysis Comparative Time Set Travel Times - March 2014

| March 2014 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Segment | Base Set | 07h00-09h00 | 09h00-11h00 | 11h00-13h00 | 13h00-15h00 | 15h00-17h00 | 17h00-19h00 | Min | Time Set |
| 1 | 1.00 | 0.90 | 0.88 | 0.90 | 0.86 | 0.83 | 0.86 | 0.83 | 15h00 - 17h00 |
| 2 | 1.00 | 0.91 | 0.90 | 0.91 | 0.88 | 0.86 | 0.91 | 0.86 | 15h00 - 17h00 |
| 3 | 1.00 | 0.89 | 0.89 | 0.87 | 0.85 | 0.80 | 0.84 | 0.80 | 15h00 - 17h00 |
| 4 | 1.00 | 0.88 | 0.89 | 0.87 | 0.85 | 0.80 | 0.84 | 0.80 | 15h00 - 17h00 |
| 5 | 1.00 | 0.90 | 0.89 | 0.89 | 0.88 | 0.84 | 0.87 | 0.84 | 15h00 - 17h00 |

Table 5.18 shows the travel time ratio's for March 2014. Interestingly the smallest ratio is during the 15h00 – 17h00 time set, whereas the smallest ratio is found in the 17h00 – 19h00 in the March 2013 and most of the March 2016 data sets, as shown in Table 5.17 and Table 5.19.

Table 5.19: R27 Probe analysis Comparative Time Set Travel Times - March 2016

| March 2016 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Segment | Base Set | 07h00-09h00 | 09h00-11h00 | 11h00-13h00 | 13h00-15h00 | 15h00-17h00 | 17h00-19h00 | Min | Time Set |
| 1 | 1.00 | 0.96 | 0.95 | 0.98 | 0.95 | 0.91 | 0.91 | 0.91 | 17h00 - 19h00 |
| 2 | 1.00 | 0.95 | 0.95 | 1.00 | 0.99 | 0.91 | 0.91 | 0.91 | 17h00 - 19h00 |
| 3 | 1.00 | 0.95 | 0.95 | 1.02 | 0.94 | 0.95 | 0.87 | 0.87 | 17h00 - 19h00 |
| 4 | 1.00 | 1.05 | 1.00 | 1.05 | 1.03 | 1.05 | 0.93 | 0.93 | 17h00 - 19h00 |
| 5 | 1.00 | 1.06 | 1.00 | 1.05 | 1.06 | 1.04 | 0.98 | 0.98 | 17h00 - 19h00 |

The smallest time ratios mean that the travel times for those periods are the shortest, compared to the base time set. This is interesting as the base set is, in most cases in all three data sets, is larger than the time sets for the rest of the day, although the 85$^{th}$ percentile speeds were highest during the base time set.

This observation is interpreted as an indication that the average speeds of vehicles during the daytime are higher than during the night time (the base time set), although the night time speeds are higher. This means that, during the day, more vehicles are travelling at uniform higher speeds, but that most of them travel within the speed limit. At night time one would find fewer vehicles, but greater differences in their speeds.

Another observation has reference to the drivers' behaviour at the Buffelsfontein camera. Both the March 2014 and March 2016 85$^{th}$ percentile speeds in Figure 5.29 fall in the immediate vicinity of the camera. This is indicative of drivers braking before the camera. This can be explained by the fact that there are drivers who do not understand how ASOD works. These drivers then mistake the cameras for static speed cameras and therefore adjust their speed just as they reach the camera.

The probe data analysis confirms the findings of the time series analysis in Chapter 5.1.1 that there was a significant reduction in speed on the R27 West Coast Road after the implementation of ASOD. It also found that the calming effect of the ASOD enforcement continued beyond the ASOD sections.

## 5.3 Accident analysis

This chapter aims at analysing the occurrence of accidents on the routes studied. Although accident data was not available for all the routes in this study, complete data was available for the R27 and N1-8.

Many of the records in the database do not indicate an exact kilometre mark or GPS location of the accidents. It is thus not possible to determine whether these accidents occurred within or outside the ASOD sections. Although the SAPS branch where the accident was reported is noted in the data, it cannot be assumed that if an accident was reported at a SAPS station close to the ASOD section, the accident occurred within the ASOD section. The converse is also possible: an accident that occurred within the ASOD section could have been reported at a SAPS station where the ASOD section lies outside the borders of that station. If no location was recorded with the accident, the record was omitted from the study.

There are, for example, accidents reported at the George SAPS station, some 500km from the actual accident location. More often than not, this can be attributed to the fact that the accident did not have serious consequences, so there was not the need to immediately report the accident to the closest SAPS station. It would then only be reported at a later stage for insurance purposes. Those involved in the accident would not be able to claim from their insurance if they did not have a SAPS case number for the accident.

### 5.3.1 Accident analysis on the R27

The data obtained from the integrated provincial accident system (iPAS) contains data from January 2000 to March 2015.

In this period a total of 1876 accidents was recorded for the R27 West Coast Road. Note that this is reflected for the R27 between Cape Town and Veldrif, and not just the section under ASOD. The yearly accidents are summarised in Table 5.20 below:

**Table 5.20: Summary of all accidents on the R27 between Cape Town and Veldrif**

| All accidents R27-route between Cape Town and Veldrif | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Number of accidents** | **Sum of Killed** | **Sum of Serious** | **Sum of Slight** | **Sum of No Injury** | **Sum of Total** |
| **2000** | 123 | 10 | 20 | 33 | 122 | 185 |
| **2001** | 99 | 5 | 15 | 65 | 81 | 166 |
| **2002** | 111 | 13 | 21 | 38 | 121 | 193 |
| **2003** | 105 | 6 | 21 | 27 | 104 | 158 |
| **2004** | 111 | 4 | 13 | 29 | 71 | 117 |
| **2005** | 141 | 5 | 29 | 51 | 135 | 220 |
| **2006** | 102 | 4 | 23 | 41 | 117 | 185 |
| **2007** | 149 | 3 | 30 | 37 | 165 | 235 |
| **2008** | 137 | 8 | 29 | 47 | 137 | 221 |
| **2009** | 164 | 5 | 29 | 66 | 183 | 283 |
| **2010** | 149 | 3 | 36 | 82 | 201 | 322 |
| **2011** | 124 | 11 | 27 | 35 | 159 | 232 |
| **2012** | 108 | 12 | 23 | 45 | 125 | 205 |
| **2013** | 111 | 3 | 17 | 30 | 135 | 185 |
| **2014** | 125 | 12 | 16 | 32 | 178 | 238 |
| **2015** | 17 | 0 | 0 | 2 | 25 | 27 |
| **Totals** | **1876** | **104** | **349** | **660** | **2059** | **3172** |

Of the 1876 records, 549 records do not contain an exact kilometre mark for the location of the accidents. This leaves a total of 1327 records with the location of those accidents captured. Each of these 1327 records were investigated to determine whether the accident occurred within the ASOD-section or not. The data is summarised below:

**Table 5.21: Data from R27 accident database with no location**

| Accident data in database with no location | | | | | | |
|---|---|---|---|---|---|---|
| **2000** | 3 | 0 | 0 | 4 | 4 | 8 |
| **2001** | 4 | 0 | 0 | 3 | 2 | 5 |
| **2004** | 2 | 0 | 0 | 0 | 2 | 2 |
| **2005** | 1 | 0 | 0 | 0 | 1 | 1 |
| **2006** | 1 | 0 | 0 | 0 | 1 | 1 |
| **2007** | 41 | 2 | 2 | 9 | 47 | 60 |
| **2008** | 47 | 0 | 6 | 8 | 40 | 54 |
| **2009** | 78 | 2 | 10 | 18 | 95 | 125 |
| **2010** | 74 | 3 | 15 | 48 | 91 | 157 |
| **2011** | 79 | 9 | 14 | 20 | 89 | 132 |
| **2012** | 84 | 8 | 20 | 37 | 98 | 163 |
| **2013** | 65 | 3 | 10 | 23 | 72 | 108 |
| **2014** | 59 | 4 | 4 | 10 | 80 | 98 |
| **2015** | 11 | 0 | 0 | 2 | 11 | 13 |
| **Totals** | **549** | **31** | **81** | **182** | **633** | **927** |

Of the 1327 accidents, 667 occurred within the borders of ASOD, the other 660 outside of ASOD-implementation. As summarised in Table 5.22.

**Table 5.22: Accidents within the ASOD-section on the R27 West Coast Road**

| Accidents within ASOD-section on the R27 West Coast Road | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **Number of accidents** | **Sum of Killed** | **Sum of Serious** | **Sum of Slight** | **Sum of No Injury** | **Sum of Total** |
| **2000** | 57 | 6 | 8 | 19 | 54 | **87** |
| **2001** | 54 | 3 | 10 | 39 | 46 | **98** |
| **2002** | 59 | 7 | 10 | 17 | 63 | **97** |
| **2003** | 59 | 6 | 15 | 16 | 51 | **88** |
| **2004** | 57 | 0 | 6 | 9 | 30 | **45** |
| **2005** | 72 | 3 | 22 | 25 | 64 | **114** |
| **2006** | 42 | 3 | 18 | 18 | 53 | **92** |
| **2007** | 69 | 1 | 20 | 17 | 68 | **106** |
| **2008** | 51 | 5 | 13 | 24 | 55 | **97** |
| **2009** | 49 | 2 | 9 | 39 | 49 | **99** |
| **2010** | 36 | 0 | 14 | 11 | 62 | **87** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2011** | 21 | 0 | 6 | 7 | 30 | **43** |
| **2012** | 9 | 0 | 1 | 1 | 13 | **15** |
| **2013** | 16 | 0 | 7 | 4 | 14 | **25** |
| **2014** | 15 | 0 | 3 | 7 | 36 | **46** |
| **2015** | 1 | 0 | 0 | 0 | 2 | **2** |
| **Totals** | **667** | **36** | **162** | **253** | **690** | **1141** |

There was a total of 648 accidents, affecting 1089 people before the implementation of ASOD in October 2013. The data is summarised in Table 5.23.

**Table 5.23: Number of accidents before and after implementation of ASOD**

| | **Count of Accident No** | **Sum of Killed** | **Sum of Serious** | **Sum of Slight** | **Sum of No Injury** | **Sum of Total** |
|---|---|---|---|---|---|---|
| **Pre-implementation: January 2000 to September 2013** | 648 | 36 | 159 | 246 | 648 | 1089 |
| **Post-implementation: October 2013 - March 2015** | 19 | 0 | 3 | 7 | 42 | 52 |

The values in the Table 5.23 above work out to an average of 51 accidents per annum pre-implementation and 13 accidents per annum post-implementation.

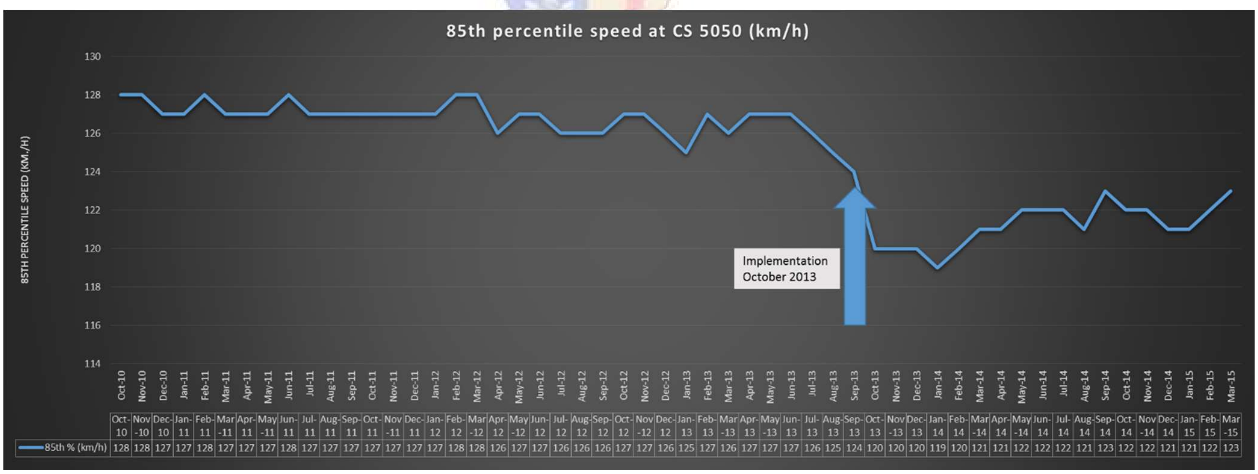


**Figure 5.30: 85th Percentile speeds at CTO 5050**

Unfortunately the 85th percentile speeds in Figure 5.30 only go back as far as October 2010, therefore it was not possible to draw a direct correlation between the speeds and accidents. The 85th percentile speed was constantly around 127 km/h until the implementation of ASOD. There had already been a decrease in speed during the construction phase of the project, reflected in the months of July, August and September 2013 before implementation in October 2013.

**Table 5.24: Number of accidents on R27 within ASOD stretch one year both before- and after implementation**

| | Count of Accident No | Sum of Killed | Sum of Serious | Sum of Slight | Sum of No Injury | Sum of Total | Average 85th percentile |
|---|---|---|---|---|---|---|---|
| September 2012 - September 2013 | 16 | 0 | 7 | 4 | 16 | 27 | 126.15 km/h |
| November 2013 - November 2014 | 7 | 0 | 0 | 4 | 13 | 17 | 121.15 km/h |

The reduction in the number of accidents attributable to the reduction in speed was tested against Nilsson's power model for all injury accidents:

$$A_2 = A_1\left(\frac{v_2}{v_1}\right)^2$$

**Equation 5.1: Nilsson's Power equation for all accidents**

Cameron, *et al* estimated the power applicable to serious casualties on rural highways to be 2.59 (Cameron & Elvik, 2010).

Nilsson's power model specifically refers to accidents where there have been injuries.

Table 5.24 showed that there were no fatal accidents either before or after ASOD implementation. Accidents which did occur caused only serious or slight injury.

With Nilsson's Power equation for all injury accidents, the result was (data obtained from

Table 5.24):

$$A_2 = \mathbf{11}\left(\frac{\mathbf{121.15}}{\mathbf{126.15}}\right)^2$$

$$A_2 = \mathbf{10.145}$$

The actual number of all injury accidents after ASOD implementation, $\boldsymbol{A_2\ actual}$, was four, which is much lower than the anticipated value of 10.145 calculated by Nilsson's Power equation.

The fact that the actual value is less than the theoretical value means that the reduction in the number of accidents due to the reduction in speed was even greater than had been expected.

### 5.3.2 Accident analysis on the N1-8 between Beaufort West and Riemhoogte

The data obtained from the iPAS system contains data from January 1999 to December 2013.

In this period a total of 1 102 accidents was recorded on the N1 route. Note that this is reflected for the entire N1 between Touwsriver and the Western Cape border and not just the section under ASOD.

These accidents accounted for the following injuries on these different sections of the N1:

**Table 5.25: Injury type due to accidents on the N1**

| Route | Killed | No Injury | Serious | Slight | Unknown | Grand Total |
|---|---|---|---|---|---|---|
| NR001-4 | 95 | 1275 | 267 | 730 | 137 | 2504 |
| NR001-5 | 216 | 1781 | 389 | 1075 | 226 | 3687 |
| NR001-6 | 109 | 988 | 203 | 536 | 110 | 1946 |
| NR001-7 | 149 | 2046 | 305 | 827 | 201 | 3528 |
| NR001-8 | 74 | 1609 | 126 | 517 | 112 | 2438 |
| NR001-9 | 41 | 347 | 85 | 201 | 37 | 711 |
| **Grand Total** | **684** | **8046** | **1375** | **3886** | **823** | **14814** |

The data obtained could be used to analyse only Phase 2 of the ASOD implementation, i.e. the ASOD section between Beaufort West and Riemhoogte in 2012. There was not enough data to do any post-implementation analysis for the other phases of ASOD. They all were implemented during or after 2013. The dataset contained 792 records of injuries resulting from accidents that fell within the ASOD section.

For the analysis of Phase 2, one year's accident data, both before- and after ASOD implementation were compared in Table 5.26.

**Table 5.26: Number of injuries on the N1 within the Phase 2 ASOD stretch one year before- and after implementation**

| | Number of accidents | Sum of Killed | Sum of Serious | Sum of Slight | Sum of No Injury | Sum of Total | Average 85$^{th}$ percentile |
|---|---|---|---|---|---|---|---|
| November 2011 - November 2012 | 43 | 3 | 6 | 47 | 103 | 159 | 114 km/h |
| December 2012 - December 2013 | 23 | 0 | 0 | 1 | 34 | 35 | 113.46 km/h |

Nilsson proposed the following equation for the Injured (z):

$$z_1 = (\frac{v_1}{v_2})^2 y_0 + (\frac{v_1}{v_0})^4 (z_0 - y_0)$$

*Where*

$v_1$ = speed before implementation

$v_2$ = speed after implementation

$y_0$ = number of accidents before implementation

$z_0$ = number of injured before implementation

$z_1$ = number of injured after implementation

$$z_1 = \left(\frac{113.46}{114.0}\right)^2 43 + (\frac{113.46}{114.0})^4(56 - 43)$$

$$z_1 = 55.35\ injuries\ post\ implementation$$

The theoretical number of injuries after implementation is far higher than the actual number of injuries. For the period December 2012 to December 2013, only 1 person was slightly injured in the 23 accidents which occurred. Nilsson's Power Model had predicted it to be 55 injuries.

It is therefore found that there was a reduction in the number of accidents. This can partly be attributed to the implementation of ASOD, but because of the small change in speed, other factors that can explain the findings need to be explored. The accident database also did not have data going back far into history, so that a time series analysis could be done to explore the trends in the data.

## 5.4 Benefit-Cost Analysis

The benefit cost analysis was based on the implementation of ASOD on the N1-8 between Beaufort West and Riemhoogte – see Figure 3.2. A period of one year each pre-and post-implementation was chosen for the analysis. All costs and benefits were calculated for base year 2016.

### 5.4.1 Discussion on the costs for the benefit-cost analysis

The costs were made up of the following factors:

#### *5.4.1.1 Initial costs*

Initial costs such as the costs of construction, purchasing of the equipment and the installation and commissioning of the sites. The costs of the land surveyor were also included here. The land surveyor determined the exact distances between the sites for prosecution purposes.

#### *5.4.1.2 Recurring monthly costs for each ASOD site*

The recurring monthly costs comprised of the following:

- High speed WiFi network costs.
- Electricity costs.
- Routine maintenance costs. These were physical visits to sites for routine maintenance purposes, such as top-up of batteries, cleaning of camera lenses and overall system health checks
- Remote monitoring and support costs. These costs were for the continual monitoring of the sites to ensure maximum uptime. The sites were also monitored to make sure images captured by the cameras were clear and in focus.
- Ad-hoc site maintenance. No electronic system is 100% reliable and there were times when physical maintenance had to be done on the sites, over and above the routine maintenance.
- Project management costs for the overall management of all the different facets of the project.
- All of the above were calculated per site. In this analysis two sites were used.

#### *5.4.1.3 Recurring costs for the system*

The recurring *monthly* costs for the system as a whole included the following:

- The costs owed to Microsoft for the use of the Azure platform for the system's database.

- Datacentre costs for the hosting of the servers.
- Mobile network access point network for 3G failover in case the high speed WiFi should fail.
- Firewall costs as part of the secure environment of the system.
- Operational software costs for the platform whereby real time information is pushed to the traffic officers at the roadside.

The *annual* recurring costs included the annual costs for the ASOD system's software.

All of these system costs are fixed, irrespective of the number of ASOD sites that feed into the system.

#### 5.4.1.4 Rehabilitation costs

Rehabilitation costs were a cost item for the periodic replacement of various components at the sites, as the ASOD sites with their equipment are exposed to harsh conditions. These include extreme temperatures from below freezing in winter to temperatures in excess of 50°C in summer, dust, and high concentrations of salt in the air along the coastline. These conditions all play a part in the rapid deterioration of the electronic components, such as computers, network switches, batteries, cameras, solar panels and wind turbines. These items are all replaced within 3-year cycles.

Replacement costs due to vandalism would also fall under this category. However, in the case of the N1-8 there were no reported cases of successful vandalism at any of the sites.



There was no need to do a sensitivity analysis on the costs as the costs used in this analysis were actual costs.

### 5.4.2 Discussion on the benefits for the benefit-cost analysis

The literature consulted suggested a range of benefits to be investigated. Some of these benefits were not relevant to the study. This is discussed below:

#### 5.4.2.1 Travel time

The travel time benefit is most often used when some form of physical upgrade on the road as taken place, such as the addition of another lane. In this case no such change was made and thus the effect on travel times was not considered as a benefit.

#### *5.4.2.2 Vehicle costs*

There is a definite effect on the fuel consumption and associated vehicle running costs because of ASOD. The nature of ASOD forces drivers to maintain consistent speeds, therefore reducing the unnecessary fuel consumption associated with harsh acceleration and braking. In this case fuel consumption would decrease – a benefit. This benefit was not included in the analysis, as there were no definitive data on the different vehicle classes that use the road, and as each vehicle class had different consumption levels.

#### *5.4.2.3 Safety and accidents*

The reduction in accidents together with increased safety is the largest benefit in this study. It coincides with the main purpose of the project – to reduce the number of accidents and fatalities. The number of accidents and their severity for the year before implementation were compared to the accidents a year after implementation. Implementation was 1 December 2012. The cost of crashes were taken from the 2016 report published by the RTMC. The following tables were used from the report:

**Table 5.27: Unit cost per person by severity of RTI (Rand) (CSIR Built Environment, 2016)**

| | Unit cost per person by severity of RTI (Rand) | | | |
|---|---|---|---|---|
| **Area** | **Death** | **Serious** | **Slight** | **No injury** |
| **Anywhere** | R 3,916,187.00 | R 423,858.00 | R 71,352.00 | R 1,085.00 |
| **Urban** | R 4,004,117.00 | R 438,651.00 | R 72,241.00 | R 1,351.00 |
| **Rural** | R 2,400,452.00 | R 404,070.00 | R 69,629.00 | R 605.00 |

**Table 5.28: Cost per crash by severity of RTC (Rand) (CSIR Built Environment, 2016)**

| | Cost per incident (crash) by severity of RTC (Rand) | | | |
|---|---|---|---|---|
| Area | **Fatal** | **Major** | **Minor** | **Damage only** |
| Anywhere | R 181,092.00 | R 127,462.00 | R 20,662.00 | R 19,618.00 |
| Urban | R 196,402.00 | R 130,735.00 | R 25,099.00 | R 22,494.00 |
| Rural | R 153,217.00 | R 121,544.00 | R 14,477.00 | R 14,334.00 |

**Table 5.29: Unit cost per vehicle type (Rand) (CSIR Built Environment, 2016)**

| | Unit Cost per vehicle type (Rand) | | |
|---|---|---|---|
| | **Anywhere** | **Urban** | **Rural** |
| **Sedan** | R 14,563.00 | R 14,414.00 | R 15,011.00 |
| **Minibus** | R 14,658.00 | R 14,506.00 | R 15,112.00 |
| **Midi-bus & Bus** | R 15,136.00 | R 14,973.00 | R 15,625.00 |
| **Light Delivery Vehicle** | R 14,511.00 | R 14,363.00 | R 14,954.00 |
| **Goods vehicle** | R 15,489.00 | R 15,318.00 | R 16,004.00 |
| **Heavy goods vehicle** | R 21,825.00 | R 21,499.00 | R 22,803.00 |
| **Any vehicle** | R 14,609.00 | R 14,459.00 | R 15,060.00 |

The accident data as used in chapter 5.3.1 is summarised as follow:

**Table 5.30: Number of accidents by injury type**

| | | Injury type | | | |
|---|---|---|---|---|---|
| | **Number of accidents** | **Death** | **Serious** | **Slight** | **No injury** |
| **Pre-ASOD** | 41 | 3 | 6 | 47 | 103 |
| **Post-ASOD** | 32 | 0 | 1 | 7 | 42 |

In order to determine the costs of the accidents (incidents) themselves, the accident data was summised as follow:

**Table 5.31: Number of accidents by incident severity**

| | | Incident severity | | | |
|---|---|---|---|---|---|
| | **Number of incidents** | **Fatal** | **Major** | **Minor** | **Damage only** |
| **Pre-ASOD** | 41 | 1 | 3 | 8 | 31 |
| **Post-ASOD** | 32 | 0 | 0 | 5 | 29 |

The types of vehicles involved in these accidents were also determined:

**Table 5.32: Vehicle types involved in accidents**

| | Vehicle types | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sedan | Minibus | Midi-bus & Bus | Light Delivery Vehicle | Goods vehicle | Heavy goods vehicle | Any vehicle |
| **Pre-ASOD** | 20 | 2 | 2 | 8 | 4 | 12 | 1 |
| **Post-ASOD** | 10 | 0 | 2 | 6 | 6 | 15 | 0 |

Note that the accident data does not specify how many vehicles were involved in each accident – it only specifies the type of the main vehicle type involved in the accident.

The costs of the accidents were calculated using Table 5.27, Table 5.28 and Table 5.29 for rural areas. These calculations amounted to the following:

**Table 5.33: Costs per injury type**

| | Costs per Injury type | | | | |
|---|---|---|---|---|---|
| | Death | Serious | Slight | No injury | Total |
| **Pre-ASOD** | R 7,201,356 | R 2,424,420 | R 3,272,563 | R 62,315 | **R 12,960,654** |
| **Post-ASOD** | R - | R 404,070 | R 487,403 | R 25,410 | **R 916,883** |

**Table 5.34: Costs per incident severity**

| | Costs per Incident severity | | | | |
|---|---|---|---|---|---|
| | Fatal | Major | Minor | Damage only | Total |
| **Pre-ASOD** | R 153,217 | R 364,632 | R 115,816 | R 444,354 | **R 1,078,019** |
| **Post-ASOD** | R - | R - | R 72,385 | R 415,686 | **R 488,071** |

**Table 5.35: Costs per vehicle type**

| | Costs per Vehicle type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sedan | Minibus | Midi-bus & Bus | Light Delivery Vehicle | Goods vehicle | Heavy goods vehicle | Any vehicle | Total |
| **Pre-ASOD** | R300,220 | R30,224 | R31,250 | R119,632 | R64,016 | R273,636 | R15,060 | **R472,344** |
| **Post-ASOD** | R150,110 | R0 | R31,250 | R89,724 | R96,024 | R342,045 | R0 | **R527,793** |

All the above costs were added together so that a comparison could be made.

**Table 5.36: Total accidents costs pre- and post-ASOD**

| | Total cost pre-ASOD | Total cost post-ASOD |
|---|---|---|
| Injury type | R 12 960 654,00 | R 916 883,00 |
| Injury severity | R 1 078 019,00 | R 488 071,00 |
| Vehicle type | R 834 038,00 | R 709 153,00 |
| | | |
| **Total saving =** | **pre-ASOD-** | **post-ASOD** |
| **=** | **R14 872 711,00** | **R2 114 107,00** |
| **=** | **R12 758 604,00** | |

The saving of R12 758 604 is regarded as the benefit in the benefit-cost analysis.

It is interesting to note that although the number of accidents went down by 20%, the costs due to these accidents went down by more than 85%. This is attributed to the fact that the *severity* of the accidents had been reduced.

#### *5.4.2.4 Emissions*

The reduction in speed by some of the road users brought about a reduction in their $CO_2$ emissions. In terms of the benefit-cost analysis, this effect is not as great as that of factors such as safety, because the location of this intervention is not an urban area where, for example, the need for stop-start traffic might have been eliminated.

Also, in order to do a thorough analysis of the emissions, comprehensive data in terms of the exact vehicle classes would be required. Heavy motor vehicles and light motor vehicles emit very different types and volumes of emissions. This level of details was not available in the data and therefore this factor could not be used in the benefit-cost calculation, although it would be insignificant.

#### *5.4.2.5 Induced travel*

ASOD did not have an effect on induced travel on the routes. This factor plays a much larger role in projects where major roadworks are undertaken and new alternative routes are being constructed on the network.

In the case of the N1-8, no alternative routes are available to motorists. Therefore, this factor was not included in the analysis.

#### *5.4.2.6 Travel time reliability*

The implementation of ASOD did not have a major influence on the travel time reliability on the N1 between Beaufort West and Three Sisters. The route's volume-capacity ratio is very small.

The route also offers ample passing opportunities along the whole length of the route with no major intersections or other infrastructure that could influence the travel time reliability. The main factor influencing travel time reliability is road volumes, when the volumes start to reach capacity and the only time this comes into play is during peak holiday seasons. However, ASOD as such does not have any influence on this factor and hence this was not regarded as a benefit in this analysis.

#### *5.4.2.7 Noise*

The factor of noise plays a significant role in urban developments, where the reduction in noise contributes as a major benefit for a project. This project is located in rural areas and, although noise pollution was brought down slightly due to lower speeds, the project's aim was not to achieve any major reduction. In order for this factor to play a role in the benefit-cost analysis, speeds would have had to be brought down significantly. This was confirmed not to be the case as discussed in chapter 5.1.3.

#### *5.4.2.8 Construction disbenefits*

The construction of the ASOD brought about no disbenefits to the road users, as the construction occurred along the shoulders of the roads. The only case where there was an interruption to the normal traffic flow, was during the initial setup of the cameras. The technicians had to make use of lifting machinery and the safe work environment for them required half-width road closures. The rural nature of the road, and associated relatively low traffic volumes, ensured that road users were not inconvenienced during this time.

#### *5.4.2.9 Economic effects*

Economic effects includes costs such as medical and funeral costs, lost productivity, vehicle damage costs, property damage cost, vehicle operating costs of response units such as law enforcement and ambulances, legal costs and the human rehabilitation costs in cases of disabilities.

Other economic costs included the reporting of the incidents, data capturing and analysis, the investigation of the incidents and the time delays and increase of emissions due to congestion in cases of severe accidents. The costs of the repair of roadside furniture can also be counted.

All of the above costs were included in the unit costs as discussed in 5.4.2.3. These costs were all included in the amounts reflected in Table 5.27, Table 5.28 and Table 5.29.

The effect of ASOD would have been to reduce these costs, bring about an economic benefit.

Another economic effect is the generation of fines by the system and their associated monetary gain. This was not included in the benefit-cost analysis as the generation of fine revenue never formed part of the justification by the Western Cape Government for the ASOD-project.

#### *5.4.2.10 Community impacts*

Although not easily quantifiable, the benefit communities derive from the knowledge that speeds are reduced on ASOD-routes, and that thereby accidents are reduced, is also worth mentioning. This benefit was not monetised for this benefit-cost analysis.

#### *5.4.2.11 Wider benefits*

The ANPR functionality of the system contributes to the detection and investigation into crimes as the system can detect things like stolen vehicles and alerts the appropriate authorities in real time. These benefits were not included in the analysis, as they do not form part of the purpose of the ASOD-project.

### 5.4.3 Benefit cost calculation and discussion

The benefit-costs analysis was carried out for the implementation of ASOD on the N1-8 north of Beaufort West towards Three Sisters. This implementation comprised of two ANPR sites. The major benefit derived from the system, which was also in line with the main purpose of the project, was the reduction in the number, as well as the severity, of accidents. The analysis was carried out for only one year of implementation.

The total costs for the N1-8, in real terms in 2016 amounted to a total of R5 988 934.

The total benefits for this project amounted to R12 758 604.

Therefore, the Benefit-Cost Ratio calculates to:

$$12\ 758\ 604 : 5\ 988\ 934$$

$$2.13 : 1$$

The benefit of the implementation of this project was already double the amount of the costs within the first year of implementation.

It is important to note that this analysis focused only on the initial capital expenditure and the subsequent maintenance of the infrastructure for the cost-component of the analysis. The benefit component consisted primarily of the accident statistics, as this encompassed the primary purpose of the ASOD-project. There are, however, far wider factors that could also have been included such as the reduction in the operational costs of the law enforcement officials who are deployed on these routes, the back-office processing of the Section 341 notices, and costs in delivering the notices to the vehicle owners. Psychological benefits could also be investigated – interviews with regular road users on these routes indicated that they perceived the roads to be much safer, as the ASOD had a calming effect on motorists. It is, nonetheless, difficult to quantify and monetise such a view.

A benefit-cost analysis of a project such as this must take into account the fact that costs and benefits are realised over a period of time (Hooke, et al., 1996). The concept of net present value states that an early investment yields a much higher return. This is especially true for road safety projects such as this. If the project is highly successful, and in the process reduce accidents and fatalities to zero, the costs will exceed the benefits, as the main benefit, safety, would reduce to zero as there will be no accidents. It is important, then, to determine the benefit of maintaining the status quo by keeping the system running. One must not lose sight of the fact that no system can ever replace or control human behaviour. Statistically it is, therefore, never possible to reach a zero-accident rate. This then necessitates the continuous operation of the system, so as to minimise the likelihood of accidents.

# 6 Conclusion

This chapter gives an overview and further interpretation of the results of the data analysis of Chapter 5 and gives recommendations based on the findings. Possible future research options are also discussed.

## 6.1 Findings of the results

The aim of this study was to determine whether ASOD had had a significant impact on excessive speeding on the roads of the Western Cape. A case was made in the literature review that the reduction in speed bring about a reduction in accidents. The main focus of the study, therefore, lay with the speed analysis. Three routes with different use and vehicle classifications were identified for the study: the R27 West Coast Road between Ganzekraal and Langebaan, the N1 between Touwsriver and Riemhoogte and the N2 between Somerset West and Botriver. Two data sources for the speed analysis were used: data from CTO-stations strategically placed on the road network, and probe data obtained through an online dashboard. The focus was on excessive speeding, therefore the study focused on the speeds above 130 km/h for a road with a speed limit of 120 km/h, as there is a 10 km/h grace before prosecution, and on the 85$^{th}$ percentile speeds in the probe data analysis.

A time series analysis was performed on the CTO data for the different routes.

### 6.1.1 Findings on the R27 West Coast Road

The interrupted time series analysis conducted on the data from CTO-station 5050 on the R27 West Coast road revealed that there had been an abrupt and permanent change in the number of vehicles that sped excessively. In fact, there was an approximate 50% reduction in the number of vehicles exceeding 130 km/h. The major reduction in the number of vehicles exceeding 130 km/h could also be attributed to the fact that approximately 91% of the vehicles on the road are light motor vehicles. It is very unlikely that heavy motor vehicles would have travelled in excess of 130 km/h either before or after the ASOD implementation. The forecast model indicated only a slight decrease after the initial decrease. The model had forecast a consistent number of vehicles exceeding the 130 km/h mark. This confirms the notion prevalent in South African that one would always have approximately 5% of drivers speeding, irrespective of any intervention.

The probe data analysis was conducted on the R27 and yielded similar results as the interrupted time series analysis: there was a significant reduction in the 85$^{th}$ percentile speeds on the route, as confirmed by the paired t-test that was done on the data. The analysis also revealed that the ASOD cameras have a calming effect on drivers that extend beyond the enforcement area. It also found that there seems to be a tendency of drivers braking at the camera sites because they do not fully understand how ASOD works and that the cameras are not spot speed cameras. An interesting finding of the probe data analysis was that, although the highest speeds are recorded during the night time, the average speeds, during the most of the day, are higher. The effect of this is uniform speeds of all the vehicles as they travel along the route, rather than some vehicles travelling fast and some vehicles travelling very slowly. This points to a calming effect that the ASOD cameras have on the drivers. They all rather travel at the same speed, just below the speed limit.

In both the time series analysis and the probe data analysis, the hypothesis was proven to be correct. The implementation of ASOD did bring about a reduction in excessive speeding.

The accident analysis conducted on the data for the R27 confirmed the above finding. The actual number of accidents was far lower than the theoretically calculated figure, thereby confirming that the reduction in speed made a significant difference in both the frequency of occurrence of accidents and their severity.

### 6.1.2 Findings on the N1

The analyses on speed on the N1, on the other hand, did not display such drastic changes. At both CTO stations 480 and 306 it was found that none of the three intervention models were statistically significant. This meant that it was not possible to make a conclusive finding that ASOD had made a significant change in the occurrence of excessive speeding. However, it is important to note that there had been a downward trend even before ASOD was implemented and that trend continued downward after ASOD implementation. One could therefore say that ASOD assisted in keeping the downward trend going. If one were to take into consideration all the factors that contribute to drivers speeding, the trend could easily have gone upwards were it not for the presence of ASOD.

Simple before-and-after studies are very common in quantifying the results of specific interventions.

With speed cameras, some critics have argued that the effect of regression-to-the-mean cannot be discounted when presenting the estimates of the effects of the cameras' interventions. The regression-to-the-mean effect is the statistical phenomenon that roads with a high number of crashes in a particular period are likely to have fewer during the following period. This is the case even if no measures are introduced. Since speed enforcement is usually concentrated on roads with large numbers of crashes, the effects of any road safety intervention may be overestimated due to this effect.

The accident analysis conducted on the data for the N1 found that there was a significant reduction in accidents and injuries after the implementation of ASOD. The actual number of injuries, being one (slight injury), was far below the theoretically calculated value of 55 injuries.

This confirms that, although ASOD might not have brought down excessive speeding, it did play a role in the reduction of accidents. This can be attributed to the other advantages of the ASOD system, such as the identification of un-roadworthy and unlicensed vehicles. If those vehicles were removed from the road, the risk of accidents also would have gone down.

### 6.1.3 Findings on the N2 Sir Lowry's Pass

The time series analysis on the N2 in Sir Lowry's Pass was based on CTO 1243, located in the pass. As the speed limit in the pass is 80 km/h, the analysis was done for excessive speeding for speeds greater than 90 km/h. The analysis showed that there was an abrupt and permanent change in the number of vehicles exceeding the 90 km/h speed threshold.

### 6.1.4 Findings on the benefit-cost analysis

The benefit-cost analysis indicated a ratio of 2.13:1 within the first year of implementation on the N1-8 north of Beaufort West towards Three Sisters. This ratio indicates that the investment by the Western Cape Government had yielded a more than double return. This ratio supports the notion of the success of ASOD as a road safety tool.

It is important to note that the system cannot operate on its own. Enforcement of these speed limits and alerts generated by the system are essential, to make the project truly effective.

## 6.2 Recommendations

It is recommended that this study be repeated in future, so as to do better time series analyses. In some of the cases, the time series before implementation were not long enough to build a thorough model. This especially in the case of the accident data.

It is understood that the capture of complete data onto the iPAS system is a great challenge. It is also nearly impossible to capture historical accident data, as there is no way of determining whether the data is complete. However, with the current drive by the Western Cape Government to resolve this, the data in the future will be much more complete, thereby allowing thorough research on the data.

One of the findings of the research was that the implementation of ASOD did not necessarily reduce excessive speeds on some of the routes. It has been suggested that the reduction in accidents was due to the identification and enforcement of un-roadworthy and unlicensed vehicles. In order to utilise the ASOD system fully, it is important to make sure the information supplied by the system (including the information from eNATIS) reaches to the law enforcement officers as quickly as possible. This enables them to take a pro-active approach to road safety, instead of a reactive approach.

### 6.3 Limitations of study

The modelling approach used in this study employed two methods. An interrupted time series analysis was conducted on the data from the CTO-stations. A numerical model was used to determine the effect of the reduction of speed on the occurrence of accidents.

This approach had some limitations:

- Although the time series model did make provision for seasonality, it did not include extreme events.
- The model was also built with the assumption that the road conditions stayed the same over the time series and that the only interruption in the time series was the implementation of ASOD.
- The data from the CTO-stations did not make a differentiation between light motor vehicles and heavy motor vehicles. If it were possible to differentiate between these classes, then a more thorough time series analysis could be conducted where each vehicle class is analysed against its own speed limit. A study could then, for example, be focused on just the heavy vehicles, where they would be regarded as excessively speeding when travelling in excess of 90 km/h.
- The accident data was incomplete. There were many accidents that could not be taken into consideration for the study as their exact locations had not been captured. It was therefore not possible to allocate those accidents to an ASOD section and include them in the analysis.



### 6.4 Possible future research options

Future studies can draw correlations between the probe data and CTO-station data. Once a statistical significant relationship is found, can the probe data be extrapolated to be used on any route – especially those routes where permanent CTO-stations are not installed.

This study focused mainly on the effect on speed of the implementation of ASOD. It does not take into account the various other variables that could also have had an impact on the improvement in road safety. This is mentioned specifically with reference to the other types of violations that the system picks up as well: unlicensed and unroadworthy vehicles. Active enforcement of these violations would also have brought down the risk of accidents. A worthwhile study would be to quantify this effect.

# 7 Bibliography

Aarts, L. & van Schagen, I., 2006. Driving speed and the risk of road crashes: A review. *Accident Analysis and Prevention,* Volume 38, pp. 215-224.

Botha, H., 2013. *SANRAL Traffic Count Information Mega Yeabook 2013,* Pretoria: South African National Roads Agency.

Bruwer, M., 2017. [Interview] (25 01 2017).

Cameron, M. & Elvik, R., 2010. Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads. *Accident Analysis and Prevention,* Volume 42, pp. 1908-1915.

Collins, G. & McConnell, D., 2008. Speed harmonisation with average speed enforcement. *Traffic Engineering and Control,* 49(1), pp. 6-9.

CSIR Built Environment, 2016. *Cost of Crashes in South Africa,* Tshwane: Road Traffic Management Corporation.

Dinga, N., 2014. *Black Spot Analysis. Infrastructure impacts on the occurance of black spots on the N1 highway in the Western Cape. MEng Thesis,* Cape Town: University of Cape Town.

Donnell, E. T. et al., 2009. *Speed Concepts: Informational Guide,* Washington, D.C.: Federal Highway Adminstration.

Elvik, R., Christensen, P. & Amundsen, A., 2004. *Speed and road accidents. An evaluation of the Power Model,* Oslo: Institute of Tranport Economics.

Fildes, B., Rumbold, G. & Leening, A., 1991. *Speed behaviour and drivers' attitude to speeding,* Victoria: s.n.

Google Earth, 2013. s.l.:Google Earth.

Hooke, A., Knox, J. & Portas, D., 1996. *Cost benefit analysis of traffic light & speed cameras.* London: The Home Office Police Research Group.

Kloeden, C., McLean, A. & Glonek, G., 2002. *Reanalysis of Travelling Speed and the Risk of Crash Involvement in Adelaide South Australia,* Adelaide: Australian Transport Safety Bureau.

Maycock, G., Brocklebank, P. J. & Hall, R. D., 1998. *Road layout design standards and driver behaviour,* s.l.: Transport Research Laboratory.

Montella, A., Imbriani, L. L., Marzano, V. & Filomena, M., 2015. Effects on speed and safety of point-to-point speed enforcement systems: Evaluation on the urban motorway A56 Tangenziale di Napoli. *Accident Analysis and Prevention,* Volume 75, pp. 164-178.

Montella, A., Persaud, B., D'Apuzzo, M. & Imbriani, L., 2012. Safety evaluation of automated section speed enforcement system. *Transportation Research Board,* Issue 2281, pp. 16-25.

Montella, A., Punzo, V., Chiaradonna, S. & Mauriello, F., 2015. Point-to-point speed enforcement systems: Speed limits design criteria and analysis of drivers' compliance. *Transportation Research Part C,* Volume 53, pp. 1-18.

Montella, A., Punzo, V. & Montanino, M., 2011. Design and Evaluation of Speed Limits for an Automated Section Speed Control System. 90th Annual Meeting of the Transportation Research Board, Transportation Research Board of the National Academies, Washington, DC

Nilsson, G., 2004. *Traffic Safety Measures and the Power Model to Describe the Effect of Speed on Safety.* Lund: Traffic Engineering.

NIST/SEMATECH, 2003. *e-Handbook of Statistical Methods.* [Online]
Available at: http://www.itl.nist.gov/div898/handbook/
[Accessed 25 10 2016].

NSW Centre for Road Safety, 1996. *Historical Perspective.* [Online]
Available at: http://www.arrivealive.co.za/Historical-Perspective
[Accessed 27 02 2015].

NSW Centre for Road Safety, 2014. *Annual NSW Speed Camera Performance Review,* s.l.: NSW Centre for Road Safety.

October, K., 2015. *Western Cape Safely Home Programme* [author Interview] (22 06 2015).

Olde Kalter, M., van Beek, P. & Stemerding, M., 2005. *Reducing speed limits on highways: Dutch experiences and impact on air pollution, noise-level, traffic safety and traffic flow,* s.l.: Association for European Transport and contributors.

Peden, M. et al., 2004. *World report on road traffic injury prevention,* Geneva: World Health Organization.

Quimby, A., Maycock, G., Palmer, C. & Buttress, S., 1999. *The factors that influence a driver's choice of speed - a questionnaire study,* s.l.: Transport Research Laboratory.

Soole, D. W., Fleiter, J. & Watson, B., 2012. *Point-to-Point Speed Enforcement,* Sydney: Austroads.

Soole, D. W., Watson, B. C. & Fleiter, J. J., 2013. Effects of average speed enforcement on speed compliance and crashes: A review of the literature. *Accident Analysis and Prevention,* Volume 54, pp. 46-56.

Statistics South Africa, 2014. *Mortality and causes of death in South Africa, 2013: Findings from death notification,* Pretoria: Statistics South Africa.

Tasima (Pty) Ltd, 2015. *eNatis Live Vehicle Population.* [Online]
Available at: http://www.enatis.com/index.php/statistics/71-live-vehicle-population-per-registering-authority
[Accessed 20 10 2015].

ter Huurne, D. & Andersen, J., 2014. *A Quantitative Measure of Congestion in Stellenbosch using Probe Data.* Stellenbosch, Stellenbosch University.

TomTom, 2014. *TomTom Traffic Stats.* [Online]
Available at: http://trafficstats.tomtom.com/static/html/help/index.html
[Accessed 19 10 2015].

Transport Scotland, n.d. *Average Speed Cameras.* [Online]
Available at: http://www.transportscotland.gov.uk/road/road-safety/average-speed-cameras
[Accessed 06 September 2015].

Transportation Research Board, 1998. *Managing speed: a review of current practice for setting and enforcing speed limits,* Washington, D.C.: National Academy Press.

Vanderschuren, M. & Jobanpura, R., 2011. *Hazardous Road Safety Location Analysis: A case study of the Western Cape.* Pretoria, Centre for Transport Studies, University of Cape Town.

Western Cape Government Provincial Traffic, 2014. *Traffic Offence Code Book.* Cape Town: Western Cape Government Department of Transport and Public Works.

Western Cape Government, 2015. *Road Network Information System.* [Online]
Available at:
https://rnis.pgwc.gov.za/rnis/rnisx_pcs_speed_profile.monthly_graph?p_estation_no=5050&p_month=2015/10&p_stratum=RH
[Accessed 02 10 2015].

Western Cape Government, n.d. *About Us.* [Online]
Available at: http://safelyhome.westerncape.gov.za/about
[Accessed 03 04 2015].

World Health Organisation, 2015. *Global Status Report on Road Safety,* s.l.: World Health Organisation.