Investigating Dangerous Overtaking Manoeuvres: The effect of road design elements on the psychological state of drivers

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

April 2019

ACKNOWLEDGEMENTS

First and most importantly, I thank my Father who is in heaven and my Lord Jesus Christ for the all the he has blessed me with over the course of my studies, for allowing me the privileged to study and for giving me strength in the days when I was weak. There is absolutely no way that I would have made it within his providence.

Secondly I would like to give my sincerest thanks to my amazing wife Rod who has supported me and encouraged me throughout all the late evenings, it is truly an honour to have you by my side!

I also want to thank my parents for the support that they have given me and allowing me the chance to study.

A heartfelt thank you to my supervisor, Prof. Marion Sinclair, for providing guidance with great wisdom and compassion, and for being so patient with me when things were going much slower than expected.

I would like to also thank my bursary, Department of Water and Sanitation (DWS), for the support and allowing me the opportunity to complete this project.

Thank you TomTom, SANRAL, Syntell and the Western Cape Government's Transportation division for providing the data requested from you.

Finally I want to give thanks to all my friends for providing opportunities to get my mind off work and a special thanks to my brother in Christ Lenny for your friendship.

Declaration

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

. . . .

Signature Date

Abstract

The field of traffic psychology as an independent and leading discipline in road safety research is still fairly young, as the first issue of Transportation Research Part F was only released in 1998, yet it has grown tremendously over the past two decades and numerous studies within this field have since been conducted. The most prominent argument seems to be regarding the risk compensation theory and whether or not drivers purposefully take risks on the road. Parallel to this, numerous studies have also been conducted on the influence of personality and psychology on driver behaviour. Within these, some have noted that the roadway and environmental elements surrounding the roadway influences the psychological state of drivers, even to the extent as to affect the behaviour of individuals.

In this study, the effect of road design elements on drivers' choice to conduct dangerous overtaking manoeuvres is investigated. Many have discussed the effect of roadway elements on the psychological state of drivers, but few have considered which roadway elements contribute to drivers conducting dangerous overtaking manoeuvres and therefore this study aimed to fill this gap.

The main objective of this study was achieved by analysing vehicle speed data, traffic volume data, accident data and also observing driver behaviour on three selected roadway sections. The three road sections that were selected were all two-lane, undivided class 2 (major arterial) rural roads. This allowed for the identification of locations along the roadway sections at which drivers exhibited more dangerous behaviour. Furthermore the roadway design elements present at these identified locations were recorded and analysed in order to determine which elements contributed to drivers conducting dangerous overtaking manoeuvres.

It was found that two road design elements and one environmental element indeed contributed to drivers conducting dangerous overtaking manoeuvres. The first roadway element is the posted speed limit and the effect thereof on the psychological state of drivers and the second was the placement of road markings permitting or prohibiting overtaking. The first environmental element was the behaviour of other drivers in the vicinity. It was discovered that a wrongly applied combination of these three factors often led to drivers conducting dangerous overtaking manoeuvre.

Opsomming

Die veld van verkeersielkunde as 'n onafhanklike en toonaangewende dissipline in padveiligheidsnavorsing is steeds relatiewe 'jonk', met die eerste weergawe van 'Transportation Research Part F' of 'Vervoer Navorsing Deel F' wat vir die eerste keer in 1998 uitgebring is. Sedertdien het hierdie veld geweldig gegroei oor en talle studies in hierdie veld is reeds uitgevoer.

Die mees prominente argument binne hierdie veld blyk te wees met betrekking tot die risiko vergoedingsteorie (risk compensation theory in engels) en of bestuurders doelbewus risiko's op die pad inneem. Parallel hiermee is talle studies ook uitgevoer oor die invloed van persoonlikheid en sielkunde op die gedrag van bestuurders. Met hierdie studies het sommige opgemerk dat die pad-en omgewingselemente rondom die pad die sielkundige toestand van bestuurders benvloed, selfs tot die mate om die gedrag van individue te benvloed.

In hierdie studie word die effek van padontwerp-elemente op bestuurders se keuse om gevaarlike verbysteek bewegings uit te voer, ondersoek. Baie navorsers het reeds die effek van padelemente op die sielkundige toestand van bestuurders bespreuk, maar min het die moontlike pad-elemente was mmontlik kan bydra tot bestturders wat gevaarlike verbysteek bewegings uitvoer, oorweeg en daarom het hierdie studie gemik om daardie gaping te vul.

Die hoof doel van hierdie studie is behaal deur die ontleding van voertuie se spoeddata, verkeersvolume data, ongeluksdata en die waarneming van bestuurders se gedrag op drie geselekteerde paaie. Al drie van die verkose paaie was tweerigting, onverdeelde, klas 2 (hoof arterile), landelike paaie. Die ontleding van die data voorheen genoem het dit moontlik gemaak om plekke op die paaie te identifiseer waar bestuurders gevaarliker gedrag uitgeoefen het. Verder is die verskeie padontwerp-elemente teenwoordig by hierdie gedentifiseerde liggings aangeteken en ontleed om te bepaal watter elemente bygedra het tot bestuurders wat gevaarlike verbysteek bewegings uitvoer.

Daar is bevind dat twee padontwerp-elemente en een omgewingselement inderdaad bygedra het tot bestuurders wat gevaarlike verbysteek bewegings uitvoer. Die eerste

padontwerp-element is die aangeduide spoedgrens en die effek daarvan op die sielkundige toestand van bestuurders en die tweede is die ligging/plasing van padtekens wat verbysteek bewegings toelaat of verbied. Die omgewingselement wat bygedra het tot gevaarlike gedrag van bestruurders, was die gedrad van ander bestuurderd in die omgewing. Die is bevind dat 'n verkeerd toegepaste kombinasie van hierdie drie faktore daartoe gelei het dat bestuurders gevaarlike verbysteek bewegings uitvoer.

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Chapter 1

INTRODUCTION

”Every kind of beast and bird, of reptile and sea creature, can be and has been tamed by mankind, but no human being can tame the tongue.” - Ya’aqov

This quote by Ya’aqov was written approximately 1940 years ago and yet it still hold true today, but it can even be extended into the field of engineering and say that mankind cannot tame the actions of mankind, especially it seems when it gets to driver behaviour. The amount of illegal and dangerous overtaking manoeuvres that are conducted on a daily basis is very concerning.

For a long time driver behaviour has been troubling and engineers and psychologists alike have worked together in trying to find a solution to this problem and to minimize the number of road fatalities occurring worldwide. Much has been achieved over the past 20 years with regards to this topic, but could more have been done? In 1999, Ezra Hauer made this statement with regards to road design standards:

”Designers of roads believe that roads built to standards are safe. Lawyers and judges assume that roads designed to standards are appropriately safe. Beliefs, no matter how passionately held, and assumptions, no matter how repeatedly applied, are fallible guides to truth. The truth is that roads designed to standards are not safe, not unsafe, nor are they appropriately safe; roads designed to standards have an unpremeditated level of safety.” - Ezra Hauer

This quote by Hauer (1999) is probably not the most famous within the field of Civil Engineering, for it is a tough one to chew on and to accept if you are an engineer, yet the question remains, is this true?

This study will aim to determine which roadway and environmental elements, if any, contribute to drivers conducting dangerous overtaking manoeuvres. This will be achieved by completing a traffic volume, vehicle speed and accident data analyses in combination with observing driver behaviour on site and collecting all the information with regards to the roadway and environment at locations where drivers exhibit dangerous behaviour. By identifying such elements, more emphasis could be placed on them and solutions can be found that will decrease the contribution that the road design may have to drivers exhibiting dangerous behaviour.

1.1 Project Background and Origin

South Africa has one of the highest ratios of road fatalities per capita in the world, with approximately 25.1 fatalities per 100 000 inhabitants per year. Many of these accidents can be attributed to a combination of the high speeds at which vehicles travel and the long distances that some motorists need to travel between origin and destination. The questions therefore arises, 'who is to blame for these accidents, are the blame of the accidents primarily the drivers' or should more emphasis be placed on the road design?'

Numerous studies have been conducted about the psychology and behaviour of drivers on the road, most of which have focussed more on the human aspect thereof, but few have looked at which roadway elements may be tied to what type of behaviour. The most predominant theories in this field seems to be that of risk compensation and risk homeostasis, both of which have been an ongoing argument for some time, but the core principles are universally accepted Lu *et al.* (2012).

One of the ever increasing areas of concern in road safety however, is the amount and severity of accidents that occur due to dangerous overtaking. This is especially concerning, due to the fact that these types of accidents can and should be avoided, as it involves one or multiple drivers making a cognitive decision to attempt a manoeuvre which will put their own life, as well as the lives of others, at risk.

It could be argued that the occurrence of such accidents are purely due to driver error and that drivers should be held solely responsible when such accidents occur. Although this might be the case in some instances, the impact that the road design and the surrounding environment have on the psychological condition of drivers should not be neglected (Stanton & Salmon, 2009). When considering the causes for drivers exercising dangerous behaviour while driving, it would be wise to account for both the psychological state of drivers prior to embarking on any journey, as well as the impact that the road design and surrounding environment could have on their psychological state as they move along their journey (Reason, 1990). It may therefore be considered irresponsible from an investigative point of view to simply assume that the fault of such behaviour is found solely with human error, as the impact of the road design and surrounding environment on the psychological state of drivers may be of such significance as to influence their behaviour.

According to Neisser (1976), the information with regards to the surroundings that a driver samples as he/she moves along the roadway, serves to modify and update the internal, cognitive, schema of the world, which will direct further search by influencing the type of information being searched for (Stanton & Salmon, 2009). This then implies that past experiences, whether short or long term, will serve to influence the attitude, and therefore behaviour of a driver, as well as give direction with regards to the expectation of encountering certain events or obstacles along his/her journey. From this, one can draw the conclusion that the psychological state of drivers is continuously influenced by the information gathered from outside factors, even though the influence may vary in extent and manner (Stanton & Salmon, 2009).

This is not to say that the primary blame should be given to the road design, for that too would be incorrect, as driver behaviour is very much dependant on a driver's personality and cognitive ability (Hirsh *et al.*, 2008). Therefore from this, it could be noted that a possible combination of road design and environmental elements may strongly contribute to drivers conducting dangerous behaviour. One element by itself may have some impact on the psychological state of drivers, but it is the visual field as a whole that the driver takes into account and therefore a combination of roadway elements is likely to have a much greater effect on a driver's psychological state Vaa (2014).

Furthermore, it is also important to note that the psychological state of any individual prior to embarking on a journey will most likely be the greatest factor in determining the choice of action that a driver will take when faced with certain scenarios (Michon, 1985) (cited by Verster & Roth (2012)).

1.2 Project Objectives

The primary objective of this study is to determine which roadway and environmental elements contribute to drivers conducting dangerous overtaking manoeuvres. Secondary objectives to this will be:

i) Does these factors impair the driver's ability to accurately perceive the risk of the situation and therefore causing him/her to make a decision based on misinterpreted information, or does the driver accurate perceive the risk of the situation, but still choose to conduct the dangerous overtaking manoeuvre?

ii) In what manner can these identified roadway and environmental elements be adjusted to decrease the contribution to drivers conduction dangerous overtaking manoeuvres? (Even though this is not the primary aim of this study and future research into this area is advised, this will briefly be considered and discussed at the end).

As mentioned in section 1.1, the psychological condition of drivers prior to embarking on any journey, but also how their psychological state is influenced as they travel along their journey, needs to be considered and investigated if the conclusion is to be as accurate as possible. The danger therefore, is to over-emphasize one area of consideration while neglecting another. It is therefore necessary to examine and consider these two fields of study - human behaviour in traffic and the effects that the road design may have on psychological state of drivers - parallel to one another.

1.3 Limitations

The greatest limitation to this study is the fact that is is based on cultural driver behaviour, meaning that study specifically considered South African road users and even more specific than that, the three roads that were selected are all within the same province (Western Cape). It is therefore important that there might be a difference between behaviour found in this region than in other parts of the world. For this reason it would be advised to consider this type of study for your own region, but this could be a basis from which to build. This again places emphasis on the psychological state of drivers before embarking on any journey and shows that this should not be neglected when considering driver behaviour.

This study was also limited to the data that was available from the various sources, for examples a difficulty was encountered with regards to the accident data of one of the roads that were selected and therefore an accident data analysis could not be conducted for this roadway. There was difficulties in determining the location of the accidents and included within the data was numerous accidents that did not occur on the section that was investigated. For this reason the data could not be used for the purpose of this study.

Furthermore determining the extent to which the roadway elements influenced the psychological state of drivers also proved troublesome and is likely to be a talking point for many years in the future, as it is already clear that many people have a lot of different opinion with regards to this topic. Luckily this study was not very reliant on this and therefore it only served as a slight limitation.

This study was also only conducted on two-lane rural major arterial roads and although some of the principles can be applied to other type of roadways, the ones mentioned here are specific to this type of road.

Additionally, the data that was requested from TomTom consisted only of normal weekdays, meaning that all weekends and public holidays were excluded from the data.

Chapter 2

LITERATURE STUDY

2.1 Human Behaviour in Traffic Environment

Generally, the behaviour of drivers are largely influenced by their psychological condition and characteristics, both of which is likely to differ from one individual to the next (Lu *et al.*, 2012). Furthermore, the psychological state of any individual does also not remain constant at all times and is continually affected by the environment that the individual finds themselves in (Stanton & Salmon, 2009). The difference in the current psychological state of individuals therefore also influences the manner and degree to which the surrounding environment affects the psychological state of individuals.

The theories of risk homeostasis (Trimpop (1996); Malnaca (2008); Vrolix (2006)), behavioural adaptation (Hoedemaeker & Brookhuis (1998); Jonah *et al.* (2001); Lewis-Evans & Charlton (2006); Reinhardt-Rutland (2001)), risk compensation (Dulisse, 1997), and risk adaptation (Koornstra, 2009), all agree that perceived risk affects one's driving behaviour. For this reason the decisions that drivers make with regards to vehicle manoeuvres in any given situation, appear to be a function of perceived risk (Lu *et al.*, 2012).

Risk compensation theory (RCT), also known as behavioural adaptation, states that drivers compensate the difference between perceived and acceptable levels of risk (Trimpop, 1996). According to Lewis-Evans & Charlton (2006), the phenomenon of drivers reacting to safety interventions in a manner contrary to what was intended, can be seen as behavioural adaptation. Therefore according to WILDE (1988), behavioural adaptation occurs when drivers change their behaviour due to a perceived change in risk of some behavioural patterns or when a gain in safety in one area offsets to a loss in safety in another (Ward, 2000). A commonly found example is the increase in speeds that occur due to lanes being widened, therefore the intention was to increase the safety of motorists by increasing the lane width, bu the increase in speeds negate any increase in overall safety (Lewis-Evans & Charlton, 2006). The name of risk compensation comes from the hypothesis that drivers respond to any decrease in perception of situational risk by adapting their behaviour to such reductions in risk (Assum *et al.*, 1999).

Taylor (1964) examined behavioural compensation in traffic and observed that driving is a self-paced task which is governed by anxiety levels and emotional tension which represent a transformation of the physiological experience of risk; these experiences, in turn, influence the driving task in a closed-loop feedback process (Trimpop, 1996). This argument therefore suggests that individuals can perceive risk signals apart from conscious knowledge and compensate any undesirable levels of perceived risk through their behaviour (Lu *et al.*, 2012). From this theory, theories of risk homeostasis were developed.

Homeostasis, or also known as the process of fluctuation around a target level, is the property of a system that regulates its internal environment in order to maintain a stable, constant environment (Cannon, 1929). As an example, humans maintain a near-constant body temperature to adapt to diverse climates. Researchers such as Malnaca (2008), Trimpop (1996), and Vrolix (2006) all view risk-taking as homeostatic.

Risk homeostasis theory (RHT), developed by Wilde (1982), extended the risk compensation concept to risk homeostasis, which argues that instead of compensating for risk, individuals aim to maintain a subjectively optimal level of tolerated risk. This optimal level is determined on the basis of accepting a certain level of subjectively estimated risk to their health and safety in exchange for the benefits that they hope to receive from that activity (Malnaca, 2008). The debate over risk hemeostasis and risk compensation theory have continued for over a quarter of a century and is likely to still continue for some time, fortunately however, its key components are universally accepted (Lu *et al.*, 2012).

Drivers tend to base the decision with regards to their behaviour on perceived dis-utility, which is the sum of the subjectively estimated cost of travel time, perceived risk of being in an accident and its potential consequences, and the perceived risk of being fined by enforcement of speed limits (Lu *et al.*, 2012). These factors all include a biased estimation or perception from individual drivers, thus the exact ratio between these three factors will differ from one individual to the next. A study conducted by Tarko (2009), indicated that perceived dis-utility as a whole, is a non-linear function of speed.

Furthermore every driver has a specific hierarchy of action sequences, which are determined by previous experiences or memory units. These action sequences are invoked when particular events occur or particular conditions are satisfied (Stanton & Salmon, 2009). Meaning that every driver will have a default choice of actions that they will take when faced with specific scenarios. These action choices have been shaped and influenced by past experiences. This idea corresponds with that of Taylor (1964) and Trimpop (1996) as mentioned previously.

For this reason, a driver's knowledge, or presumed knowledge of how the world works, leads to specific anticipation of certain kinds of information and provide a pre-determined and ready means of interpretation thereof (Stanton & Salmon, 2009). In other words, when a driver starts a journey, the driver will have a subconscious expectation of events and obstacles that he/she will encounter along the way due to past experiences. As a driver moves along the selected roadway, information regarding the surroundings is sampled during the course of events. Neisser (1976) stated that the information sampled serves to modify and update the internal, cognitive, schema of the world, which will direct further search by influencing the type of information being searched for (Stanton & Salmon, 2009). Therefore every individual needs to be able to screen from the current attentional focus any stimuli that has previously been experienced as irrelevant. The ability to screen irrelevant information is a phenomenon called latent inhibition (LI) (Lubow, 1989), and is important especially for motorists travelling at high speeds, as an increase in LI capacity will bring forth a in reaction time due to drivers having to process less information.

When a driver is met with circumstances outside of the expected events or obstacles, the driver tends to interpret the information more slowly, leading to delayed decision making and very often leads to wrong decisions being made or the right decisions being made too late, which is likely to cause an accident (Stanton & Salmon, 2009). Furthermore, LI may also differ to a large degree from one individual to the next, therefore even when having the same expectation of events or obstacles, the reaction time of individuals are likely to differ even when faced with the same event or obstacle (Carson *et al.*, 2003).

Every individual therefore, whether in a traffic environment or not, will behave in a unique manner different from others due to the difference in personality and cognitive ability (Hirsh *et al.*, 2008).

A concept in which driver tasks were divided into three basic levels were first developed by Michon (1985). The first is the Strategic level, the second is the Tactical level and the third is the Operational level (Michon, 1985). At the Strategic level, decisions are made before travelling, which means that one's attitude toward the road environment and other road users are decided before embarking on any journey. This is where one's own physical status, the route choice, condition on the car, etc. needs to be reflected upon. A person is influenced by various factors on this level, such as emotions, stress, work load, motives, etc. The Tactical level is where most of the decisions that a driver make while driving are determined and is the level on which drivers anticipate driving manoeuvres that are going to happen from other road users (Michon, 1985). Two major factors that drivers estimate on this level are speed and distance, not only of oncoming vehicles, but also of vehicles travelling in the same direction and also estimating one's own driving speed in comparison to others (Michon, 1985). Therefore perception and cognition play very important roles within this section. The Operational level is where the actual manoeuvres or vehicle control occurs in order to avoid danger, such as braking, swerving and speeding (Michon, 1985). This is mainly determined by the performance and risk perception of the individual drivers.

Rasmussen (1986) developed another model, differing slightly to the one introduced by Michon, he suggested that driver behaviour can be categorised into three basic levels, namely Knowledge-based, Rule-based, and Skill-based. Knowledge-based behaviour involves consciously formulating a goal or goals and also developing plans for achieving these goals (Rasmussen, 1986). Rule-based behaviour is when a driver acts or makes decisions from his/her own moral values (what they perceive as correct or acceptable behaviour). This determine the relationship and attitude of any individual toward the posted speed limit and all other roadway laws and rules. Skill-based behaviour might be best described as automated behaviour and require no conscious decision or attention to perform the action due to the action being completed many times before (Rasmussen, 1986). Table 2.1 was developed by Verster & Roth (2012) from a combination of Michon and Rasmussen's models.

Table 2.1: Driver tasks according to Michon and Rasmussen

	Strategic Level (Planning)	**Tactical Level (Normal driving action)**	**Operational Level (Vehicle control)**
Knowledge Based	Navigation in unfamiliar town	Controlling a skid in icy roads	Novice driver at first lesson
Rule Based	Choice between familiar routes	Passing other vehicles	Driving an unfamiliar vehicle
Skill Based	Home-to-work travel	Negotiating familiar junctions	Vehicle handling around corners

As can be seen from the information presented in table 2.1, the decision on when and how to pass other vehicles fall as a combination of tactical and rule-based levels, therefore the type and risk level of overtaking manoeuvres that individuals view as acceptable are predominantly determined within these two levels (Verster & Roth, 2012). Therefore before an individual embarks on any journey, they have already formulated for themselves what type of behaviour they should or should not exhibit. This once again points to the preceding psychological state of drivers indeed playing an important role in behaviour.

Pitting short-term against the demands of long-term goals is one of the most difficult tasks in human decision making and the temptations that appear from one's immediate surroundings can often conflict with the requirements of longer term goals (Hirsh *et al.*, 2008). Therefore the problem lies with desire and the action that stems from it (Willard, 2018). Therefore the decisions previously made within the Tactical level may be affected and changed as time passes while drivers travel along the roadway and requires a firm resolution within the Rule-based level not to give in to the desires that arises against previously determined decisions. As an example, one may not want to break the law by conducting an illegal overtaking manoeuvre, but when driving behind a vehicle moving much slower than one's desired speed, the desire to overtake the slower moving vehicle emerges and it therefore requires a firm resolution not to give in to such desires.

Reaching long term goals or remaining loyal to moral convictions therefore require the ability to modulate the desire for short term or immediate gratification (Hirsh *et al.*, 2008). Therefore it is the lack of this ability that contributes to drivers exhibiting dangerous behaviour. Individuals that tend to choose smaller, but more immediate rewards are most often characterised by impulsive stimuli-driven behaviours that can interfere with long term goal pursuits (Mischel *et al.*, 1989).

It is also important to note that behavioural patterns can differ from male to female, and also between age groups (Galvan *et al.*, 2007). Adolescents tend to make more impulsive and emotional decisions, rather than practical and logical ones and also tend to miscommunicate with other road users (Galvan *et al.*, 2007). Deery (1999) stated that research indicated that younger, inexperienced drivers tend to underestimate the risk involved in a variety of situations, while at the same time overestimating their own capabilities. Inexperienced drivers also showed a willingness to accept a higher level of risk than experienced drivers (Deery, 1999). Galvan *et al.* (2007) further stated that adolescent drivers find it more difficult to accurately estimate speed, distance and time as compared to more experienced drivers. Further research indicated that the inability to accurately estimate the risk involved in certain scenarios were especially apparent with young male drivers, as they tend to be influenced more easily by their peer group (Shinar, 2007). Hosking *et al.* (2010) conducted a study on the visual search patterns and hazard responses of experienced and inexperienced motorcycle drivers and found that experienced drivers exhibited more flexible visual scanning patterns that were sensitive to the presence of hazards than inexperienced drivers.

Communication between road users is important, because it encompasses not only the formal, written laws and rules of the road, but also the informal ones that exist between road users. It is therefore important to consider the driving behaviour of motorists in a specific region when designing or upgrading road networks (Lamm *et al.*, 1995). Interpersonal communication has an immediate impact on driver behaviour and will impact choice of speed, following distance, choice of overtaking and yielding to other vehicles and pedestrians (Bucchi *et al.*, 2012).

According to Rumar (1985), driver behaviour is governed not only by the individuals knowledge and skills, but also by the environment in which the behaviour takes place and indirect influences, such as road design and layout, vehicle nature, traffic laws and enforcement, affect driver behaviour (Stanton & Salmon, 2009). Although an individual is most often consistent in his/her actions, he/she frequently adopts attitudes, some of which may be irrational (Bucchi *et al.*, 2012).

2.1.1 The role of psychology in the development of driver behaviour theories

Traffic psychology as an independent and leading discipline in road safety research is still a fairly new field, as the first issue of Transportation Research Part F was only released in 1998 (Vaa, 2014), yet it has grown tremendously over the past two decades and numerous studies within this field have since been conducted. The earliest studies in this field were, however, conducted already in the first half of the 20th century, but has only recently picked up some speed in terms of the attention given to it. In this section, a quick overview of the role of psychology in the development of driver models will be given.

The most prominent early study was done by Gibson & Crooks (1938), which was built on the work of Lewin (1936). Lewin (1940) introduced and described the field theory, which as a summary is the life space containing a person and his/her psychological environment (Lewin, 1936). The psychological as named here is the environment as perceived and understood by a person, but more than that, it is the environment as related to his/her personal needs (Vaa, 2014). Many objects that are perceived are of no concern presently and therefore exist only in the background of an individual's psychological environment (Lewin, 1940). Or in a more modern description, unwanted information is screened out in order to process information faster and make room for more information to be processed (Carson *et al.*, 2003) and (Stanton & Salmon, 2009). Other objects, according to Gibson & Crooks (1938), have positive and negative 'valences'; positive if the object promises to meet a present need and negative if it threatens survival.

Gibson & Crooks (1938) argued that the field of safe travel is not fixed in physical space, but rather that the field is moving with the car though space as it moves along the roadway. The point of reference therefore, is not a stationary object within the environment, but rather the driver himself. They continue to explain this with an analogy of brakes, stating that, excluding the case of an emergency, more efficient brakes will not in themselves make driving safer (Gibson & Crooks, 1938). It is true that better brakes will reduce the minimum stopping distance, but the driver will soon learn this new zone/distance and since it is his field-zone ration that remains constance, he will allow only the same relative margin between field and zone as before (Gibson & Crooks, 1938). Meaning that the driver's understanding of the car's better brakes will cause him/her to drive closer to other vehicles, or allow for a shorter stopping distance as he/she previously did and therefore the safety of the situation remains constant.

This is the very essence of risk compensation. The first classical study that followed this was only found again in 1987, when ... tested the effect of ABS brakes on driver behaviour among taxi drivers in Munich. This study confirmed that risk compensation indeed exists, as drivers adapted their behaviour with the improvement of their brakes (Vaa, 2014).

One major theory that has been neglected for a long time, or at least have received very little attention, is the learning theory (Vaa, 2014), which is the process by means of which the individual adopts his own behaviour, which manifests with the need to not merely observe and explore, but to experiment the surrounding reality (Bucchi *et al.*, 2012). Bucchi *et al.* (2012) further explains that there are two types of learning that interact with one another: the first is the intended acquisition of notions, while the second is based on past experienced and the motivation of learning. The second type of learning is the most important in the case of driving and requires joint biopsychological and mental participation (Bucchi *et al.*, 2012). This, based on the sense of discovery and research, is self-motivating and contributes, when the subject learns, to altering behaviour (Bucchi *et al.*, 2012).

Atkinson *et al.* (1996) explained the learning theory as encountering a discriminative stimulus, which will bring forth a response, which will result in a reinforced stimulus, resulting in the feeling of greater mastery over something. Vaa (2014) uses the learning theory at described by Atkinson *et al.* (1996) to assert that this is what brings forth the change in behaviour when driving, it is the feeling of a greater mastery of the vehicle and therefore based purely on the psychology of the driver. He argues that it is not the fact that drivers aim to maintain a stable level of risk, but rather that they feel more in control of the vehicle, that results in the change in behaviour. In agreement with this, Bucchi *et al.* (2012) stated that the individual "makes experience his own," and with his intelligence, participates in many situations, referring al the while to information from the past. The individual then changes his behaviour according to what he/she has learned and therefore adapts to the environment (Bucchi *et al.*, 2012).

Fuller (1984) attempted to conceptualise driving as mostly threat-avoidance, but most stand in opposition to this view and says that driving is much more than simply trying to avoid threats. It is clear that some part of driving does indeed involve avoiding threats, but according to Vaa (2014), driving is much more than this, it is also "an arena of social interaction", displaying the extra motives (Näätänen & Summala, 1974), experiencing passion and pleasure (Rothengatter, 1988), personality traits (Ulleberg, 2001), and sensation seeking (Jonah *et al.*, 2001).

The work of Damasio (1994) also played brought forth a paradigm shift in the field of driver psychology. The works of Gibson & Crooks (1938), Taylor (1964), Näätänen & Summala (1974), and Wilde (1982) can all be labelled as motivational, meaning that they all view a person's motive as being fundamental, while Damasio (1994) suggests that emotion might be a more fruitful concept. The main idea that Damasio (1994) suggests, is that every individual has a target 'feeling' at which they feel most comfortable and function the best at and he argues that every driver seeks to maintain or restore that target feeling. According to Vaa (2014), there is no doubt that driving is motivational, but feelings and emotions are both concepts that comes closer to what is actually going on organically in an individual.

Vaa (2014) took the position of agreeing with Damasio (1994) and stated that if Miller's explanation of the cognitive span (which will be explained shortly) is true, then this poses serious questions for the risk homeostatis theory. The core idea of the work presented by Miller (1956), is that the number of items that a human can keep within the working memory, is 7+-2. Memory also depend on categorising the information, or named chunking by Miller, which involves organizing bits of information perceptually and cognitively into larger 'chunks. An example of this is trying to memorise the the number 2486513790 when it is written as one number it is difficult, but when categorizing the information in becomes easier, for example 24865 13790 or even better 24.86.5 and 13.79.0 (Miller, 1956).

Later research revealed that memory span is not constant, but depends on the category used, for example the span is approximately 7 for digits, six for letters and five for words (Cowan, 2001). Cowan (2001) proposed that the working memory has a capacity of approximately four 'chunks' of information. This serves as a reminder that the cognitive span of working memory is limited, and driving is no exception to this and also serves to show that there is a difference between recalling digits from memory in an experimental context and having to compare alternatives of what the best actions to take is (Vaa, 2014). This then gives a strong stand point against the rationalist belief that it is possible for an individual to consider and weigh all possible alternatives against one another and finding the best solution without involving emotions or feelings (Vaa, 2014).

Wilde (1982) stated that a driver compares all different alternatives with one another and then chooses the most beneficial one based from a costs-benefits analysis. Vaa (2014) and Damasio (1994) stands in opposition to this and said that it is not possible for a human to accurately compare every alternative with one another, as this is far above the capabilities of a person. It is just not possible to weigh up all of the possible benefits and losses associated with certain action, for the possibilities are too vast (Vaa, 2014). Damasio (1994) stated that in his view, it is rather the opposite; it is still a cost-benefit analysis of some sort, but the alternatives are limited and one's feelings and emotions are applied to consider them. For his own explanation of this principle, see pg 173 of his work.

Finally it should be noted that one should never neglect the personality traits of a person (Vaa, 2014), for this is sure to influence the manner in which a person will act (Hirsh *et al.*, 2008). All drivers contribute to the social system of road traffic, only all do it in different ways:

some by creating conflict, some by solving or avoiding conflict and others simply use the road environment and what it can offer in terms of sensation seeking (Vaa, 2014).

2.1.2 Impact of Society of Behaviour

One of the factors that influences human behaviour in general, not only when driving, is the society that an individual lives in (Bucchi *et al.*, 2012). It takes a person of immense strong will to act contrary to the society surrounding such a person (Hirsh *et al.*, 2008). But even the strongest of wills will in some manner be influenced by the norms and behavioural patterns of the society. A person's socialisation is strongly influenced by what people of public authority do and say. Media, whether positive or negative, influences the public's perspective on the transportation system. it may lead to motorists ignoring the speed limits, or even people refusing to pay their speed fines as a result of bad publicity; or it may lead to motorists paying more attention and being more obedient to the rules of the road. Accurate or inaccurate enforcement is largely linked with the public's view and tendency to obey or neglect the speed limit (Abele & Møller, 2011). The attitude of police officers need to change from trying to get money to trying to prevent unsafe driving (Shinar, 2007), whether that is speeding, unlawful overtaking, or any other offence.

Even though the society has a large impact on behavioural patterns and moral standards of a person, that individual will always be alert to any kind of limitation that threatens to take away from his/her freedom (Bucchi *et al.*, 2012). For instance there are some who speed and drive aggressively simply because they find pleasure out of it and want to dominate others around them, which tends to happen more with men than with women (Jonah *et al.*, 2001). Others simply do not agree with the society in term of what amount of risk is socially acceptable, and therefore do not conform to the standards and norms around them (Bucchi *et al.*, 2012). The driver therefore, whilst driving, does not simply manifest his/her own personality, but also expresses a social conditioning, which may either be positive or negative (Bucchi *et al.*, 2012).

2.1.2.1 Stress

Stress is one of the major contributing factors for speeding and underestimating risk (Ge *et al.*, 2014), both of these phenomenon are serious behavioural problems with drivers. Stress tend to lead to distortion of information during the perception process as well as cause a lack of attention while driving (Ellenbogen *et al.*, 2002). This will lead to problems with processing the information and ultimately to erroneous decision making due to stress hormones affecting the prefrontal brain regions and dopaminergic pathways (Moghaddam & Jackson, 2004). The negative effect of stress on a driver will only be multiplied when fatigue and time pressure is added, which is often the case in the modern day transportation system (Ge *et al.*, 2014). In most of the cases while driving, time pressure is a factor that influences the driver, as the driver only has a limited amount of time to make a decision and that while moving at high speeds as well. Add to the time pressure and high speed environment a fatigue individual, and one has a driver that is placed under a severe amount of stress (Shinar, 2007). Thus stress from a transportation point of view does not only refer to the emotional aspect of the word, but also the physical. A driver that finds themselves in the circumstances mentioned, will find it very difficult to make accurate decisions, and even if the correct decision is made, it is likely that the time delay to make that decision would place them in a dangerous situation (Shinar, 2007). Thus it is clear why so many accidents occur on the road. It is also clear from this that the road needs to be designed in such a way that it limits the amount of stress that is placed upon the drivers.

The above mentioned information refers more to the physical effect of the roadway environment on a person, but another factor that influences a driver's capabilities, is emotional stress. Driving related stress mainly stems from environmental factors an personal experience that causes drivers to be anxious when driving (Rowden *et al.*, 2011). Driver stress usually occurs when an individual perceives his/her abilities to be incapable/insufficient of managing the dangers and demands of driving and may result in a strong dislike of driving (Gulian *et al.*, 1989);(Matthews, 2002). Kontogiannis (2006) have found that high stress levels are associated with traffic violations while driving and an increase in self-reporting mistakes (Ge *et al.*, 2014).

A person that experiences stress tends to simplify thinking and acting in order to make faster decisions or react faster, but this very often leads to the accuracy of those decisions decreasing and risky strategies occur (Ge *et al.*, 2014). When a driver is faced with this, they tend to individualise decisions, thus focussing on one decision at the expense of others (Shinar, 2007). In essence, the driver loses sight of the broader situation and focusses of that which they perceive as most important, which can easily result in an accident. Very often, drivers fall back on automatisms and thus neglecting attention to the environment.

2.1.2.2 Motives

The behaviour of every driver is influenced by their motive behind the trip, whether they are aware of it or not (Vaa, 2014). The motives of individuals serve them in two ways. Firstly, it is for setting or avoiding any behaviour or situation that would take away from the satisfaction of their own needs (Wilde, 1982). Secondly, the motive of an individual sees to it that the preconditions for satisfaction of their relevant needs are met(Wilde, 1982). Often individuals are influenced by several motives at the same time, even if they be contradicting. The needs, wishes and interests of an individual all produce or reflect one's motives (Bucchi *et al.*, 2012). All people differ to some extent and some individuals tend to be more selfish than others, such individuals tend to want to satisfy their own needs, wishes and interests (Vaa, 2014). In contrast to this, other drivers are willing to sacrifice some of their own wishes and interests for the benefit of others, as long as their needs are fulfilled.

Conflicting motives may arise at various levels. The first being between an individual or a group and society. In this case the individual's interests are opposing to that of the society and therefore leads to certain individuals behaving differently to the other road users around them (Bucchi *et al.*, 2012). The second is at communication level, where inter-individual conflict of interests occur. When measures are taken to encourage drivers to drive in a different way that they are used to or want to, it is experienced negatively by drivers (Reason, 1990). The third happens at an individual level, where intra-individual conflict of interests occur. This happens when an individual has two or more different, and sometimes opposing interests (Bucchi *et al.*, 2012). When this occurs, people tend to weigh the consequences of certain behaviour against one another. The more positive or the more the person can gain from the consequences of certain behaviour, the more this type of behaviour will be aimed for Lu *et al.* (2012). The opposite is also true for this, the worse the consequences, the more a person will tend to steer clear of such behaviour.

Most drivers feel that others should adapt their behaviour, but not themselves (Shinar, 2007). Drivers tend to think that they are better than the average driver, thus they think that they can drive above the allocated speed limit and complete risky overtaking manoeuvres (Shinar, 2007). People tend to be very subjective with regards to self-evaluation. Before embarking on any journey, it is important for every individual to soberly assess themselves.

2.2 Psycho-Physiological Limitations

There are thee psycho-physiological limitations, namely:

- Concentration
- Memory and Information Processing
- Vision

Due to humans only being able to concentrate for short periods at a time, drivers tend to neglect paying attention for periods of time while driving (Reason, 1990). This causes drivers to stop expecting the environment to change, perception performance decreases drastically, as drivers stop reading the environment and are very slow to respond to any change (Haapalainen *et al.*, 2010).

The amount of stimuli that an individual receives per day exceeds the capacity of a human brain (Lubow, 1989). This is only multiplied while driving and for this reason drivers are very selective regarding the information that they acknowledge from the environment. On average, driver only recall 20% of the road signs that they passed. Drivers can only recall the ones that they perceive as most important (Haapalainen *et al.*, 2010). The information that is estimated as not important is immediately rejected and forgotten in order to continually process and give attention to the information that is estimated as important.

Vision limits the road user and road designer to quite a large extent. A driver's eyes are only tracking 80% of the time and there are therefore time periods where very little attention is given to the environment outside of their direct point of view (Reason, 1990). This means that the spacing and placement of road signs are very important. Difficulties that arises due to this will be discussed later on.

2.2.1 Perception

Perception and accurate perception is one of the most important factors to accurate decision making and therefore plays a very important role in driving (Gray & Regan, 2005).

Perception is something that differs from person to person and it may differ quite dramatically and is one of the major influences of decision making of drivers (Shinar, 2007). It is often what causes miscommunication or disagreements between road users (Bucchi *et al.*, 2012). The one might perceive something as dangerous, where the other does not. Perception is not just as simple as what is seen or heard by a person. It is not only one single process that happens spontaneously, on the contrary, it is a series of phases that take place in order for the correct perception of information to occur (Bucchi *et al.*, 2012). Perception is an active process, where drivers need to select, organize and interpret the information that is sent to the brain (Hirsh *et al.*, 2008). Although drivers may do their best to accurately process and perceive the stimuli received, most drivers tend to make major misjudgements during either one of the three processes (Stanton & Salmon, 2009). Another factor to take into account is that perception is guided by purpose. Thus perceived risk may differ from day to day for an individual as the reason for their trip changes.

During the selection process, a driver needs to filter and identify the information that they want to perceive (Gibson & Crooks, 1938). As drivers become more experienced, they tend to form patterns with regards to the type of information that they will require for the type of trip that they are making (Gibson & Crooks, 1938). When an experienced driver is driving on a familiar road, this may lead to missing valuable information, especially when identifying an unfamiliar object within the road. This may lead to misinterpretation of information and thus lead to a wrong action, which in turn may lead to an accident as mentioned in section 2.1.

During the organization process, drivers need to gather the stimuli in groups in order to give them meaning. Thus in perception, there is synergy, since it is an overall perception of what is perceived from the information gathered and it cannot be reduced to separate stimuli characteristics (Miller, 1956).

During the interpretation process, after the driver has organized all the selected stimuli, they then proceed to give them meaning, completing the perception process. The interpretation process is modulated by the driver's past experiences and expectations.

Each individual's perception of situations is influenced by both biological and psychological factors. The biological factors are:

- Hormones
- Metabolism
- Ability/capacity of function of sensory organs
- Drugs, alcohol and medication

The psychological factors are:

- Attention
- Memory
- Expectation
- Feelings/stress
- Anticipation
- Attitude
- Socialisation
- Environment

From a design point of view, it is important to note that most of the fixations are in the central part of the view, which means that all traffic signs or other elements of the road environment that are outside of this area cannot be perceived by the drivers immediately or directly (Vaa, 2014).

Based on past experiences, every individual gathers information and formulates an acceptably low level of risk at which the individual perceives a situation as safe enough to attempt an overtaking manoeuvre (Stanton & Salmon, 2009). The experiences used to formulate this acceptably low level did not need to take place while the individual was driving, but could also have come from being in a vehicle and observing situations from a third person perspective (Bucchi *et al.*, 2012). The experience that happened from a third person perspective is unlikely to influence the individual to the same degree as when driving the vehicle themselves. Nevertheless, third person experiences will be called upon when no first person experience can account for any given situation.

From this, it becomes clear that the past experiences influence the future perception of individuals, while to a lesser degree the present perception also seems to influence experience

(Hirsh *et al.*, 2008). The latter can be explained by considering that two individuals may be faced with exactly the same circumstances and yet experience it in completely different ways. When asked to describe the event, their accounts may even differ to a large degree due to their perception of the matter differing. Therefore it is clear that the difference in perception was the only factor that caused them to have a different experience.

The former can be explained using another analogy. If an individual attempts a certain manoeuvre and it results in either an accident or a near miss experience, this individual will perceive this manoeuvre in the future as containing more risk compared to their view of it in the past. Furthermore, a person who has been in an accident due to a certain manoeuvre is likely to perceive that manoeuvre as containing more risk as compared to other people. From this it is then also clear that past experiences influence future perception. But due to perception influencing the experience, it can be said that the past perception influences future perception.

Seeing that perception to some degree influences experience and is therefore not solely dependant on experience, a third, foundational factor should exist on which perception is primarily based. This foundational factor is the personality or character of the individual (Hirsh *et al.*, 2008). The difference in personality then is what brings forth the difference not only in the perception of individuals, but also in the action that they choose to take with the information processed (Ulleberg, 2001).

On the other hand every individual also formulates a level of risk at which the situation is perceived to contain too much risk to attempt any form of overtaking manoeuvre, which will be called the acceptably high level of risk (Damasio, 1994). It is called acceptably high, for the amount of risk that an overtaking manoeuvre will entail is too high and therefore any amount of time lost due to waiting behind a slower moving vehicle for lower risk conditions is acceptable.

It is important to note that the acceptably low and high levels of risk differ between individuals and may vary to a large degree, as their perception might differ to a large degree. Furthermore it is the relationship between perceived and acceptable risk that determines when any given individual will attempt an overtaking manoeuvre (Wilde, 1982). Therefore, due to these levels differing between individuals, it is clear that not all will behave in the same way when faced with the same conditions.

Not only do the risk perception and acceptance levels differ from one individual to the next, but even fluctuated for the same individual, depending on the individual's state of mind, which can be influenced by various factors. The two primary factors that were estimated to cause a fluctuation within an individual, was time and emotional pressure (Damasio, 1994). Both driver that were under time and emotional stress tended to underestimate the amount of risk involved in manoeuvres Ge *et al.* (2014).

Drivers that were under time pressure seemed to underestimate the amount of risk that is involved in manoeuvres and at the same time were willing to accept higher levels of risk which often led to decision errors. Even though both had approximately the same consequence on the psychological state of drivers, it was noted that drivers under time stress did not misinterpret situations, but rather accepted higher levels of risk, while ones under emotional stress had more difficulty interpreting the risk levels of situations.

Even though the emotional state of drivers primarily influenced the perception of situations, it also had an impact on the level of risk accepted. This change may even occur within the same journey. An individual may be willing to accept a higher level of risk due to frustration or agitation at one stage of the journey compared to others. Therefore once again the impact of character and emotional state becomes visible, as it is these two factors that determine to what extent the frustration of an individual will influence their behaviour.

The point at which these two levels meet one another is therefore the point at which an individual perceives a situation as being safe enough to attempt an overtaking manoeuvre, whereas it was previously perceived as being too dangerous, or vice versa. This does not necessarily mean that all drivers will attempt an overtaking manoeuvre when the acceptably low level of risk is reached, for some may perceived a situation to be safe enough to overtake another vehicle and yet not attempt such a manoeuvre due to the road markings not permitting it. Therefore it cannot be assumed that all drivers will attempt an overtaking manoeuvre as soon an acceptably low level of risk is perceived.

From the above mentioned information, it is possible to draw the conclusion that of external factors can influence the psychological state of an individual, yet even more significant than these is the internal characteristics of the individual. Therefore even though there may be various elements that have the possibility to influence the psychological state of drivers, it is the internal condition of the drivers themselves that determine in which manner and to what extent these elements influence them.

2.2.1.1 Attention

The number of stimuli that individuals are exposed to daily exceeds the capacity of the human brain, thus every individual has a so-called filter that ignores information that is deemed as irrelevant and gives attention to information that seems important (Lubow, 1989). Irrelevant information is ignored in order to give more attention to relevant information (Gibson & Crooks, 1938). If a lack of attention occurs, it may lead to a delusion, which is a psychophysical condition which leads to misinterpretation of information, which in turn leads to misjudgements.

The attention aspect of driving is very important and also very important to understand from a designer and motorist's point of view. It is important to design roads that is not too intensive on the drivers (Reason, 1990). It is also very important to note for drivers that without attention, there will be no perception and will thus lead to dangerous situations (Bucchi *et al.*, 2012).

The ability to ignore useless information and take in needful information is an important aspect of driving and also forms an important part of attention (Carson *et al.*, 2003) and (Reason, 1990). Yerkes-Dodson's law states that a person's learning performance increases with mental or psychological arousal, but only to a point, when arousal levels become to high, performance will decrease (Yerkes & Dodson, 1908). For well-leaned or simple tasks, the relationship is closer to linear with an increase in performance as arousal increases. For unfamiliar and difficult tasks, the relationship between arousal and performance decreases and becomes inverse if arousal is too high (Yerkes & Dodson, 1908).

2.3 Human Error Classification

Recent research has shown that human or driver error contributes to approximately 94% of all roadway accidents. Despite this high percentage, only a limited investigation regarding the types of human errors has been done (Singh, 2015).
Although the percentage mentioned might seem catastrophic, some argues that the blame is too often shifted to human error with regards to the causation of accidents. It is important to note that identifying the causation or causations of an accident is not as simple or as easy as it seems. Even when nothing within the transportation system failed and it seems that the only reasonable explanation for the accident could be human error by the driver, it may still not be the case. There are various factors influencing the decision making and psychological condition of the driver, some of which will be discussed later on. Although it be true that the 94% mentioned earlier is accurate, it is almost never mentioned that the factors influencing the psychological condition of the driver was taken into consideration.

It may be that in some cases, the blame of the accident lies purely on human error, but mostly this is not the case and multiple factors need to be taken into consideration. It is often not as simple as one individual making one error. Rather, human error is the product of a design or a system which has permitted the existence and continuation of specific activities or factors which could lead to errors(Reason, 1990).

2.3.1 Types of Human Errors

On a very basic level, human errors are defined within four categories, namely: Slips, lapses, mistakes and violations. Both slips and lapses occur when an action was unintended, whereas mistakes are associated with intended actions. Slips are defined by attentional failure, and lapses refer to memory failure. An example of a slip would be a driver intending to push down on the brake pedal, but then inadvertently pushes the accelerator instead. An example of a lapse would be a driver forgetting to turn off the headlights after getting out of the vehicle, even though they intended to do so (Stanton & Salmon, 2009).

Mistakes occur when a driver intentionally performs and action that is wrong and therefore originates at planning level and not necessarily at execution level. For this reason mistakes can also be termed as planning failures. An example of a mistake would be a driver deciding to accelerate when the appropriate and best action would have been to decelerate. Violations occur when the driving behaviour deviates from accepted procedures, standards and rules. Violations can either be deliberate or unintentional (Reason, 1990).

Mistakes occur when the planning and/or the situational assessment are poor, whereas the execution of the action itself may have been good. With slips, on the other hand, the planning and situation assessment may be good, whereas the action execution is poor. With lapses, the execution of the action, as well as situation execution may be good, but the memory is poor (Reason, 1990).
From the information mentioned, it is clear that slips and lapses will be more apparent with experienced drivers. This is due to over confidence or being too familiar with the road and not paying enough attention to the surrounding circumstances. Mistakes will be more apparent with inexperienced drivers, as they are more likely to pay more attention to the road, but execution of actions or executing the correct action at the correct time might be bad. It is thus clear that different types of errors occur at different levels. Slips and lapses occur at a skill-based level, whereas mistakes occur at a rule-based and knowledge-based level (Reason, 1990). An increase in skill does thus not guarantee error-free performance or driving, it will simply result in different type of errors (Stanton & Salmon, 2009).

In the most modern sense, driver-related errors may be broadly classified as recognition errors, decision errors, performance errors, and non-performance errors (Stanton & Salmon, 2009). Singh (2015) conducted a study in 2015 and stated that recognition errors contributed to 41% of driver-caused accidents. This includes inattention, internal and external distractions, as well as inadequate surveillance of surroundings (Stanton & Salmon, 2009). Decision errors contributed to 33% of driver-caused accidents, which included driving too fast for conditions, illegal manoeuvre, misjudgement of distance to oncoming traffic and misjudgement of others' speed (Wierwille *et al.*, 2002). Performance errors contributed to 11% of driver-caused accidents, which included poor directional control overcompensation, etc. (Singh, 2015). Non-performance errors consisted primarily of drivers falling asleep while driving and accounted for 7% of driver-caused accidents (Singh, 2015). The information mentioned is summarized in figure 2.1.

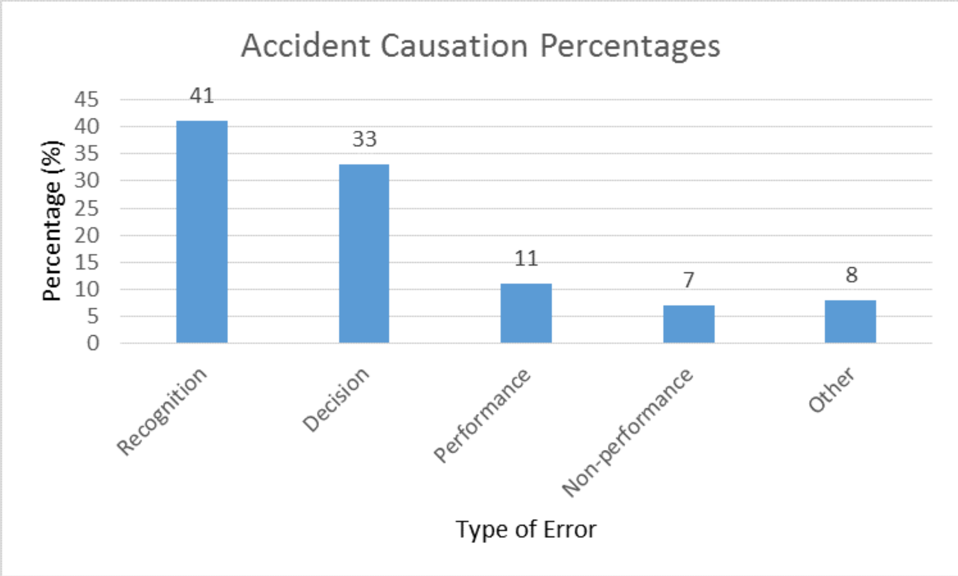

Figure 2.1: Accident Causation Percentages

Most of the time, the psychological condition of the driver is influenced by various other factors which may lead to an error or mistake being made (Bucchi *et al.*, 2012). The are however direct human causes to accidents, which should also be taken into consideration and not neglected. For the purpose of this study, only brief inspection will be given to some recognition, decision and performance errors which corresponds with direct human causes. One of the ever increasing areas of concern is external distraction. As the use of cellphones while driving has increased, the number of accidents caused by external distraction also increased. Although authorities are attempting to improve this, it is still an area of great concern. The other factors will be discussed later.

Recognition errors include 'failure to observe', 'inattention', 'internal distraction', 'external distraction' and 'improper lookout (Wierwille *et al.*, 2002).

Decision errors include 'misjudgement', 'false assumption', 'improper manoeuvre', 'excessive speeding', 'tailgating' and 'an inadequate driving technique' (Wierwille *et al.*, 2002).

Performance errors include 'panic or freezing' and 'inadequate directional control' (Wierwille *et al.*, 2002)

In some cases, a lack of knowledge, training and skills may contribute to the causation of accidents. This includes a lack of understanding or misunderstanding the traffic laws, vehicle kinetics, driving technique and own driving capabilities or limitations (Wierwille *et al.*, 2002).

One major factor that influences drivers to quite a large extent, is fatigue (Stanton & Salmon, 2009). Most drivers go through a phase while driving that would classify as fatigue drivers and a major issue with this is that drivers tend to tire without realising it. Fatigue causes the visual and perception performance of the driver to decrease dramatically. The reason for drivers tiring may be attributed to various factors, but the only remedy for it is to stop and either sleep or rest for as least 45 minutes. Law enforcement is also very difficult with regards to fatigue, as it is difficult to measure.

In some instances however, one will find that drivers wilfully disobey the law and behave in an inappropriate manner. It is important to note that each situation needs to be assessed with an open mind and without any preconceived ideas, as each case is unique. It is however needed to address the emotional and behavioural components of drivers, and not necessarily the cognitive components (Shinar, 2007).

2.3.2 Decision Errors the Greatest Concern

Decision making of drivers is the area with regards to human errors that may lead to the best decrease of accidents if addressed and adapted correctly. Faulty decision making, especially deciding to attempt an overtaking manoeuvre in unsuitable circumstances, causes the majority of overtaking accidents (Gray & Regan, 2005), which compiles a sizeable amount of the total amount of accidents. The root of the faulty decision making stems from faulty choices of timing and speed for the overtaking manoeuvre, and not a lack of vehicle control skills (Gray & Regan, 2005). In correspondence to this, drivers often make wrong decisions due to miss-perception of the situation, as drivers frequently underestimated the time that will be needed to complete an overtaking manoeuvre, thus they were frequently inaccurate in deciding whether it was safe to overtake in front of an oncoming vehicle (Gray & Regan, 2005).

It it also important to note that human errors that involves decision making, often involves problems with the situational awareness of the decision making process. In most cases, faulty decision making is caused by a loss of situational awareness as opposed to the choice or action portion of the process (Strauch, 2016). When drivers have repeated successful encounters with risky situations, their expectation of success is enhanced when encountering similar circumstances (Strauch, 2016), which lead to more risky decisions and a higher acceptance of risk.

Drivers are faced with high-stressed situation continually as they continue along their journey, as they are required to make decisions with uncertainty of information, time pressure and high stakes (Stanton & Salmon, 2009). It is thus no surprise that drivers do make errors when deciding what would be the correct or appropriate action to take. After a decision has been made, it requires additional cognitive effort to recognize that the situation has changed since the initial decision was made and that a different course of action is needed. For most drivers that do make a wrong initial decision, the time to recognize and correct the decision takes quite a lot of time, thus leading to hazardous situations. It is often the case that the oncoming vehicle needs to take evasive action in order to avoid a collision when a faulty decision is made with regards to attempting an overtaking manoeuvre.

Another reason for the high level of error involved in overtaking is the complexity of the visual judgements involved (Gray & Regan, 2005). Drivers must simultaneously estimate the time to collision with an oncoming vehicle, estimate and monitor the time to collision with the vehicle that they are attempting to overtake as to avoid a rear-end collision, and estimate the time required to complete the overtaking manoeuvre based on the current speed, road conditions, and the knowledge of the capabilities of the vehicle (Gray & Regan, 2005).

Drivers have little to no opportunity to practice and learn the difficult manoeuvre of overtaking during driver training. Due to this, it is not surprising that there are such a high degree of error in judging when it is safe to initiate an overtaking manoeuvre (Gray & Regan, 2005).

2.4 The Problem with Current Accident Causation Analysis

Although most blame for accident causation is given to human error, there are various aspects of the environment and road design that affect the psychological condition of the drivers as have already been asserted in section 2.1 (Damasio, 1994). Most of the time drivers are stressed too greatly by the environment, causing them to misinterpret the information and thus making an error. These type of errors are still given to the driver and all the emphasis over the past few years have been on educating the drivers in order to improve behaviour, while very little focus has been given to the design of the roads, which over-stresses drivers in most cases, requiring too much of them.

Although all of the genuine 'looked-but-did-not-see' errors may be attributed to simple human error, two psychological phenomenon that could be implicated have been identified (Stanton & Salmon, 2009). The first being that the limited information processing capacity of individuals may mean that the information is simply not processed, as there are competition for attention, especially in complex scenes (Stanton & Salmon, 2009). The second being that the attentional selectivity may result in certain characteristics of the visual scene being given priority over others (Stanton & Salmon, 2009).

The roadway environment can affect a driver's choice of speed by influencing both the speed that he/she think is appropriate for the road that he/she is on and also the driver's perception of their current speed (Edquist *et al.*).

Although in some accidents, the blame rests solely on human error, most of the time there are various factors that need to be taken into account. Unfortunately in modern accident analysis, very seldom are the factors influencing the drivers taken into account when a human error does occur. The aim of this section is to identify factors that has an impact on the psychological condition of the driver and to further estimate to what extent these factors influences the driver when working in combination to one another. There are five basic categories into which the various factors which contribute to human behaviour can be divided, these categories are: road factors, vehicle factors, traffic factors, environmental factors, driver factors (Shinar, 2007).

Consider once again a statement of Ezra Hauer - "The fact that almost all crashes could have been prevented had the involved persons acted differently does not mean that the most effective way to reduce crashes is to alter peoples behaviour or tendency to make errors. Effective action must aim jointly at the human element, the vehicle and the road. Road design can reduce the incidence of human error, road design can reduce the chance of a human error to end up as a crash, and road design can ameliorate the severity of the consequences of crashes that are initiated by human error" (Hauer, 1999).

2.4.1 Vehicle Factors

The vehicle type and characteristics of the vehicle contributes to a large extent with regards to the communication of motorists. Motorists travelling in a larger vehicle tend to feel more dominant and tend to underestimate the perceived risk than motorists travelling in a smaller vehicle. That being said, better educated individuals tend to buy more expensive and thus better performing cars, which leads to them driving at higher speeds (Shinar, 2007). Even though the more expensive vehicles are smaller than those surrounding it, the fact that it has more power and better performance than the others tend to make the drivers over-confident and thus taking more risks.

With the improvements of modern vehicle, drivers tend to get very little feedback from the vehicle itself. Modern vehicles have a reduced motor sound, almost no vibrations, very little of the outside climate influencing the driver and no effort needed from the driver to speed. All these characteristics are good from a comfort point of view, but when considering human performance and communication within the transportation system, this tend to cause some issues, as motorists are growing less and less familiar with the performance capabilities and the physical condition of the vehicles.

2.4.2 Traffic Factors

As mentioned in section 2.1, motorists tend to adapt to the driving norms of the surrounding vehicles (Shinar, 2007). The acceptable norms of various regions may differ vastly, but within a specific region, it will remain nearly constant between various drivers, with exceptions as can be imagined. More than this, drivers tend to adapt their behaviour as the density and vehicle composition of the road changes. Higher density will cause drivers to drive at slower speeds and will lead them to pay more attention to the roadway. As the vehicle composition changes, so will the behaviour of driver change. If the composition consists of a higher percentage trucks, drivers using cars will be more tentative to drive at higher speeds and pay more attention to overtaking manoeuvres. Although a higher percentage trucks may also leas to other drivers getting frustrated due to the lower speeds, which might bring forth erroneous decisions due to the frustration.

2.4.3 Environmental Factors

Although the environment does not contribute as much to the psychological condition of drivers, it is still something to be mentioned and taken into consideration. This plays a especially important role when looking at night time driving. One limiting factor for drivers is the natural light that is present, as the sight distance is much shorter in the evening, drivers should driver much slower in the evening. Although there is a slight drop in speed during the night periods, it does not decrease as much as expected and thus leads to a much larger accident rate during the evening than during the day.

One very important characteristic of the environment that influences the drivers, are the presence or absence of law enforcement. Law enforcement can either have a positive impact or a negative impact on the attitude of drivers. When enforcement is accurately applied, it leads to drivers paying more attention to the road laws and being more willing to be obedient to the law. Unfortunately in the transportation system, enforcement is very often not applied correctly in the eyes of the public and thus leads to drivers being more prone to ignore and rebel against the stipulated rules. Law enforcement is only effective if drivers are aware that they are speeding and consider the risk of being caught as large enough to cause them to modify their behaviour (Abele & Møller, 2011). According to Martens *et al.* (1997), law enforcement only serves as a temporary solution, as it does not positively affect the attitude of the drivers, on the contrary, drivers tend to feel that they are being forced to drive slower than they ought to (Abele & Møller, 2011).

Another aspect that influences the behaviour of drivers is the presence or absence of pedestrians and cyclists on the road. Drivers that come into contact with pedestrians or cyclists often tends to pay more attention and drive slower when entering an area where there might be a possibility of a conflict point with pedestrians or cyclists.

2.4.4 Road Factors

There are various aspects of the road and the road design that influences the psychological condition of the drivers. Other than the driver factors itself, it is the one that plays the biggest role in driver behaviour. These factors include the width of the road, the gradient, alignment, layout, surface quality, road signs, speed limit, etc (Shinar, 2007). The drivers perception with regards to the infrastructure and the design of the role is one of the primary considerations when designing a road. The way that a driver perceives a road will influence their attitude toward the road and the rules, which will in turn influence their decision making. It is very important that the road signs should correspond with the impression that a road user will have, as a driver will likely start ignoring the rules if the road signs are contrary to their impression (Shinar, 2007).

Very often in accident causation analysis, road factors are considered as a primary cause, but very seldom are the road factors taken into account as a secondary cause. Various factors mentioned in the list above is also confirmed by (Abele & Møller, 2011), who noted that road width, vertical and horizontal alignment, roadside and on-road markings are all factors that influences a driver's perception of the traffic situation.

The horizontal curvature of a road tends to bring forth a lot of possible-accident events. As this is one of the main focusses of this project, it is one of the areas of concern that will be investigated more deeply. As drivers approach and go around a horizontal curve, they tend to move more toward the centre of the roadway, further away from the outer barriers (Abele & Møller, 2011). This indicates that drivers tend to feel safer nearer the middle of the road when going around a bend, even though this means that the lateral clearance to oncoming traffic is smaller. This indicates that drivers are more wearing for over-steering than for skidding or under-steering. This may help a lot with finding a reason why so many accidents occur around horizontal bends. As vehicles tend to drive more toward the centreline of the roadway, vehicles that want to overtake or attempt an overtaking manoeuvre will have less lateral clearance to oncoming traffic to complete the manoeuvre. This phenomenon is an indication why there are proportionately so many conflict points, which has the possibility to result in an accident, around horizontal bends. Any driver attempting to overtake in such circumstances will have to keep track of their own speed and movement around the bend, as well as that of the vehicle they are attempting to pass, as well as that of the oncoming traffic. This is an impossible task for any individual, giving a clear indication why overtaking around horizontal curves are so dangerous and irresponsible.

The road layout mainly influences the choice of speed for drivers. Broader roads with a hard shoulder will produce higher speeds than that of narrower roads without a hard shoulder (Abele & Møller, 2011). The presence of a hard or paved shoulder, gives the drivers the perception that the road is broader and therefore they are capable of moving at higher speeds. A hard should does however cause drivers to driver closer to the road edge. This will decrease the possibility of a head-on collision as well as make overtaking manoeuvres easier with fewer conflict point with oncoming traffic, but it increases the possibility of run-off-the-road accidents, which is considered to be more severe and more frequent. This also has an unfavourable effect on the safety of cyclists driving on the side of the road, even though this is not legal with most of South Africa's highways.

A total of 207 drivers were asked to indicate to what extent the various factors influenced their choice of speed. They rated the extent of the influence from 0 to 10, with 0 being very low and 10 being very high. Out of the total amount of drivers, 134 indicated that they usually obey the speed limits, where 73 indicated that they do not (Kanellaidis, 1995). It is therefore important to note, that even though some factors may be applicable to some drivers, the moral system and perceived risk of all drivers are not the same and therefore not all factors will influence all drivers the same. In correspondence with this, it was noted that the average rating for non-violators were higher than that of the violators, which implies that drivers who do not aim to obey the speed limit, will probably feel less constrained by the road environment in selecting their speed on curves (Kanellaidis, 1995). Table 2.2 indicates the various factors that and the weight of the extent to which they influences the drivers' choice of speed for going around curves.

Table 2.2: Factors influencing driver's choice of speed

Elements	Mean Roating	Rank
Pavement Condition	8,34	2
Number of Lanes	7,11	10
Lane Width	6,72	12
Existence of free roadside space	5,62	14
Existence of median	7,60	6
Existence of safety barriers	7,44	7
Sharp Curvature	8,31	3
Standard curve-warning sign	7,78	5
Additional warning sign	8,09	4
Speed-limit sign	5,78	13
Superelevation	7,33	8
Sight distance	8,64	1
Length of curve	7,23	9
Gradient	7,06	11

Source: (Kanellaidis, 1995)

From the information presented in Table 2.2, four factors can be identified by which drivers are influenced to choose their speed around curves. These factors are separation from oncoming traffic; alignment; cross-sectional characteristics; and signing. Separate analysis has shown that drivers indicating that they don't violate the speed limit $non - violators$, are primarily influenced by signing, while violators' speed is determined by the road layout (Kanellaidis, 1995). The road layout is defined as a combination of the sight distance and the curvature.

Although this indicates only the way that some factors of the road design influences drivers' choice of speed, it is a clear indication that the road design does affect the psychological condition of the drivers. This may also prove to be an accurate indication of the impact that the road design has on the attitude of drivers. Although this indicates that drivers are affected by the design of the road, the extent of this effect is still unknown, especially when considering the various factors in combination to one another.

In order to determine the influence that the various factors have on one another and thus on the drivers in combination to one another, the four primary factors mentioned earlier were compared in combination with the various factors mentioned in Table 2.2.

Table 2.3: Factor Loadings for Various Road Aspects

Elements	Factor 1 (Road Layout)	Factor 2 (Cross Section Characteristics)	Factor 3 (Signing)	Factor 4 (Separation of Oncoming Traffic)
Pavement Condition	0,45	0,50	-0,38	-0,11
Number of Lanes	0,12	0,75	-0,05	0,27
Lane Width	0,02	0,87	0,11	0,09
Existence of free roadside space	-0,08	0,62	0,22	0,36
Existence of median	0,04	0,36	0,08	0,84
Existence of safety barriers	0,10	0,12	0,02	0,86
Sharp Curvature	0,67	0,05	0,15	0,01
Standard curve-warning sign	0,37	-0,07	0,74	0,04
Additional warning sign	0,49	-0,14	0,67	0,18
Speed-limit sign	0,04	0,21	0,74	-0,09
Superelevation	0,60	0,01	0,14	0,21
Sight distance	0,81	-0,03	-0,01	0,06
Length of curve	0,50	0,30	0,35	-0,15
Gradient	0,57	0,21	0,38	-0,08

Source: (Kanellaidis, 1995)

From the results show in Table 2.3, it can be seen that the curvature and sight distance have high loadings, while pavement condition and additional warning signs have fairly high loadings on the road layout factor. From this information, one can assume that the road layout factor is of prime importance in determining drivers' choice of speed (Kanellaidis, 1995). Keeping this in mind, it is therefore important to set the correct or appropriate speed limits. If speed limits are set too low when drivers perceive that higher speeds are possible, drivers tend to start ignoring the speed limits as well as most other rules (Shinar, 2007). This may be attributed to the drivers losing their trust and confidence in the guidance and accuracy of the road signs.

It is also important to note that when the desired speed limit is low from a designer's point of view, then the design of the road should give the drivers a perception that aligns with this, else they may start ignoring most, or at least some rules, which is an undesirable phenomenon.

2.4.5 Driver Factors

It should be noted that although external factors do influence a driver's psychological condition, a driver's personal norm $whattheythinktheyshoulddoaccordingtotheirownmoralvalues$ has the greatest impact on a driver's attitude towards the rules of the road and other road users (Shinar, 2007).

Drivers are very much influenced by the immediate positive or negative effect that their behaviour will have. In general, humans are too often selfish, impatient and boastful in their actions and word. These are character and psychological traits that become all the more transparent when placed in the stressful and often straining traffic environment. As mentioned earlier, most drivers tend to think that they are better drivers than they actually are and tend to perform the action that will be most beneficial to them. When another road user makes a mistake, drivers experience it as a provocation and an intentional act, but they struggle to recognise their own faults. Drivers tend to often shift the blame of their own bad behaviour to the behaviour of others. This might seem as small things, but it has lead and still today leads to most of the accidents on the road.

As mentioned in section 2.1, there are various factors that influences a driver's current moral state and attitude. Some of these factors include (Shinar, 2007):

- Age
- Sex
- Reaction Time
- Attitude
- Thrill-seeking
- Risk Acceptance
- Hazard perception
- Alcohol Level
- Ownership of Vehicle
- Circumstances of Journey
- Occupancy of vehicle

It is important to note that hazard perception and risk acceptance in combination with one another is among the primary reasons, if note the primary reason for accidents. Thus it can be noted that crashes are a correspondence of actual risk, perceived risk and driver action (Shinar, 2007). From these three factors, only actual risk does not include the psychological condition of the driver, and in some cases that too may include the driver's state of mind, if a faulty action has lead to the actual risk. However for the purpose of this study, attention will be drawn to the other two factors, namely perceived risk and driver action, as this directly involves the drivers' state of mind.

Both of these factors should be addressed and have an opportunity to be greatly improved with most, if not all drivers. These two factors may be closely related to one another, but they are influenced by different things and they in turn influences the driver in different ways. Both are affected by past experiences or exposure and both are also influenced by the driver's personal mental and emotional state. The mental and emotional state of drivers are in turn affected by various other factors.

The risk perception of a driver has been discussed in some detail in section **??**. Driver action is directly proportionate to the risk acceptance of the individual, as a driver will only be willing to take action when they perceive that the risk is worth the benefit from taking the risk. These two factors differ vastly between different drivers, as a considerable variability in the ability to make judgements are transparent (Gray & Regan, 2005). Some mental and emotional factors are pressure and strain; drivers being emotionally upset; and being in a hurry or rush (Wierwille *et al.*, 2002).

When drivers are emotionally upset, they tend to underestimate risk perception and tend to accept more dangerous circumstances. The combination of these two often leads to drivers attempting dangerous and irresponsible manoeuvres. Pressure and strain exercises much the same effect on drivers as when they are emotionally upset, with the exception that they tend to miss more information, thus paying less attention. Drivers that are in a hurry also tend to exercise much the same behaviour as that of drivers that are emotionally upset or under pressure and strain, with the exception that they tend to drive faster and have a much higher risk acceptance level.

The experience and exposure of drivers include familiarity with the vehicle that they are driving; road over-familiarity; road or environment unfamiliarity; and driver experience or inexperience. When a driver is unfamiliar with a vehicle, they may either under-or overestimate the performance of the vehicle, which could lead to performing incorrect actions. When a driver is over-familiar with the road, attention and perception levels tend to decrease, which in turn will cause drivers to react much slower when faced with an unexpected event or obstacle and could lead to the wrong actions being performed. Unfamiliarity of the road are especially of concern when driving during the night, as drivers are not familiar with the layout of the road, nor do they know what event or obstacles to expect on their journey.

The psychological condition of drivers may vary significantly when considering the impact that the circumstances of the journey, the occupancy of the vehicle and the attitude of the driver. As the circumstances of the journey vary, so also will the attitude of the driver vary. Commuters commuting to and from work tend to drive faster, as they don't want to waste any unnecessary time in traffic, while drivers that are on holiday will drive much slower. This may cause frustration and conflict between the drivers. It is also important to ensure that the speed difference between the motorists are not too big, as the risk of an accident increases as the speed between vehicles increases (Shinar, 2007).

One positive to note is that as the occupancy of a vehicle increases, the behaviour of the driver improves and they tend to be more obedient to the traffic laws. The primary reason for this is that the drivers tend to feel responsible for the safety of the passengers. This indicates that when drivers have a sense of responsibility, they tend to drive more conservatively, whether that responsibility be the safety of the passengers or getting home safely to a family. Seeing that this may be part of the solution to better behaviour from drivers, it is worth asking the question, "How do one get drivers to feel a sense of responsibility all the time while driving?" This question will be addressed later. It is quite worrisome to note that it is quite common for drivers to have a false sense of reality when driving, and thus feel a lack of responsibility, and thus have a higher risk acceptance and lower hazard perception. This is a problem that needs to be addressed at a very personal level for each individual.

Chapter 3

METHODOLOGY

As mentioned in chapter 1, the aim of this study is to identify possible roadway elements that may contribute to conducting dangerous overtaking manoeuvres. This would in turn help to direct further studies in finding a way in which to reduce or even negate the contribution of these elements on dangerous behaviour being exhibited. In order to achieve this primary objective, the following procedures were completed:

- Identify road sections on which to conduct the study
- Vehicle speed analysis on the various road sections
- Analysis on the volume and distribution of vehicles
- Examine driver behaviour on these road sections
- Accident data analysis on the various road sections
- Complete and analyse questionnaires
- Investigate and compare road design elements at identified locations at which drivers conduct dangerous overtaking manoeuvres

The traffic volume, vehicle speed and accident data were all obtained from the applicable various institutions, while driver behaviour observations as well as the data obtained from the questionnaire needed to be obtained on site. Observance of driver behaviour happened in two ways, the first was from a stationary position from a safe distance from the road, while the second was driving within the traffic stream in order to gain a better understanding of the conditions faced by drivers as they moved along the selected roadway sections.

A camera and video camera were also used during the collection of data. This allowed for further analysis of driver behaviour and road design elements, which may have been missed the upon first analysis of the data. The time of day that the data was collected differed in order to obtain the most complete and extensive data set. While at a stationary position, detection from drivers were aimed to be avoided when choosing the location of the device in order to observe the most natural behaviour of drivers.

3.1 Roadway Selection

Due to this study not being base on a post-accident approach, a total of three roadway sections were selected on which to conduct an in depth investigation of the roadway design elements and driver behaviour. By recording the type of behaviour that was observed at various locations along these roadway section, it was possible to draw a correlation between certain behavioural patterns and the roadway elements present when these patterns occurred and by so doing narrowing down possible roadway design elements that may contribute to dangerous behavioural patterns.

It may be possible for a single road design element to contribute significantly to drivers conducting dangerous overtaking manoeuvres, but a combination of elements will have even a greater contribution. For this reason, even though it is important to identify the single elements, it is even more importance to determine which elements in combination with one another contributed the most. In order to determine combinations that led to a certain kind of behaviour, all design elements at which these behavioural patterns were observed, were dotted down individually. Furthermore, the roadway design leading up to these behavioural patterns were also taken into account, as the roadway elements previously encountered by drivers also influence their present psychological state (Stanton & Salmon, 2009).

By comparing every individual road design element that were recorded at points where dangerous behaviour were recorded, in combination with the preceding roadway conditions, it was possible to determine which combination of roadway elements were present when dangerous behaviour was observed. Therefore it was possible to determine what individual and combination of roadway design elements contributed to drivers exhibiting dangerous behaviour.

Even though the roadway elements may influence the psychological state of drivers to a large degree, it is very important not to negate the preceding psychological state of drivers, which is influenced by the personality, cognitive ability, as well as the type of living environment that an individual finds themselves in (Hirsh *et al.*, 2008).

The roadways were selected on the basis of their design and function and all three are two-lane rural major arterial (highway) roads without any separation between the two opposing traffic flow directions. According to the specifications as stipulated by the Committee of Transport Officials (2012), all three of these roadways were classified as class 2 rural roads as they met all the requirements.

The Committee of Transport Officials (2012) specified that the primary function of rural major arterials are mobility and they carry inter-regional traffic between smaller cities with a population greater than 25 000 people. The AADT on such roads usually exceed 2000 veh/day and intersections should give priority to vehicles travelling on this roadway or it should be grade separated.

The road sections that were selected for the purpose of this study, is:

- Route 44 North of Stellenbosch, South of the R101
- Route 45 West of Franschhoek, East of the R101
- The N2 between Knysna and Plettenberg Bay

The following road design elements were considered during data collection:

- Speed limit
- Road markings
- Road signs
- Road and lane width
- Pavement conditions
- Road section length
- Shoulder characteristics
- Horizontal alignment
- Vertical alignment
- Number of intersection
- Characteristics of preceding roadway

3.1.1 Route 44

The R44 is the shortest of the three road sections, with a total length of 10,5 km, but is the only section that prohibited overtaking for the entire length of the section. The large number of crests and horizontal alignment made overtaking on this roadway difficult and the small number of flat and straight sections therefore gave little opportunity for vehicles to complete overtaking manoeuvres. As overtaking is prohibited for the entire length of this road section, all overtaking manoeuvres recorded were therefore classified as illegal. Figures 3.1 and 3.2 shows the layout and the elevation profile of the R44 respectively.

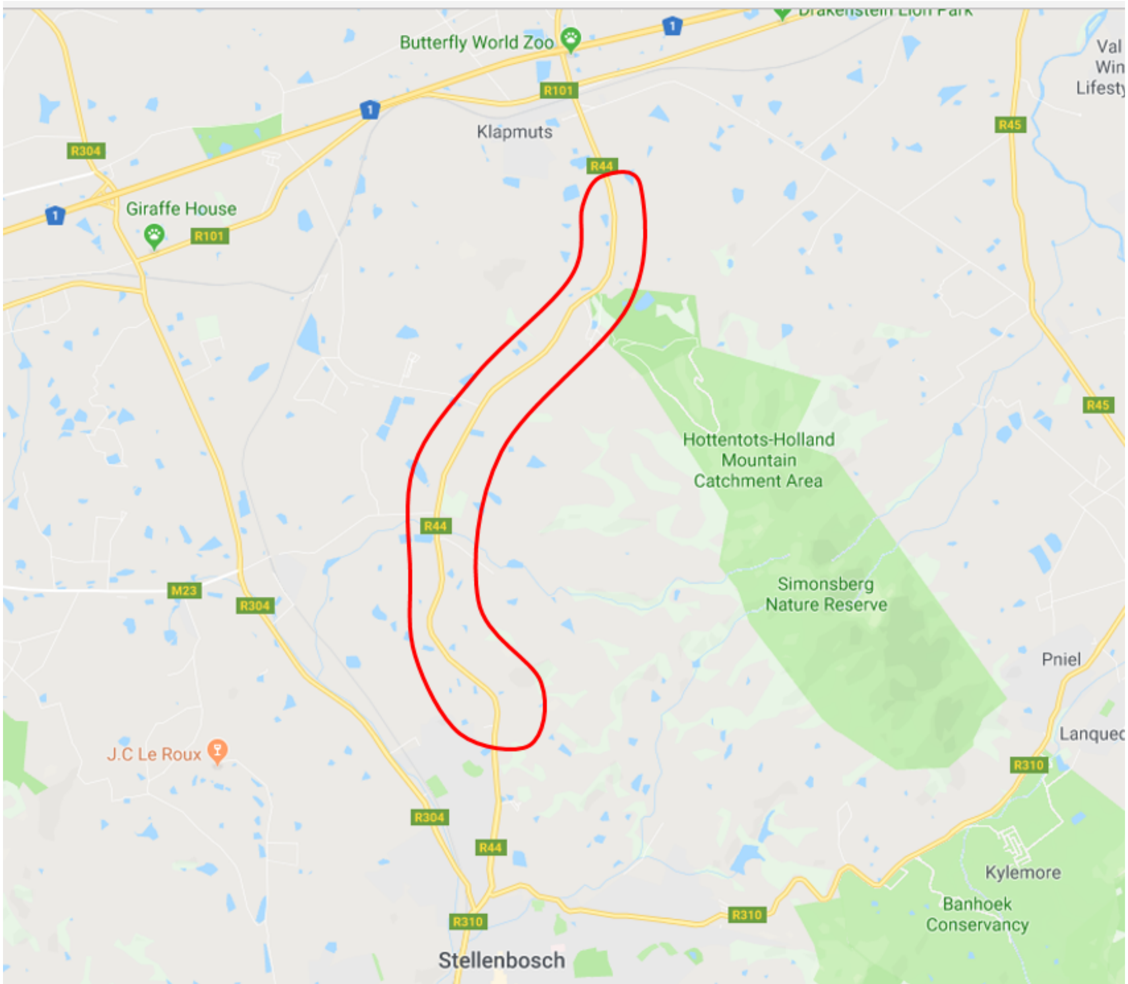

Figure 3.1: Aerial view of the Route 44 road section

Source: (Google Maps, 2018)

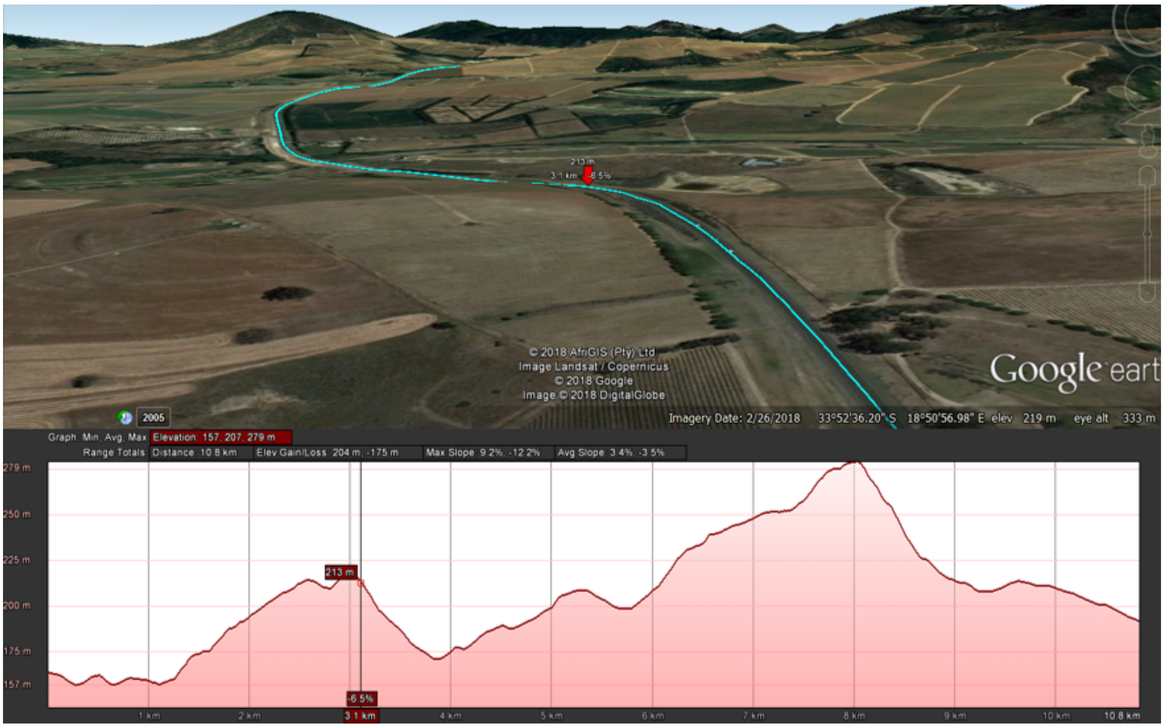

Figure 3.2: Elevation profile of the R44

3.1.2 Route 45

The R45 is the second longest section of the three with a total length of 11,8 km and is the only roadway on which the length of sections permitting overtaking is longer than that of sections prohibiting overtaking. The R45 is also the flattest of the three roads and therefore the highest speeds were recorded on it. Figures 3.3 and 3.4 shows the layout and the elevation profile of the R45 respectively.

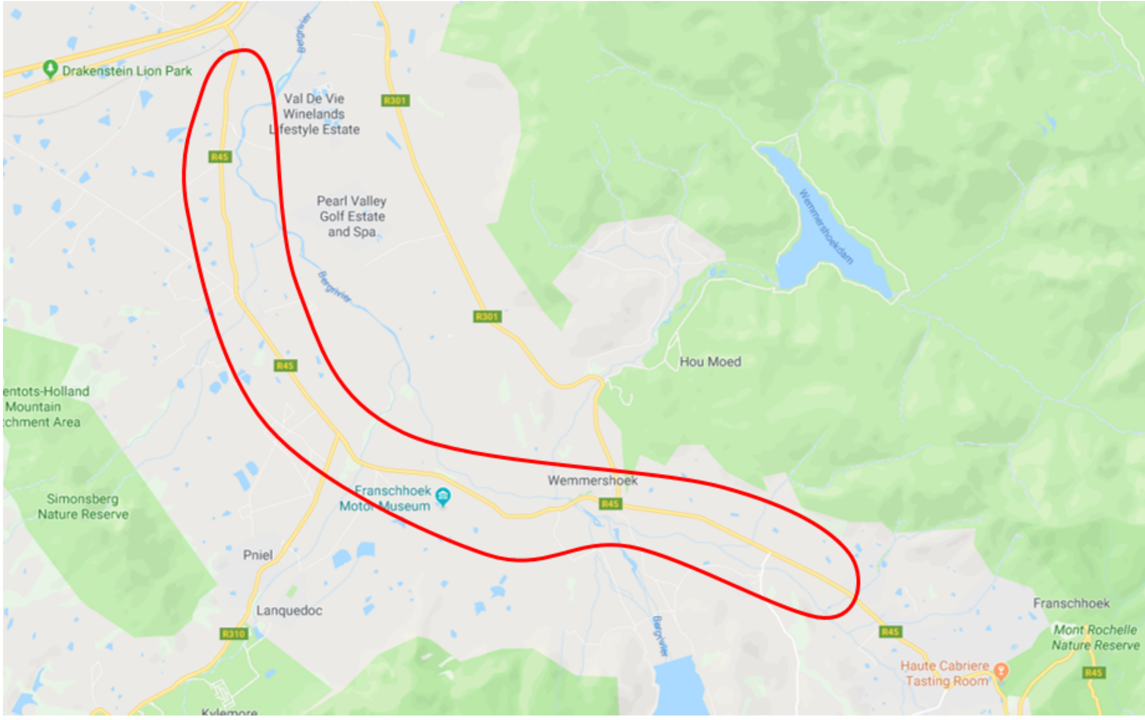

Figure 3.3: Aerial view of the Route 45 road section

Source: (Google Maps, 2018)

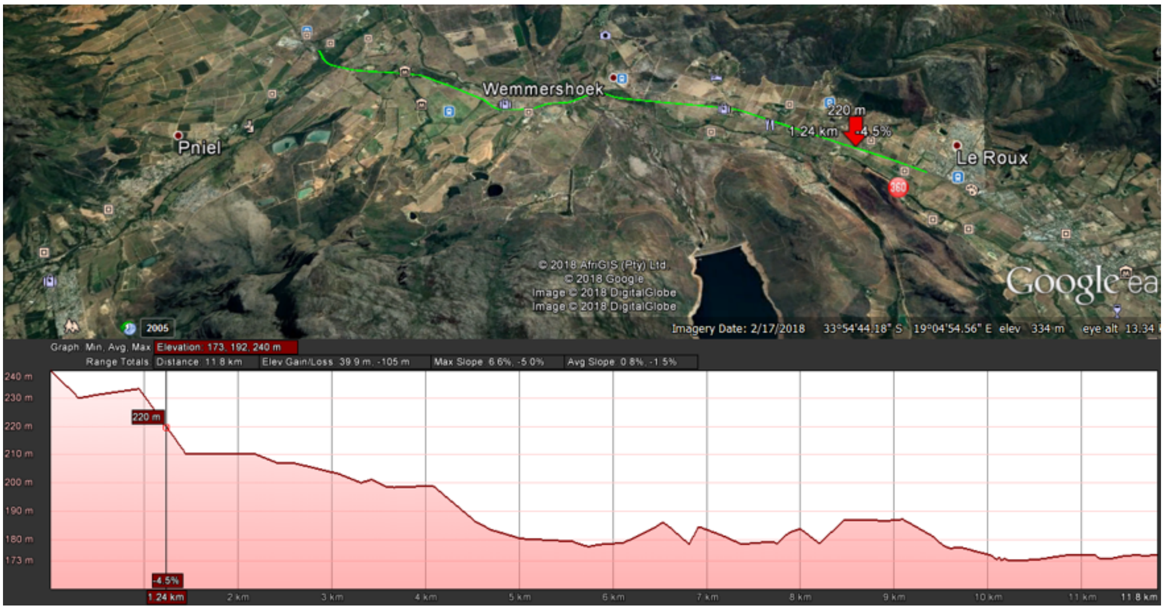

Figure 3.4: Elevation profile of the R45

3.1.3 National Road 02

The N2 is the longest of the three sections that were investigated, with a total length of 18,5 km. Furthermore, the N2 was also the road section that contained the longest consecutive section on which overtaking is prohibited. The layout of the N2 is much like a combination of the R44 and R45. The western 11 km of the N2 had much the same layout and design as the R44 with numerous crests, troughs and horizontal curves. Overtaking was also prohibited for the entire 11 km, while the eastern 7,5 km resembled much the same characteristics as the R45, as it was flatter, straighter and also provided sufficient opportunity for drivers to conduct overtaking manoeuvres. Figures 3.5 and 3.6 shows the layout and the elevation profile of the N2 respectively.

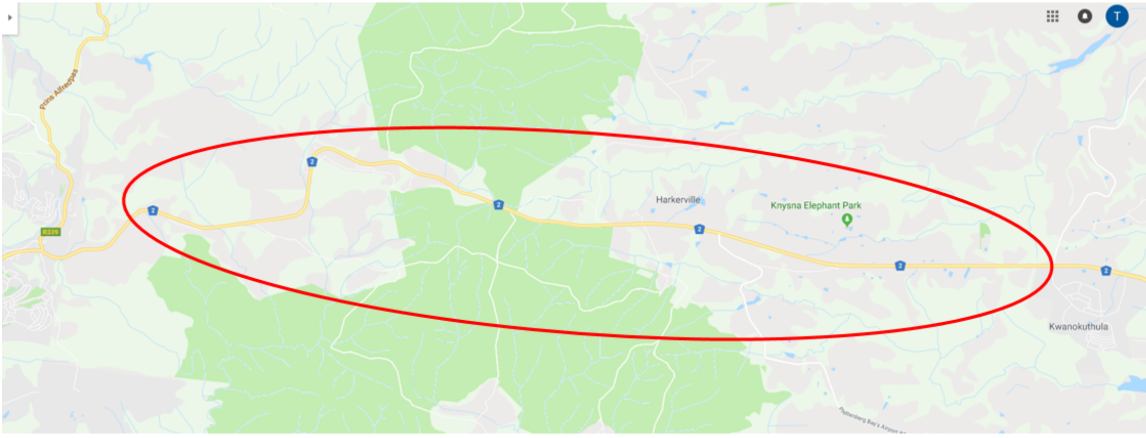

Figure 3.5: Aerial view of the N2 road section

Source: (Google Maps, 2018)

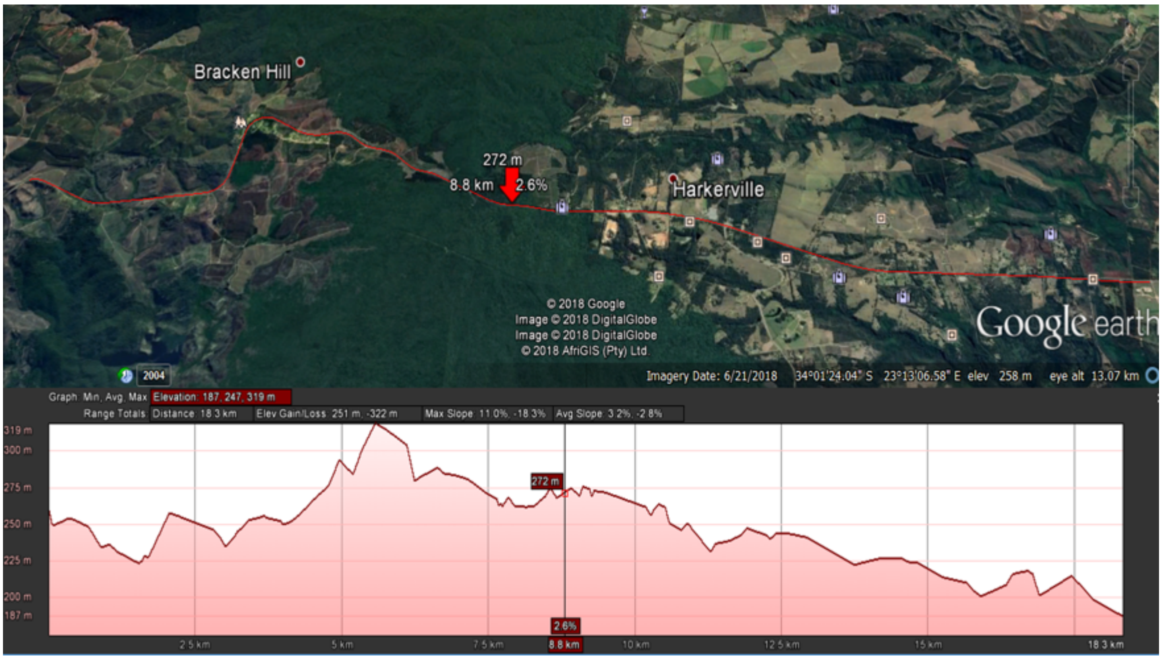

Figure 3.6: Elevation profile of the N2

3.2 Volume Analysis

The traffic volume of the three road sections were analysed in order to gain a better understanding of the number and type of vehicles making use of the sections. This data was provided by Mikros Traffic Monitoring (Pty) Limited and Syntell (Pty) Limited upon request. Both the R44 and R45 had permanent traffic counting stations installed on the roadway and therefore these stations provided the data for these two road sections, while the N2 did not have a permanent station, but two traffic counts were conducted by Mikros Traffic Monitoring (Pty) Limited.

The two traffic counts conducted on the N2 were during the periods 2016/01/27 - 2016/02/23 and 2017/10/26 - 2017/11/23 and therefore only the data recorded during these periods were available for analysis. The data for the R44 and R45 on the other hand were recorded for the full length of the year and therefore the periods used for this study, were 2016/01/01 - 2016/12/31, 2017/01/01 - 2017/12/31, and 2018/01/01 - 2018/10/02. Figure is a side view of a permanent traffic counting station located on the R44.

Figure 3.7: Side view of the R44 Traffic Count Station

Two of the major factors that were considered, were the AADT and the percentage of trucks travelling in each direction on the various roadways. A high AADT had two influences on roadway conditions, firstly higher AADT in a single direction is likely to cause more overtaking manoeuvres being conducted or vehicles travelling in queues more frequently due to the density being higher and therefore the headway between vehicles being lower. Secondly, a high AADT also makes completing an overtaking manoeuvre more difficult, as the oncoming traffic is also likely to be higher.

A modal split distribution on each road section was also taken into account. This was important to consider, as it is not necessarily only higher speeds that prove dangerous, but more particularly, the difference in speed between vehicles on the road, which increases the risk of an accident. Most large trucks in South Africa are not allowed to drive faster than 80 km/h according to the law. Most of the road sections which were inspected for this project had a predominant speed limit of 100 km/h, which meant that the speeds between larger and smaller vehicles were potentially relatively large, thus decreasing the safety of the roadway. For this reason a high percentage of trucks on the road is likely to lead to slower average speeds, as trucks generally travel at slower speeds than passenger cars. Furthermore trucks are also more difficult to overtake, as they are longer and therefore require more time to overtake and vehicles following trucks also find it more difficult to see oncoming traffic de to the size of trucks. For this reason trucks are the most likely vehicles to cause queues to develop on roadways.

The vehicle distribution was divided into two main categories, namely passenger cars and trucks, with trucks consisting of short, medium and long. Vehicles such as minibuses and buses fell within the category of trucks. Minibuses were estimated to be the equivalent of short trucks, while larger buses were estimated to be the equivalent of large or medium trucks, depending on the size of the bus. Examples of large trucks were an interlink truck, cement mixer, crane truck, large bus and garbage truck with a double axle at the rear of the truck. The distributional split on the road sections were provided within the data obtained from Mikros traffic Monitoring (Pty) Limited and Syntell (Pty) Limited. A brief manual traffic count was also conducted in order to confirm the distribution percentages provided.

When sufficient data was provided, the percentage of vehicles travelling less than two seconds behind another vehicle, as well as the percentage of vehicles travelling during periods when the traffic flow was greater than 600 veh/hour was also recorded.

Figure 3.8 is a representation of the traffic volumes on some of the roads within the Stellenbosch municipal region as obtained from the Western Cape Government Road Network Information System. Both the R44 and R45 can be seen within this figure, as well as the roads surrounding them. Varying colour ranges have been provided for various traffic volumes on the roads. The volume range for the various colours can be found in table 3.1.

Furthermore a level of service representation of the traffic volume data can be found in figure B.1 and table B.1 in appendix B. The level of service for the R44 were classified as D and E, while the R45 had were classified as LOS C and D.

Figure 3.8: Road Volumes North of Stellenbosch

Table 3.1: Road Volume Colours

Colour	AADT Volume Range
(dark green)	301 - 500
(light green)	501 - 1 500
(yellow)	1 501 - 4 500
(orange)	4 501 - 13 500
(red)	13 501 - 40 000

3.3 Speed Analysis

Vehicle speeds are a critical factor in road safety and need to be taken into consideration whenever considering the road safety. For this reason, the vehicle speeds of each of the three road sections were analysed using data provided by TomTom.

The nature of the speed data made it possible to assess the speed at which vehicles were travelling as they moved along the route and not simply at stationary positions along the route. This helped in the assessing of the road design as well as driver behaviour, for it was possible to identify troublesome locations along the route at which vehicle speeds were either too high, or a drop in speeds occurred. The comparison between the actual speed at which motorists were travelling and the posted speed limit may prove to be an important factor within road safety, as this is probably the most conspicuous physical measurement that may influence the attitude of motorists.

Drivers are likely to compare the speeds at which they can travel with the posted speed limit and therefore if the actual speeds of motorists were found to be too low in comparison with the posted speed limit, drivers would be likely to become more frustrated, impatient, and agitated due to knowing that they are losing valuable time on the road (Shinar, 2007). Shinar (2007) further stated that data obtained from a study indicated that most drivers actually aim and think it is acceptable to driver at speeds slightly above the speed limit. Therefore the desire to drive at higher speeds but being unable to do so is likely to have an effect on the psychological state of drivers (Hirsh *et al.*, 2008) and may contributed to drivers exhibiting more dangerous behaviour (Shinar, 2007).

On the other hand, if the speeds were too high, it would indicate that drivers perceived that they could drive faster than the posted speed limit while maintaining an adequate level of risk (Lewis-Evans & Charlton, 2006). Vehicles travelling at higher speeds only increase the risk of accidents and is thus something that needs to be avoided (Aarts & Van Schagen, 2006). Furthermore, if the posted speed limit is too low in comparison to the design of the road according to the perception of drivers, it could lead to drivers losing their confidence in the adequacy of the posted speed limit, which is likely in turn, to cause drivers to doubt the adequacy of the road design in its totality (Shinar, 2007). This may have the unwanted consequence of drivers starting to ignore the road laws as they lose their confidence in the adequacy of the road design.

In order to eliminate extraordinary or special events, the 85th and 15th percentile speeds were predominantly used in this study. The 15th percentile is used in order to eliminate any extraordinary cases like vehicles breaking down or stopping next to the road, but also serves to eliminate the speeds of vehicles leaving the roadway at an intersection. Even though the speeds of vehicles leaving will be eliminated, vehicles slowing down in order to leave the roadway is likely to have an effect on the speed of vehicles immediately behind and therefore speeds at intersections are expected to be slightly lower than the surrounding region. The 85th percentile speed simply means that 85 percent of vehicle were either travelling at such a speed or slower.

The data which was provided by TomTom was for the month of March 2018. All weekends, public holidays, as well as school holidays were excluded for the purpose of this study in order to ensure that the results represented ordinary weekday speeds at which motorists travel on the various road sections. For this reason, the dates that were excluded were 3, 4, 10, 11, 17, 18, 21, 24, 25, 29, 30, 31 March 2018. The 21st and 30th were both public holidays, while the 29th was when the school holidays began and the rest were weekends. Thus the data which was obtained represented the speeds of the remaining days of March 2018.

The TomTom database could only provide speed data for a total of 7 time periods. These periods were chosen in order to gain the greatest understanding of the speeds of vehicles on the various road sections. The periods needed to be selected in order to determine the difference in speeds during different times of the day. This in turn also enabled evaluating the difference in speeds of vehicles during the same period of time by making use of the speed percentiles. The periods that were chosen were 22:00 - 06:00 (Base set); 07:00 - 08:00; 10:00 - 11:00; 13:00 - 14:00; 16:00 - 17:00; 17:00 - 18:00; 18:00 - 19:00.

The base set (22:00 - 06:00) was selected in order to get an estimation of the free-flow speed (FFS) for the various road sections, as this is the time during which the lowest number of vehicles were present on the road. It should be noted that the base set was not a completely accurate representative of free-flow speed, due to the base set being during the night. As such the conditions did not fully represent free-flow and it was expected that the speeds during the base set were indeed a bit slower than actual free-flow conditions, due to speeds being slower in the night. Comparing the base set speeds with that recorded during other periods of the day was used to determine to which extent the traffic volume affected vehicles speeds during the day.

3.4 Accident Data Analysis

Only the accidents data for the R44 and R45 were used for this study, as the location of the accidents that occurred on the N2 were unknown. The data that was provided with regards to the N2 section also contained numerous accidents that occurred on other sections that were not considered and therefore none of the data could be used, for this would lead to a misrepresentation of the results.

The accident data for both the R44 and R45 were obtained from the Western Cape Government and it was possible to identify the location of accidents provided for these roads. The accident data ranged from January 2015 to October 2018.

3.5 Risk Classification

Not all overtaking manoeuvres contain the same level of risk, as some pose a greater possibility of resulting in an accident than others. For this reason, various types of overtaking manoeuvres needed to be allocated to certain risk levels. Three basic levels were decided upon for the purpose of this study, namely low, medium and high risk. Manoeuvres were categorised on the basis of the possibility it posed on resulting in an accident, therefore manoeuvres classified as containing a high level o risk were the most likely to result in an accident, while low risk level manoeuvres were the least likely.

The risk involved with any manoeuvre was based upon the possibility and consequence of a conflict point occurring between two or more vehicles. Both the number of conflict points and the consequence of each individual conflict point influence the risk involved in a manoeuvre. A conflict point is considered a point at which two vehicles will collide if correct and accurate action is not taken by either one or more vehicles. For example if a faster moving vehicle is catching up to a slower moving vehicle ahead on the road, a conflict point would occur (resulting in a head/rear end collision) unless either the leading vehicle speed up, the following vehicle slow down, or the following vehicle completes a successful overtaking manoeuvre.

3.5.1 Classifying High Risk Manoeuvres

Four possible manoeuvres were identified as containing a high level of risk, the first and most often recorded one is conducting an overtaking manoeuvre without sufficient sight distance while having to cross over the centre line of the road and therefore travelling, even if only partially, in the lane of oncoming traffic. This manoeuvre was classified as containing a high level of risk, because if oncoming traffic were to appear at that moment, the chance of an accident occurring is very high and require well performed evasive action to avoid an accident. Therefore even when no oncoming traffic were present, such manoeuvres were still classified as containing high risk, for the assumption that there will be no oncoming traffic cannot be allowed to validate such manoeuvres and therefore it should rather be assumed that there will be oncoming traffic and such manoeuvres should therefore not be conducted at all.

The second manoeuvre is fly by overtaking in the face of oncoming traffic. What is meant by 'in the face of oncoming traffic,' is that oncoming traffic is clearly visible and not at a far enough distance to complete an overtaking manoeuvre without posing a serious possibility of causing an accident. These manoeuvres occurred at the highest speeds and therefore required the shortest amount of time of all the overtaking manoeuvres and it was therefore observed that in the majority of such cases, neither the behaviour of the leading vehicle, nor that of the oncoming traffic suggested that either expected an overtaking manoeuvre to occur. This in itself caused the reaction of drivers to be slower as they were faced with unexpected circumstances (Stanton & Salmon, 2009) and therefore the avoidance of an accident was most often determined by the driver conducting the overtaking manoeuvre. These manoeuvres also led to the most near miss events of all the overtaking manoeuvres recorded.

The third manoeuvre is overtaking one vehicle immediately behind another that is also overtaking the same vehicle without being able to see oncoming traffic and therefore being uncertain of being able to complete the overtaking manoeuvre before being faced with a conflict point of oncoming traffic. What made this type of manoeuvre so dangerous, was the number of possible conflict points that could lead to an accident. Firstly, if the first vehicle attempting the overtaking manoeuvre were to brake for some reason, it would be very difficult for the second vehicle conduction the overtaking manoeuvre to react in time to avoid the accident due to the close following distance. Secondly the second vehicle is dependant on the judgement and perception of the first vehicle, but runs a higher risk of not being able to complete the manoeuvre before conflicting with oncoming traffic.

The fourth and final manoeuvre is overtaking three or more vehicles consecutively without being certain of being able to complete the overtaking manoeuvre before encountering a conflict point with oncoming traffic. This manoeuvre also posed multiple possible conflict points that therefore increased the risk of such manoeuvres, the first being that if any of the two or more vehicles also following the leading vehicle attempted an overtaking manoeuvre without seeing the vehicle passing numerous vehicles, it is likely to lead to a collision between these two vehicles. The second threat being a collision with oncoming traffic if the vehicle is unable to successfully overtake all the vehicles in time and the third being that if the driver realises that he/she will not be able to successfully complete the manoeuvre in time, he/she needs to join the queue of vehicles following the leading vehicle in time to avoid a collision with oncoming traffic, but this too poses the possibility of colliding with one or multiple vehicles currently travelling in the queue. These manoeuvres are therefore very reliant on the drivers' accurate perception of distance and capabilities of his/her own vehicle. This manoeuvre occurred least of the four mentioned

Figure 3.9 is an example of a vehicle (white light heavy vehicle in the middle of the figure) conduction an overtaking with insufficient sight distance while having to cross over the centre line and partly driving in the lane of oncoming traffic. This therefore serves as an example of a high risk overtaking manoeuvre

Figure 3.9: Example of high risk overtaking manoeuvre

3.5.2 Classifying Medium Risk Manoeuvres

A total of four manoeuvres were identified as containing medium level of risk, the first is overtaking two or three vehicles in one manoeuvre without being faced with the possibility of a collision with oncoming traffic. This was classified as containing a medium level of risk due to an increase in conflict points as compared to a single vehicle overtaking manoeuvre. The additional conflict point was that which would occur when one of the other following vehicles also decided to attempt an overtaking manoeuvre. The majority of such manoeuvres were recorded when small queues (two or three vehicles) were travelling along the roadway.

A second manoeuvre containing a medium level of risk is overtaking one vehicle immediately behind another that is also overtaking the same vehicle while having sufficient sight distance to see the oncoming traffic and being sure that the manoeuvre can be completed without the possibility of a conflict with oncoming traffic. The reason why this was classified as a medium risk manoeuvre, is the danger involved with the short following distance behind the first vehicle, for if the first vehicle conducting the overtaking manoeuvre were to suddenly brake, there would not be sufficient time to react in order to avoid a collision.

The third manoeuvre is overtaking one vehicle, having to cross over the centre line of the road and therefore drive in the opposing traffic flow's lane to some degree, while at the same time having sufficient sight distance to see oncoming traffic, knowing that the manoeuvre will not be completed before being faced with a conflict point with oncoming traffic and yet to conduct the overtaking manoeuvre. In this description, it may sound like this should be classified as containing a higher level of risk, but it was observed time and again that the oncoming vehicles in such cases move more to the left when they observe such a manoeuvre and therefore the possible conflict between the two vehicles are avoided. These manoeuvres may seem to pose little chance of resulting in an accident, but the fact that it is dependant on the oncoming traffic giving way, it was classified as containing a medium level of risk, for if the oncoming traffic do not give way, it will indeed result in an accident. This manoeuvre therefore relies on other drivers to take action in order to avoid a collision, which according to Damasio (1994), is likely to happen, as a person's first instinct is to protect themselves.

The fourth manoeuvre is high speed fly by overtaking manoeuvres that were not in the face of oncoming traffic. The combination of the high speed of the vehicle conducting the overtaking manoeuvre and the difference in speed between the vehicle overtaking and the vehicle being overtaken posed a higher level of risk and these manoeuvres were therefore classified as containing a medium level of risk.

Figure 3.10 shows a photo that was taken from the vehicle conducting the overtaking manoeuvre. The driver of the vehicle conducting the overtaking manoeuvre has a clear view of the oncoming traffic (indicated in the red circle) and can therefore see that the manoeuvre will not be completed before a possible conflict with oncoming traffic, yet the driver still conducts the manoeuvre, assuming that the oncoming traffic will move more to the left in their lane in order to avoid a collision. This figure is therefore an example of the third medium risk manoeuvre described above.

Figure 3.10: Dangerous overtaking on the R44

Source: (Google Maps, 2018)

3.5.3 Classifying Low Risk Manoeuvres

Two types of low risk overtaking manoeuvres were identified, the first is conducting an overtaking manoeuvre while having sufficient sight distance, seeing that any possible oncoming traffic is far enough to complete the overtaking manoeuvre without being faced with any conflict point with them. This involves the vehicle conducting the overtaking manoeuvre to cross over the centre line of the road.

The second type is when the leading vehicle is driving so far to the left that the vehicle conducting the overtaking manoeuvre does not need to cross over the centre line of the road and therefore is not faced with any conflict point with oncoming traffic.

In figure 3.11, the vehicle conducting the overtaking manoeuvre did not need to cross over the centre line in order to complete the manoeuvre and could therefore complete the manoeuvre without any possibility of a conflict with oncoming traffic. If the vehicle conducting the overtaking manoeuvre were approximately 0,7 metres more to the right, the manoeuvre would be classified as containing a medium level of risk due to the possibility of a conflict point with oncoming traffic.

Figure 3.11: Dangerous overtaking near Knysa

Source: (Google Maps, 2018)

3.6 Questionnaire

A total of 112 individuals participated in the questionnaire and were asked to either manually complete the questionnaire or to have their answers recorded via voice recording. The majority of participants were approached in parking lots at shopping centres. All of the participants chose to complete the questionnaire manually and none chose to have their answers recorded via voice recording.

The participants were diverse in terms of age, gender and race, with the only prerequisite of partaking being that one needed a driver's license. The oldest participant was 68 and the youngest was 20. Of th 112 participants were 60 male and 52 female.

The questionnaire that participants were asked to complete can be seen in Appendix D.

Chapter 4

FINDINGS

All three of the selected roadway sections were classified as class 2 rural roads according to the road classification specifications as stipulated by the Committee of Transport Officials (2012).

4.1 Route 44 Characteristics

4.1.1 R44 Geometric Characteristics

The Route 44 north of Stellenbosch is a two-lane (major arterial) and contained the highest volume of the three roads that were inspected. Seeing that it is classified as a class 2 rural road, the primary function is providing mobility to motorists. This section serves as an important link in the roadway system within and surrounding the Stellenbosch municipality, as it serves as a primary route for motorists travelling between major towns in the region.

Residents of four major towns (Stellenbosch, Paarl, Wellington, and Somerset West) were estimated to possibly make use of this road section. According to the census count of 2011, the population of Stellenbosch and Somerset West were 155 733 and 55 000 respectively. Paarl and Wellington form part of the same municipality and therefore the population of these two towns were collected as a single number, which added to a total of 198 000.

Both Stellenbosch and Somerset West are located to the south of this section of the R44, whereas Paarl and Wellington are north of this road section. For this reason vehicles travelling between Stellenbosch and Somerset West, as well as between Paarl and Wellington, will not make use of this roadway. On the other hand, motorists travelling from either of the two towns located south of this road section to either of the two towns located north of this road section or vice versa, would most probably make use of this roadway, as it provides the most direct and quickest access for these vehicle movements. It should be noted, however, that this is not the only route that is available to motorists that wanted to travel between these towns: other alternatives were also available.

This roadway does not only serve as a link between the towns mentioned previously, but it also serves as a link for motorists that need access to Stellenbosch coming from the N1 and therefore also serves as a link between the N1 and Stellenbosch. Even though the N1 carries a large number of vehicles travelling from the Cape Town region (South-West of Stellenbosch) to Stellenbosch, the majority of these vehicles do not make use of the R44, but rather the R304, as it provides a faster and more direct route for them to Stellenbosch. It was however observed that some vehicles, especially larger trucks diverted to the R44 in order to avoid the weigh bridge located on the R304. The number of trucks diverting to the R44 has led to an increase in the percentage of trucks on the R44 and a reduction on the R304. Other than the vehicles diverting from the R304, the origin or destination of the majority of motorists making use of the R44 as a link between Stellenbosch and the N1, would most likely be toward the North-East of Stellenbosch, but the number of trips generated in this direction were observed to be significantly less than the others mentioned previously. Therefore from this information, the majority of motorists making use of this road section were estimated to be commuters travelling between the towns mentioned previously.

The length of the section of the R44 that was inspected (as indicated in figure 3.1 of section 3.1) was 10.5 km. The carriageway was re-sealed in January and February 2018 and the current condition of the road markings were only implemented of the re-seal was completed. Therefore overtaking has been prohibited for the entire length of this section only since approximately March 2018. Before this, overtaking was permitted at numerous locations along the route. Since the road has been re-sealed very recently, the surface condition of the road is still in very good condition.

The speed limit of the entire section under consideration is 100 kph. The speed limit only decreased a few hundred metres outside the boundaries of this road section due to approaching signalised intersections on either side. Thus the speed limit was effectively 100 kph for both directions. A speed camera is located 6.7 kilometres from the start of the road section travelling southbound. The camera is only set for vehicles travelling southbound and its purpose is to control the speeds of the vehicles, as this location is in the lower half of a long downhill section, with an uphill section ahead. Without the speed camera, drivers would most likely travel much faster along this section than permitted. The presence of this speed camera is of great importance, as it is located within the vicinity if two important intersections. In this way, controlling the speed of vehicles travelling along the R44 serves to decrease the difference in speed when another vehicles join the R44 from either of these two intersections.

Figure 4.1 shows the location of the speed camera next to the road. The figure also shows a medium sized truck waiting to join onto the R44 from the Kromme Rhee intersection. Also evident in the figure (which was taken before the change of the road markings) are the road markings which still permitted drivers to attempt overtaking manoeuvres. One can see from the image, that even with overtaking being permitted by the road markings, vehicles still formed quite large platoons as they moved along the roadway.

Figure 4.1: Speed camera located on the R44

The total width of the carriageway was 12 metres for the majority of this section, with a slight increase in width occurring at horizontal curves. Hard shoulders were present for the entire length of this section, with a width of 2 metres on either side, while the lane width was 4 metres in both directions for the majority of this section. The lane and shoulder width both increased slightly around horizontal curves, therefore producing a slightly wider carriageway at such instances. The measurements were all measured manually on site at various points along the route and were also confirmed using Google Earth.
The road reserve width was measured as 50 metres for the entire length of this section, with the cross-sectional position of the built carriageway predominantly on the eastern side of the road reserve. Therefore the verge was much larger on the western side of the road reserve than on the eastern side.

Figure 4.2 shows the width (within the grey boxes) of both the road reserve (which is represented by the green line in the image), as well as the carriageway (which is represented by the white line in the image). From the image, it is also possible to see the alignment of the carriageway within the road reserve.

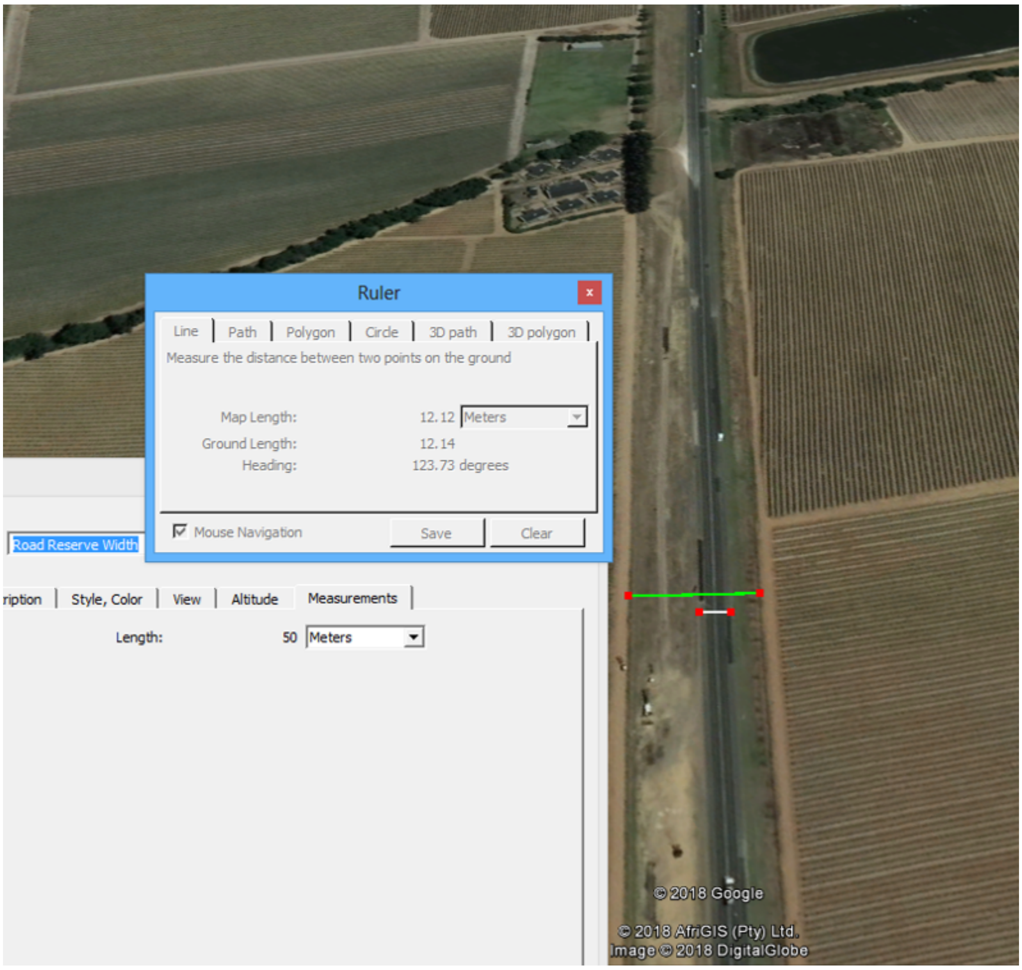

Figure 4.2: R44 road and road reserve width

Figure 4.3 indicates the elevation profile as well as the locations of the various uphill sections when travelling in a northbound direction on the Route 44 carriageway, moving from left to right along the elevation. This figure also shows an image in the longitudinal direction which illustrates the alignment of the roadway along topography. The blue line was taken down the middle of the carriageway, while the red arrow on the map corresponds with vertical line in the elevation profile. It should be noted that the southern-most 400 metres of this profile was eliminated from the calculations in order to eliminate the affect that the signalised intersection may have had on the speed of vehicles, thus the leftmost crest on the elevation profile was not taken into account.

This road section consisted of five uphill sections for vehicles travelling northbound, the fourth one being sub-divided into three parts in order to better represent the true nature of the uphill section, as it consisted of three different slope gradients. Sub-divisions of individual sections were only done when a change in the slope gradient occurred along the section. Vehicles travelling southbound were also faced with five uphill sections on this roadway, none of which needed to be sub-divided, as the gradient of each section remained relatively constant throughout.

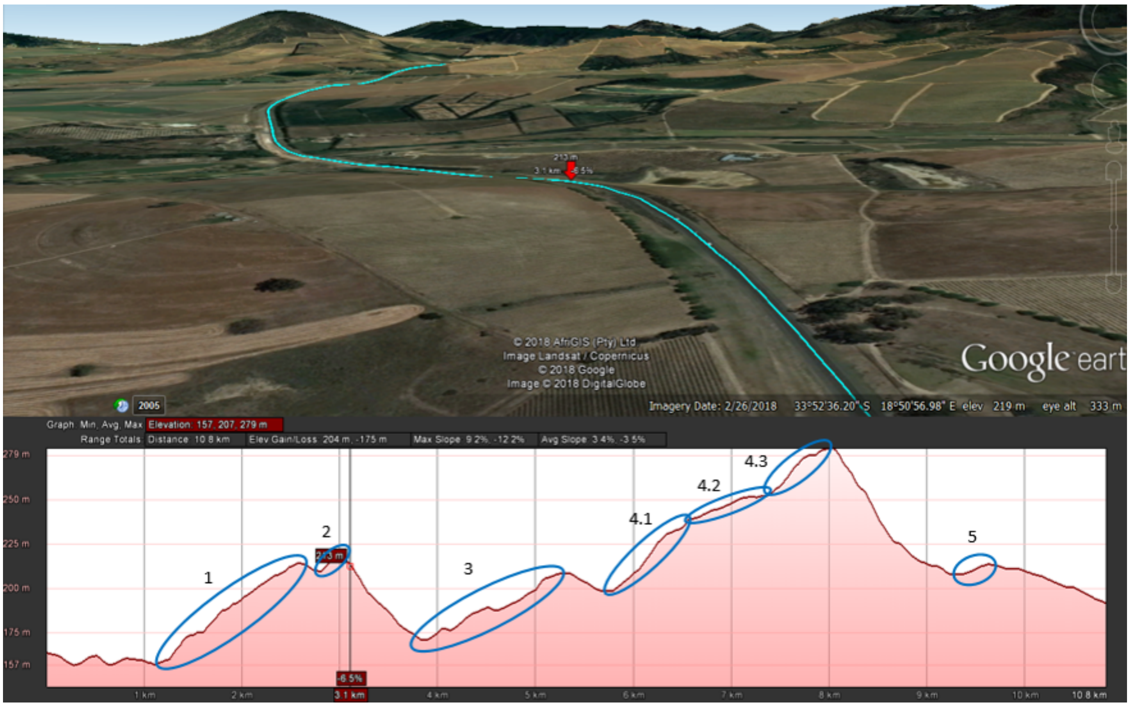

Figure 4.3: R44 Northbound Uphill Sections

It is clear from figure 4.3 that this road section has very few flat sections on which to perform overtaking manoeuvres. Furthermore, this section also does not have a lot of straight sections as illustrated in figure 3.1. The combination of the large number of vertical and horizontal alignments made overtaking difficult. Vehicles travelling northbound are faced with longer uphill sections than vehicles travelling southbound, but the slopes of the uphill sections are steeper for vehicles travelling southbound. It should be noted that the slopes as portrayed in figure 4.3 might look steeper in the figure than in reality, as the relationship between the length of the road and the change in height along the route was not in proportion to one another.

Table 4.1 is a summary of the calculations carried out in order to determine the various vertical gradients of the R44. The calculations portrays the slopes of sections as faced by vehicles travelling northbound (left to right in figure 4.3), therefore for vehicles travelling southbound, the exact reverse of this table is true. Positive and negative gradients represent uphill and downhill sections respectively for vehicles travelling northbound. The results as indicated in this table once again indicate that vehicles travelling northbound are faced with longer uphill sections, while southbound vehicles are faced with steeper inclines.

Detailed information regarding the calculations can be seen in Appendix A. Table A.1 portrays the northbound inclines, while figure A.1 and table A.2 portrays the southbound inclines.

Table 4.1: R44 Elevation Sections

Gradient type	Length	Height difference	Gradient
Uphill 1	1480 m	57 m	3.85 %
Downhill 1	170 m	- 4 m	- 2.35 %
Uphill 2	170 m	8 m	4.71 %
Downhill 2	850 m	- 47 m	- 5.53 %
Uphill 3	1370 m	38 m	2.77 %
Downhill 3	360 m	- 10 m	- 2.78 %
Uphill 4	2200 m	80 m	3.64 %
Downhill 4	1250 m	- 71 m	- 5.68 %
Uphill 5	290 m	6 m	2.07 %
Downhill 5	1170 m	- 22 m	- 1.88 %

From table 4.1, one can see that the total length of uphill sections for motorists travelling northbound was approximately equal to 5.51 km, whereas the total length of uphill sections for motorists travelling southbound was approximately 3.8 km. Thus the total length of the sections mentioned within these calculations, is 9.31 km. It should be noted that the remaining 1.2 km (which was not mentioned within these calculations) is not necessarily flat.

A total of five intersections were identified along this roadway, all of which were paved intersections (two on the western side of the carriageway and three on the eastern side). Intersections were defined as the point at which two public roads joined or crossed, as in accordance with the Committee of Transport Officials (2012). An access was defined as any private or public road, ramp, path, or driveway which joined or crossed a public road, which is also in accordance with the Committee of Transport Officials (2012). Thus an intersection is simply a specific type of access. It is important to be reminded that for a class 2 rural road, it is important to give right of way for vehicles already travelling on the class two road.

Numerous accesses were also identified along this roadway, providing access to wine estates, guest houses, single and multiple properties, as well as farmlands. Vehicles leaving and joining the R44 at these accesses caused a decrease in speed at these localised points along the route. Slower speeds at these localised points therefore also contributed to faster vehicles conducting numerous illegal overtaking manoeuvres at these points. There are a total of nine accesses to individual wine estates on the western side of the roadway, one of which also have a guest house, and there are six accesses to individual wine estates on the eastern side of the roadway, one of which also have a guest house, and another having cottages.

There are three accesses leading to single properties and one access to multiple properties on the western side of the roadway. On the eastern side of the roadway, there are four accesses leading to single properties and three to multiple properties. Furthermore, there are two accesses to farmlands and one access to a guest house on the western side of the roadway, while the eastern side have four accesses to farmlands and one access to a guest house. Therefore there are a total of 18 accesses on the eastern side of the roadway and 16 accesses on the western side.

There were a further two accesses to farmlands, as well as one access to a guest house on the western side of the roadway, while the eastern side had four accesses leading to farmlands, as well as one access to a guest house. No formal rest stops were identified along this roadway section, but two informal rest stops which were frequently used by drivers were identified on the western side of the roadway.

Table 4.2 summarises most of the mentioned characteristics.

Table 4.2: R44 Road Characteristics Summary

Description	**Northbound**	**Southbound**
Total length of section	10.5 km	
Length on which passing is prohibited	10,5 km	10,5 km
Length on which passing is permitted	0 km	0 km
Longest section on which no passing is permitted	10,5 km	10,5 km
Longest sight distance without passing permitted	850 m	800 m
Length on which speed limit is 100 km/h	10,5 km	10,5 km
Lane width	4 m	4 m
Shoulder width	2 m	2 m
Roadway width	12 m	
Road reserve width	50 m	
Paved Intersections on the Eastern side	3	
Paved Intersections on the Western side	2	
Total number of accesses on the Eastern side	18	
Total number of accesses on the Western side	16	

4.1.2 R44 Traffic Volume

The R44 had the largest traffic volume of the three routes which were inspected, with a predominant level of service E as also indicated in figure B.1 of Appendix B.

As can be expected, the traffic volumes were not distributed equally for all periods of the day. What was interesting to note however, was that the volume distribution also differed for the two opposing flow directions. During the morning peak, more vehicles travelled southbound toward Stellenbosch as compared to northbound, while the exact reverse of this was true during the afternoon peak, with more vehicles travelling northbound than southbound. This phenomenon was caused by commuters moving in and out of Stellenbosch in the morning and afternoon, with more commuters travelling toward Stellenbosch in the morning than away. Furthermore, the results indicated that this difference in volume between flow directions only took place during peak hours, while the traffic volume was near equal for both directions during off-peak periods. It was also noted that the morning peak period was shorter than the afternoon peak, which was most likely caused by the large number of motorists that aimed to be at work at 08:00, while not everyone had the same working hours and therefore left work at varying times.

The morning peak occurred at approximately the same time period for all weekdays, which was from 07:00 - 08:00. The afternoon peak also occurred at approximately the same time of day for all weekdays with the exception of Fridays. Monday to Thursday exhibited an afternoon peak period from 16:00 - 18:00, while the afternoon peak on Fridays was from 13:00 - 18:00. The results indicated that the traffic volume was higher during the morning peak than the afternoon peak period for all weekdays with the exception of Friday. The higher volumes recorded during the morning peak was primarily due to the peak period being shorter than the afternoon peak. The results showed that the highest volume was recorded during Friday afternoon peak periods and therefore the traffic conditions were their worst during these periods, as this was not only the peak period with the highest volume count, but it also lasted longer than other peak periods. The high volume on Fridays can most likely be attributed to both students and scholars leaving Stellenbosch for weekends.

The average vehicle distribution of weekdays for the three time periods mentioned earlier can be seen in figures B.2, B.3, and B.4 in Appendix B. The red, blue, and dotted green lines in the figures represent the total, northbound and southbound traffic volumes respectively.

During the period 2016/01/01 - 2016/12/31, this route had an average daily traffic of 6 776 in the northbound direction, and 6 756 in the southbound direction. The average daily truck traffic was 353 northbound and 343 southbound, therefore the percentage of trucks were 5,2% northbound and 5,1% southbound. The truck split percentages (short : medium : long) were (60 : 18 : 22) for the northbound direction, and (58 : 19 : 23) for southbound.

Furthermore, the percentage of vehicles travelling traffic during hours of darkness (20:00 - 06:00) amounted to 8,5% and 7,7% for vehicles travelling northbound and southbound respectively. Therefore the day time traffic volumes were 6 200 and 6 236 northbound and southbound respectively, with the highest hourly volumes in each direction being 926 and 1022 northbound and southbound respectively.

The data indicated that 35,3% and 30,1% of vehicles travelling northbound and southbound respectively were less than 2 seconds behind the leading vehicle, indicating a relatively small headway for a large percentage of vehicles. This serves to show that a large number of vehicles were travelling at an unsafe following distance behind the leading vehicle, as 2 seconds at 90 km/h is equal to a following distance of 50 metres. Furthermore 21,5% and 16,9% of vehicles travelling northbound and southbound respectively travelled during periods that had a flow rate of more than 600 veh/h/ per lane.

Table 4.3 is a summary of the results for the period 2016/01/01 - 2016/12/31.

Table 4.3: Traffic Volumes for R44 for the Period 2016/01/01 - 2016/12/31

Description	**Northbound**	**Southbound**
Total number of vehicles (counted)	2 479 801	2 472 753
Average daily traffic (ADT)	6 776	6 756
Average daily truck traffic (ADTT)	353	343
Percentage of trucks	5,2 %	5,1 %
Truck split (short : medium : long)	(212 : 63 : 78)	(199 : 65 : 79)
Nighttime traffic volume (20:00-06:00)	576	520
Daytime traffic volume	6 200	6 236
Highest hourly volume (veh/h)	926	1 022
% vehicles less than 2s behind vehicle ahead	35,3	30,1
Percentage vehicles in flows over 600 veh/h	21,5	16,9

The results for the period 2017/01/01 - 2017/12/31 showed a slight increase in traffic volumes and a reduction in speeds resulting from the increase in volume. The average daily traffic was 6 909 and 6 833 vehicles per lane for the northbound and southbound directions respectively. The percentages of trucks were 5,1% for both the northbound and southbound directions, with a truck split of (60 : 18 : 22) and (59 : 18 : 23) for the respective directions.

The day time traffic accounted to 6 322 and 6 360 vehicles per lane and therefore the percentage of traffic during hours of darkness amounted to 8,5% and 7,6% northbound and southbound respectively. The highest hourly volumes in each direction were 926 and 1022 northbound and southbound respectively.

Table 4.4 is a summary of the results for the period 2017/01/01 - 2017/12/31.

Table 4.4: Traffic Volumes for R44 for the Period 2017/01/01 - 2017/12/31

Description	Northbound	Southbound
Total number of vehicles (counted)	2 521 700	2 512 177
Average daily traffic (ADT)	6 909	6 883
Average daily truck traffic (ADTT)	355	351
Percentage of trucks	5,1 %	5,1 %
Truck split (short : medium : long)	(213 : 64 : 78)	(207 : 63 : 81)
Nighttime traffic volume (20:00-06:00)	587	523
Daytime traffic volume	6 322	6 360
Highest hourly volume (veh/h)	1 016	1 051
Percentage vehicles in flows over 600 veh/h	23,3	19,2

The results for the period 2018/01/01 - 2018/10/02 showed quite a large increase in traffic volumes and a slight reduction in speeds resulting from this. The average daily traffic was 8 009 and 8 065 vehicles per lane for the northbound and southbound directions respectively. A slight increase in the percentage of trucks also indicated that the number of trucks making use of this road increased substantially compared to the previous two years. The percentages of trucks were 5,3% and 5,2% northbound and southbound respectively, with a truck split of (64 : 16 : 20) and (60 : 17 : 23) for the respective directions.

The day time traffic accounted to 7 296 and 7 420 vehicles per lane and therefore the percentage of traffic during hours of darkness amounted to 8,9% and 8,0% northbound and southbound respectively. Interestingly, even though the total daily traffic increased dramatically, the highest hourly volume decreased slightly as compared with 2017, with a highest hourly volume of 934 and 991 northbound and southbound respectively.

Table 4.5 is a summary of the results for the period 2018/01/01 - 2018/10/02.

Table 4.5: Traffic Volumes for R44 for the Period 2018/01/01 - 2018/10/02

2018/01/01 - 2018/10/02 Volumes Summary		
Description	**Northbound**	**Southbound**
Total number of vehicles (counted)	992 380	999 380
Average daily traffic (ADT)	8 009	8 065
Average daily truck traffic (ADTT)	425	420
Percentage of trucks	5,3 %	5,2 %
Truck split (short : medium : long)	(272 : 68 : 85)	(252 : 71 : 97)
Nighttime traffic volume (20:00-06:00)	713	645
Daytime traffic volume	7 296	7 420
Highest hourly volume (veh/h)	934	991
Percentage vehicles in flows over 600 veh/h	21,4	17,0

4.1.3 R44 Vehicle Speeds

As mentioned in section 4.1.1, the posted speed limit for the section of the Route 44 under inspection is 100 km/h for the entire section in both directions. Due to the road markings prohibiting overtaking for this entire section, the difference between the various percentile speeds should not be too great if motorists did indeed adhere to the law as indicated by the road markings. This is not to say that no difference should exist whatsoever, but that the difference should not be very great. The reason for this is that faster moving vehicles were expected to move at their desired speeds as far as possible, but when faster moving vehicles caught up to slower ones, they would be required to travel at the speed of the slower moving vehicles if adhering to the road markings. Therefore there should be a slight difference in the percentile speeds, but a large difference would indicate that motorists did not adhere to the road markings.

The results indicated a substantial difference between the various percentile speeds, indicating that numerous motorists conducted overtaking manoeuvres and did not adhere to the road markings. In fact the R44 had the largest difference between the various percentile speeds of the three road sections under inspection, indicating the largest difference between faster and slower moving vehicles. Furthermore, both directions also showed a substantial difference between the speeds during the base set and the other time periods, indicating that the traffic volume affected the speeds considerably.

4.1.3.1 R44 Northbound Speeds

Vehicles travelling northbound on the R44 were moving away from Stellenbosch as mentioned in section 4.1.1, thus the origin of these trips were likely to be from Stellenbosch, but there were quite a few possibilities with regards to the destination.

Table 4.6 shows the 15th, average, and 85th percentile speeds of vehicles travelling northbound on the R44. It also shows the difference between the percentile speeds in order to give an understanding of the difference in speed between faster and slower moving vehicles. Figure C.1 in Appendix C provides a visual representation of the various speeds. The speeds recorded during various times of the day made it possible to determine during what time of the day the fastest and slowest speeds were recorded. Furthermore it provided an opportunity to determine the difference in speed between vehicles travelling during the same time period.

The difference between the 85th and 15th percentile speeds for the various time periods, were 28.98 km/h, while the difference between the 85th percentile and average speeds for the various time periods were 19.87 km/h. The time period that produced the highest 15th, average, and 85th percentile speeds were the base period, with the 85th percentile speeds recorded during the base set being 7 km/h faster than any other period. The slowest 85th percentile speeds were recorded during both 10:00 - 11:00 and 13:00 - 14:00, while the latter also produced the slowest average speed. The slowest 15th percentile speeds were recorded during 16:00 - 17:00. The period that produced the largest difference between the 15th and 85th percentile speeds were the base period, with a difference of 31.84 km/h.

Table 4.6: R44 Northbound Percentiles Comparison

Northbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	68,45	80,35	100,29	31,84	19,94
7:00-8:00	63,94	70,42	89,32	25,38	18,90
10:00-11:00	57,08	64,33	84,68	27,60	20,35
13:00-14:00	55,76	63,09	84,57	28,81	21,48
16:00-17:00	54,79	65,54	86,61	31,82	21,07
17:00-18:00	58,00	69,29	88,04	30,04	18,75
18:00-19:00	66,22	74,99	93,57	27,35	18,58

Figure 4.4 shows the 85th percentile speeds at which vehicles were travelling as they moved along the carriageway. All seven time periods mentioned previously were once again represented in this figure in order to compare the speeds of vehicles along the route during different times of the day. It was therefore possible to identify possible troublesome areas along the route, which was most often represented by an radical decrease or increase in speed. It is important to note that figure 4.4 does not represent continuous speeds of vehicles, but rather the speed at certain points along the route. The speed of vehicles at the various points is accurate, but the slope of the line connecting these points should be seen as a fairly accurate estimation rather than 100% accurate, for the exact speeds between the various points is not known.

The results as displayed in this figure showed that speeds recorded during the base set were significantly higher than any other periods at all points along the route. Interestingly, speeds recorded during 18:00 - 19:00 were also significantly higher than the remaining periods, which were all relatively closely spaced, being within a 5 km/h range from one another for the majority of this section. The figure also shows that the base set speeds were above the posted speed limit for the first half of this section, but the speeds then decreases and are below the posted speed limit for the majority of the second half. The slowest speeds were clearly recorded during 10:00 - 11:00, 13:00 - 14:00 and 16:00 - 17:00.

The speed profile took the same form for all time periods, indicating that the road layout influenced the speeds of vehicles travelling at different times in the same manner, only to a varying degree. The profile shows an increase in speed for the first 1500 metres, after which speeds level out until 3500 metres. A significant decrease in speed occurred from 3500 to 3800 metres before levelling out again between 3800 and 5500 metres. Another significant decrease in speed occurred from 5500 to 6000 metres, after which it increased again between 6000 and 7000 metres before levelling out until 8200 metres. This was followed by a slight increase and equal decrease before the speeds levelled out toward to end of this section.

The largest decrease in speed occurred from 5500 to 6000 metres with an average of 9.6 km/h for all the time periods. The greatest decrease in speed on this portion of road was during 10:00 - 11:00 and 16:00 - 17:00, with a decrease of 12 km/h and 15 km/g respectively.

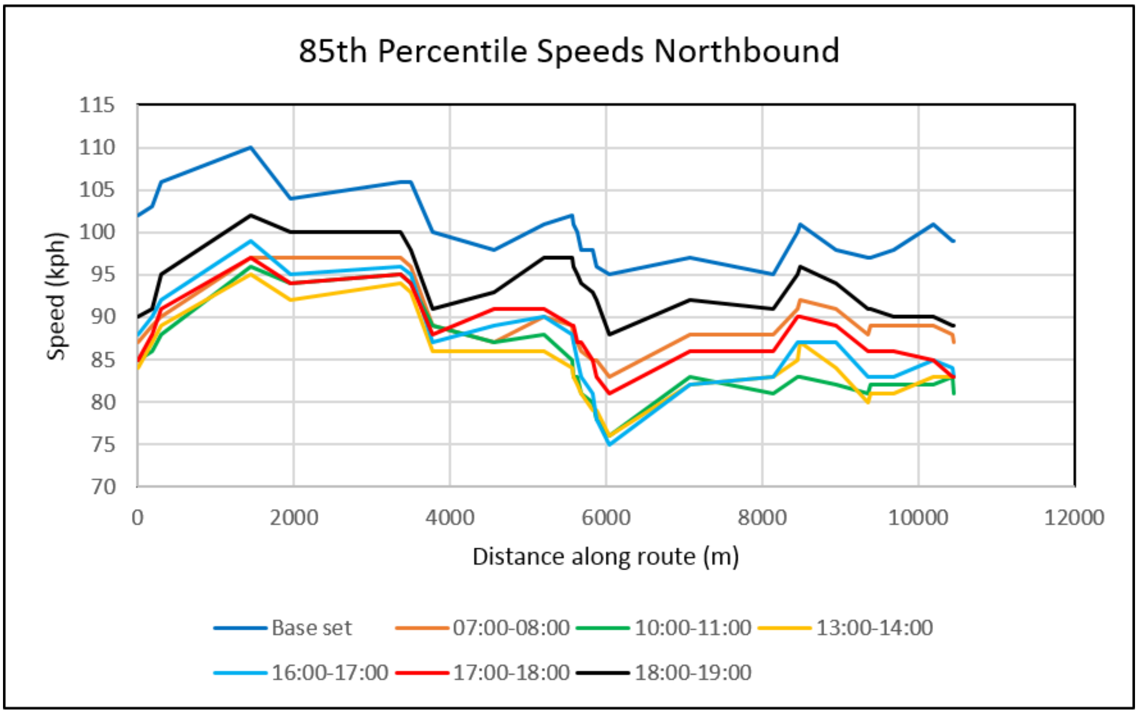

Figure 4.4: R44 Northbound 85th Percentile Speeds Along Route

The comparison between results portrayed in figure 4.4 with that of 4.5 allowed for a better understanding of the effect that the road layout might have had on larger vehicles compared to smaller ones. It was assumed that the 15th percentile speed profile was a representative of larger vehicles, whereas the 85th percentile was a representative of smaller vehicles. The comparison showed that the two speed profiles had approximately the same layout in the sense that changes in speed occurred at the same points along the route, with two major differences occurring. The first was between 4000 and 6000 metres, and the second between 8000 and 10000 metres.

One clear difference between the two profiles, was that the 15th percentile speeds recorded during the base set were not higher than the other time periods, while the 85th percentile speeds recorded during the base set were much higher than during the other periods. Furthermore, the 85th percentile speed profile indicated an increase in speed between 3800 and 5500 metres, while the 15th percentile profile indicated a reduction in speed on this section for most time periods. The 85th percentile further showed a slight increase and decrease in speeds between 8000 and

9000 metres, while the 15th percentile speeds remained relatively constant on this section.

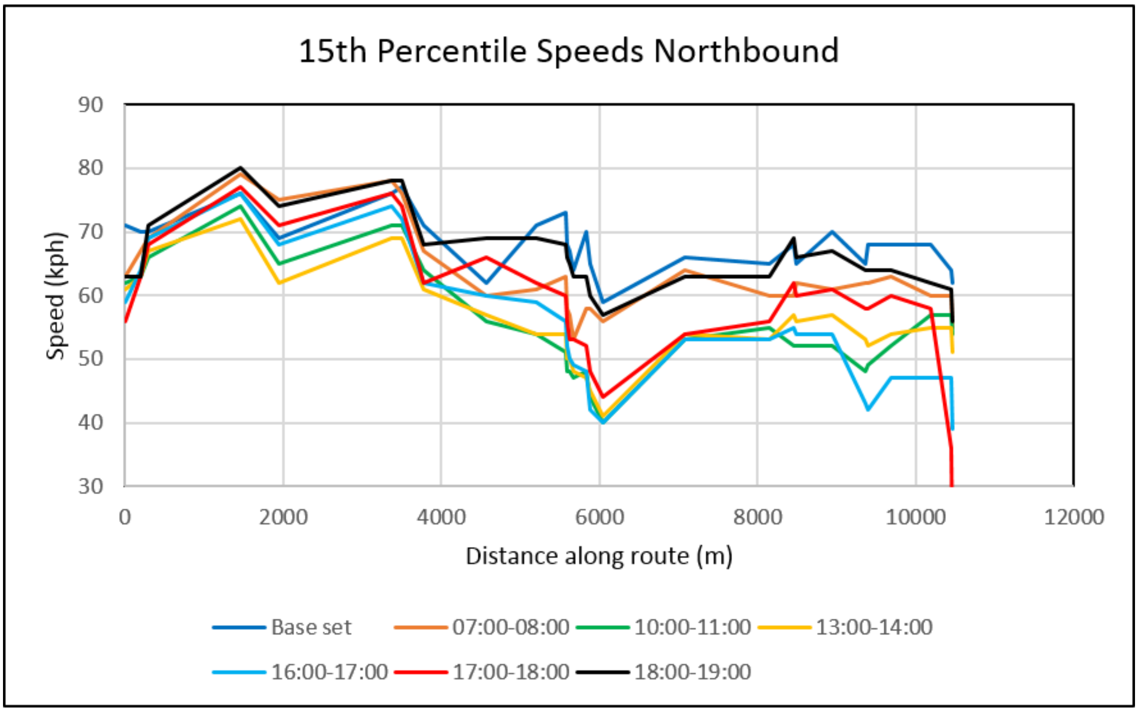

Figure 4.5: R44 Northbound 15th Percentile Speeds Along Route

4.1.3.2 R44 Southbound Speeds

Motorists travelling southbound on the R44 were moving toward Stellenbosch, with numerous possibilities of origins for these trips. The speed of vehicles travelling southbound were similar to those travelling northbound, with the exception being that the southbound speeds were higher in the afternoon than in the morning, whereas northbound speeds were higher in the morning than in the afternoon, which was largely due to traffic conditions.

Table 4.7 shows the average, 15th and 85th percentiles speeds of vehicles heading southbound on the R44. The average difference between the 85th and 15th percentile speeds for the various time periods, was 27.11 km/h, while the difference between the 85th percentile and average speeds for the various time periods was 18.73 km/h. The difference in speed between the various percentiles was therefore slightly higher for vehicles travelling northbound than southbound. Figure C.2 in Appendix C provides a visual representation of the information presented in table 4.7.

As with vehicles travelling northbound, the highest 15th, 85th percentile and average speeds were all recorded during the base set with a large difference in speed between the base set and other periods for all three percentile speeds. The slowest speeds for all three percentiles were recorded during 10:00 - 11:00 and 13:00 - 14:00, with the former produced slightly lower speeds than the latter. These two periods stood out and raised particular concern, as the lowest speeds, as well as the largest difference in speed between the various percentiles were recorded during these periods. A difference of 21.03 km/h and 21.08 km/h between the 85th and average speeds occurred during 10:00 - 11:00 and 13:00 - 14:00 respectively, while a difference of 28.92 km/h and 29.03 km/h between the 85th and 15th percentile speeds occurred during 10:00 - 11:00 and 13:00 - 14:00 respectively.

Table 4.7: R44 Southbound Percentiles Comparison

Southbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	73,81	83,62	100,50	26,69	16,88
7:00-8:00	56,89	64,70	84,73	27,84	20,03
10:00-11:00	54,35	62,2	83,27	28,92	21,03
13:00-14:00	54,93	62,88	83,96	29,03	21,08
16:00-17:00	58,96	66,80	87,38	28,42	20,58
17:00-18:00	65,47	73,72	90,23	24,76	16,51
18:00-19:00	69,85	78,97	94,00	24,15	15,03

Figure 4.6 indicates the 85th percentile speeds at which vehicles were travelling as they moved along the carriageway. As with the northbound results, this allowed for the analyses of the speed and behaviour with regards to speed of motorists along the route. As before, it is important to note that figure 4.6 does not represent continuous speed data, but rather the speed at which vehicles were travelling at certain points along the route. For this reason, this figure is not a 100% representative of the real speeds of vehicles, for the speeds at which vehicles were travelling between the measured points were not known.

Results as indicated in figure 4.6 once again showed that motorists travelling during the base set were moving at speeds higher for most of the roadway section than those of motorists travelling during other time periods. The speeds during 18:00 - 19:00 and 17:00 - 18:00 were also noticeably higher than during the remaining time periods.

It was clearly noticeable that the speeds started increasing at approximately the 4500 metre mark. The average increase in speed for all the time sets, was estimate to be 12.9 km/h between the markers of 4500 and 5800. After this large increase in speed, it levelled out before starting to gradually decrease again. By comparing the x-values recorded here with that of the elevation profile indicated in section 4.1.1, it was clear that this large increase in speed took place on the downhill sections which are labelled as sections 4.1, 4.2, and 4.3 in figure 4.3 and table A.1.

Upon inspection of the road section, it was discovered that this reduction in speed occurred on a downhill section labelled as section 3 in the figure and table mentioned previously. This decrease in speed cn most probably be attributed to a speed camera which is located near the bottom of this downhill section. The location of the speed camera along the route is shown in figure 4.6. A steep increase in speed occurred immediately after motorists had passed the speed camera, as they (most probably) attempted to gain speed for the uphill section ahead. Unfortunately, the next point at which the speeds were measured, was 1 km along the route, thus the exact speeds of vehicles as they moved along the uphill section are unknown.

It is, however, clear that vehicle speeds did decrease over this section for all time periods except the base set, indicating that vehicles travelling during the base set were able to maintain nearly the same speed, while vehicles travelling during other periods could not. This phenomenon was estimated to be caused primarily by the presence of slower moving vehicles or large vehicles on the road during the other periods and due to no overtaking being permitted by the road markings, vehicles following had to travel at the speed dictated by the slower moving, leading vehicle.

The greatest concern with this section, is the large difference between the speed of vehicles travelling during the base set and that of vehicles travelling during other periods, especially for the second half of this road section. It is clear from the base set that motorists perceive it safe to travel at speeds higher than the speed limit, while only motorists travelling during 18:00 - 19:00 of the other periods were able to drive at speeds close to the speed limit. Thus the greatest concern is the high speeds at which vehicles were travelling during the base set, especially considering that these speeds occurred during hours of darkness.

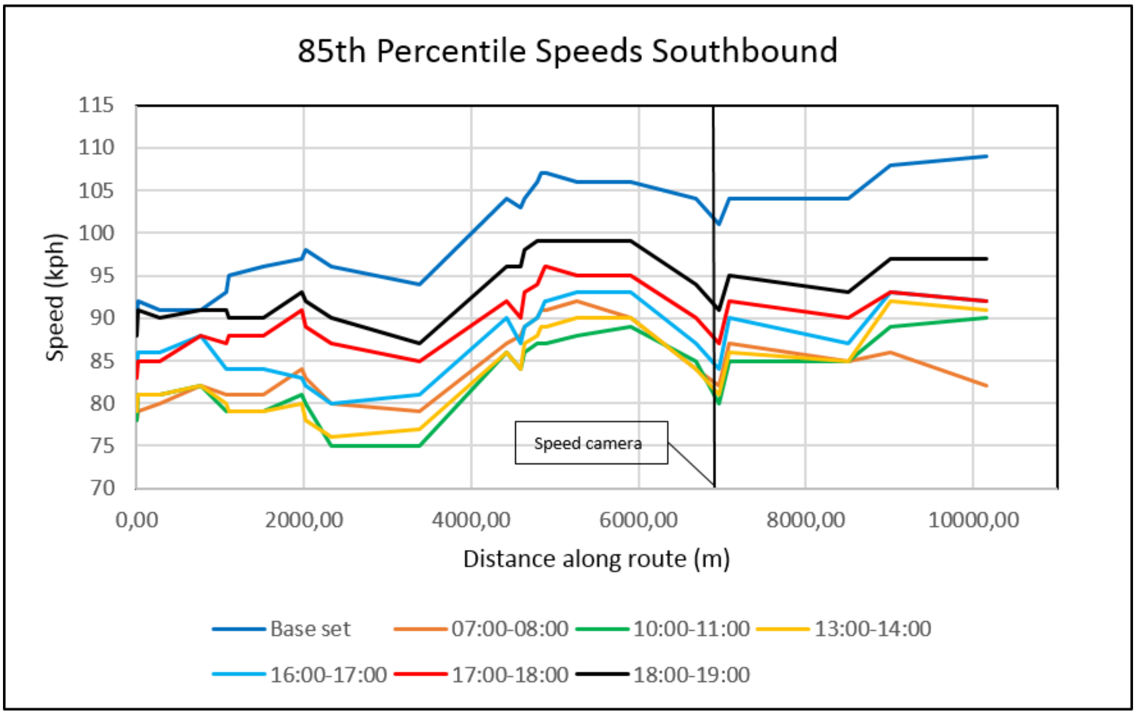

Figure 4.6: R44 Southbound 85th Percentile Speeds Along Route

The only difference between the 85th and 15th percentile speed profiles was that the period

07:00 - 08:00 indicated a sharp reduction in speed from approximately 7 000 metres for the 15th percentile speeds, whereas the 85th percentile did not indicate such a sharp reduction in speed. Other than this, not difference was identified between the shape of the profiles.

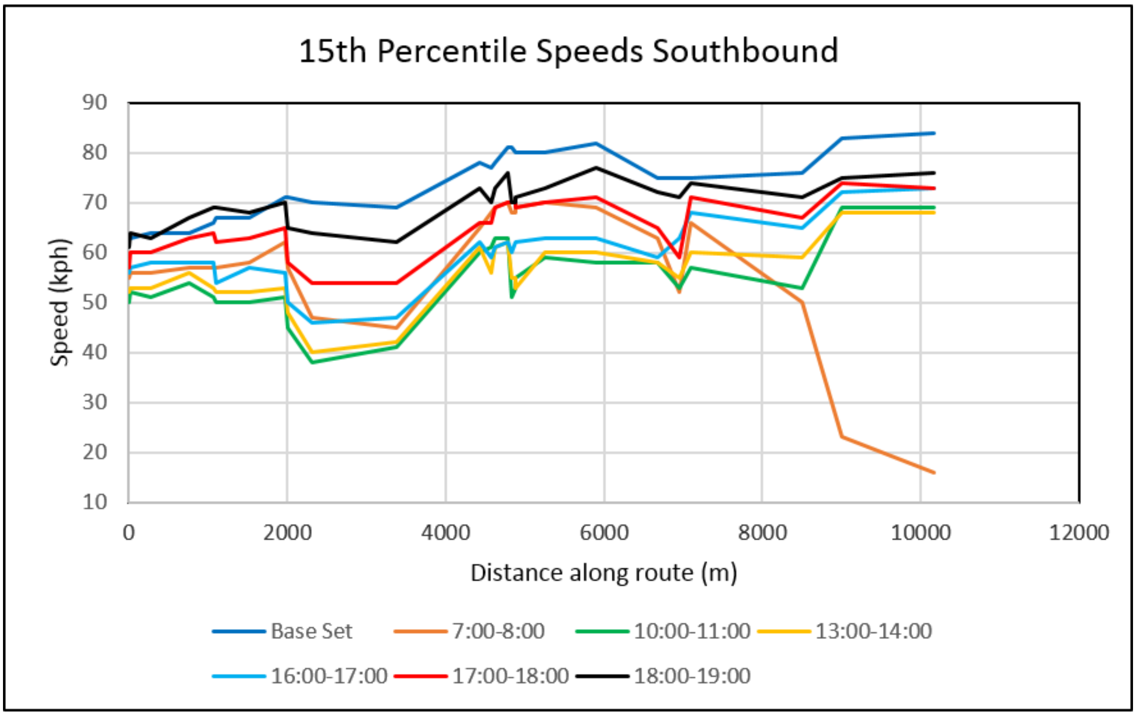

Figure 4.7: R44 Southbound 15th Percentile Speeds Along Route

Figure C.3, found in Appendix C, shows the comparison of the 85th percentile speeds between vehicles travelling northbound and southbound. From this figure, one can conclude that the greatest difference between the northbound and southbound speeds was that vehicles travelling northbound were travelling a bit faster in the morning than the afternoon, while vehicles travelling southbound were travelling a bit faster in the afternoon than the morning. These results were expected, as the slower speeds corresponds with the greater volumes.

4.2 Route 45 Characteristics

4.2.1 R45 Geometric Characteristics

The Route 45 road section under consideration is approximately 11,5 km in length and stretches from the west of Franschhoek to the R310 intersection (Helhoogte Rd). This roadway was the flattest and straightest of the three road sections that were investigated and therefore produced the highest speeds. This road predominantly carry people driving to and from Franschhoek and carries more vehicles on the eastern half or the road than the western half due to the large intersection with the R301 located almost exactly in the middle (5,2 km from the eastern end) of this section.

This road was the only one of the three investigated on which the total length of sections permitting overtaking were longer than the length of section prohibiting overtaking. This too assisted in the high speeds of vehicles, as sufficient provision was made for them to conduct legal overtaking manoeuvres without having to wait behind a slower moving vehicle. The total length on which overtaking is permitted, is 7,5 km and 7,2 km for vehicles travelling eastbound and westbound respectively. Therefore the length on which overtaking is prohibited, is 4 km and 4,3 km eastbound and westbound respectively.

There are 13 individual section permitting overtaking for vehicle driving eastbound and 10 sections for vehicles driving westbound. The shortest eastbound section is 120 metres, while the shortest westbound one is 150 metres. The longest was 1 300 and 1 600 for vehicles heading eastbound and westbound respectively.

The lane width is predominantly 4 metres for the entire length of this roadway, with a hard shoulder with a width of 2 metres on either side. The road reserve width was predominantly 30 metres, but it narrowed at some points to 20 metres in width. The speed limit was 100 km/h for the entire length of this section.

Table 4.8 is a summary of the road characteristics mentioned.

Table 4.8: R45 Road Characteristics Summary

Description	Eastbound	Westbound
Total length of section	11,5 km	
Length on which passing is prohibited	4,0 km	4,3 km
Length on which passing is permitted	7,5 km	7,2 km
Longest section on which no passing is permitted	2,4 km	1,9 km
Longest sight distance without passing permitted	-	-
Length on which speed limit is 100 km/h	11,5 km	11,5 km
Lane width	4 m	4 m
Shoulder width	2 m	2 m
Roadway width	12 m	
Road reserve width	40 m	
Paved Intersections on the Eastern side	1	
Paved Intersections on the Western side	1	
Total number of accesses on the Northern side	17	
Total number of accesses on the Souther side	10	

4.2.2 R45 Traffic Volume

As indicated in figure B.1 of Appendix B, the eastern half of this road section is classified as LOS D and the western half as LOS C. This was largely due to a relatively large intersection with the

Route 301 located near the middle of this roadway section. A sizeable number of vehicles join and leave the Route 45 at this intersection, the majority of which only make use of the eastern half of the R45 road section and therefore the R301 intersection proved to be the point at which the LOS changes from C to D.

The results also indicated the presence of morning and afternoon peak periods, but were not as prominent as in the case of the R44. As with the R44, the volume of the two flow directions differed to quite a large degree during peak periods, but were near equal during off-peak periods. More vehicles were travelling eastbound in the morning peak as compared to westbound, whereas more were travelling westbound in the afternoon peak as compared to eastbound. This phenomenon was once again attributed to a higher volume of commuters travelling toward Franschhoek in the morning than away, and vice verse in the afternoon.

The average vehicle distribution of weekdays for the three time periods mentioned earlier can be seen in figures B.5, B.6, and B.7 in Appendix B. The red, blue, and dotted green lines in the figures represent the total, eastbound and westbound traffic volumes respectively.

It should be noted that the traffic counting station was located approximately 200 metres to the east of this intersection and therefore the results as recorded represent the eastern half of this roadway. It is therefore likely that the volumes on the western half was slightly lower than the recorded volumes.

The results for the period 2016/01/01 - 2016/12/31 showed an average daily traffic of 5 459 and 5 522 vehicles per lane travelling eastbound and westbound respectively. The percentages of trucks were 5,9% and 5,6% eastbound and westbound respectively, with a truck split of (66 : 20 : 14) and (69 : 18 : 13) for the respective directions.

The day time traffic accounted to 5 044 and 5 069 vehicles per lane and therefore the percentages of traffic during hours of darkness amounted to 7,6% and 8,2% eastbound and westbound respectively. The highest hourly volumes in each direction were 989 and 917 eastbound and westbound respectively.

The results further indicated that 25,9% and 27,8% of vehicles travelling eastbound and westbound respectively were less than 2 seconds behind the leading vehicle, indicating that a large number of vehicles travelled at quite a short following distance behind the leading vehicle. On the other hand, only 2,2% and 2,1% of vehicles travelling eastbound and westbound respectively travelled during periods that had a flow rate of more than 600 veh/h/ per lane.

Table 4.9 is a summary of the results for the period 2016/01/01 - 2016/12/31.

Table 4.9: Traffic Volumes for R45 for the Period 2016/01/01 - 2016/12/31

Description	Eastbound	Westbound
Total number of vehicles (counted)	1 991 273	2 014 068
Average daily traffic (ADT)	5 459	5 522
Average daily truck traffic (ADTT)	319	309
Percentage of trucks	5,9 %	5,6 %
Truck split (short : medium : long)	(210 : 64 : 45)	(213 : 56 : 40)
Nighttime traffic volume (20:00-06:00)	415	453
Daytime traffic volume	5 044	5 069
Highest hourly volume (veh/h)	989	917
% vehicles less than 2s behind vehicle ahead	25,9	27,8
Percentage vehicles in flows over 600 veh/h	2,2	2,1

The results for the period 2017/01/01 - 2017/12/31 showed a slight increase in traffic volumes and a decrease in speeds resulting from the increase in volume. The average daily traffic was 5 764 and 5 849 vehicles per lane for the eastbound and westbound directions respectively. The percentages of trucks were 6,1% and 5,9% eastbound and westbound respectively, with a truck split of (65 : 20 : 15) and (69 : 18 : 13) for the respective directions.

The day time traffic accounted to 5 326 and 5 352 vehicles per lane and therefore the percentages of traffic during hours of darkness amounted to 7,6% and 8,5% eastbound and westbound respectively. The highest hourly volumes in each direction were 965 and 1 022 eastbound and westbound respectively.

Table 4.10 is a summary of the results for the period 2017/01/01 - 2017/12/31.

Table 4.10: Traffic Volumes for R45 for the Period 2017/01/01 - 2017/12/31

Description	Eastbound	Westbound
Total number of vehicles (counted)	2 103 819	2 135 043
Average daily traffic (ADT)	5 764	5 849
Average daily truck traffic (ADTT)	354	346
Percentage of trucks	6,1 %	5,9 %
Truck split (short : medium : long)	(230 : 71 : 53)	(239 : 62 : 45)
Nighttime traffic volume (20:00-06:00)	438	497
Daytime traffic volume	5 326	5 352
Highest hourly volume (veh/h)	965	1 022
% vehicles less than 2s behind vehicle ahead	27,5	30,2
Percentage vehicles in flows over 600 veh/h	3,2	5,5

The results for the period 2018/01/01 - 2018/10/02 showed a slight decrease in both the daily traffic as well as the speeds. The average daily traffic was 5 710 and 5 799 vehicles per lane for the eastbound and westbound directions respectively. The percentages of trucks were 6,1% and 5,8% eastbound and westbound respectively, with a truck split of (62 : 21 : 17) and (66 : 18 : 16) for the respective directions.

The day time traffic accounted to 5 288 and 5 312 vehicles per lane and therefore the percentages of traffic during hours of darkness amounted to 7,4% and 8,4% eastbound and westbound respectively. The highest hourly volumes in each direction were 873 and 892 eastbound and westbound respectively.

Table 4.11 is a summary of the results for the period 2018/01/01 - 2018/10/02.

Table 4.11: Traffic Volumes for R45 for the Period 2018/01/01 - 2018/10/02

Description	**Eastbound**	**Westbound**
Total number of vehicles (counted)	1 564 697	1 588 964
Average daily traffic (ADT)	5 710	5 799
Average daily truck traffic (ADTT)	346	338
Percentage of trucks	6,1 %	5,8 %
Truck split (short : medium : long)	(214 : 73 : 59)	(223 : 61 : 54)
Nighttime traffic volume (20:00-06:00)	422	487
Daytime traffic volume	5 288	5 312
Highest hourly volume (veh/h)	873	892
Percentage vehicles in flows over 600 veh/h	3,7	5,3

4.2.3 R45 Vehicle Speeds

As mentioned in section 4.2.1, the posted speed limit for this carriageway is 100 km/h for the entire section. According to the road markings, quite a large portion of this road section permitted overtaking. For this reason, a substantial difference between the 85th and 15th percentile speeds was expected for vehicles travelling in both directions. The morning peak period was estimated to be 07:00 - 08:00, while the evening peak period was estimated to be 15:30 - 17:30 for both flow directions.

This R45 section proved to be the road on which the highest 85th percentile speeds were recorded from the three road which were inspected. It further proved to be the road which had the second highest difference between the 85th and the average, as well as the 15th percentile speeds. Furthermore, the difference between speeds recorded during the base set and other periods was fairly high, especially for vehicles travelling westbound.

The layout of this road section was slightly different to those of the other two roads under considerations (R44 and N2), due to the R45 being much flatter than the other two. Flatter roads and road markings which permitted overtaking for a large portion of this carriageway therefore provided for conditions conducive to higher speeds. It should be noted that higher speeds were not desirable, but it was expected that vehicles would move at higher speeds due to flatter roads. Even though this was the case, the presence of horizontal curves along the route were likely to produce a reduction in speeds.

4.2.3.1 R45 Eastbound Speeds

Motorists travelling eastbound on the R45 were moving toward Franschhoek, either coming from the R101, R310 or R301. These three were the main feeder roads of vehicles travelling eastbound on the R45.

Table 4.12 shows the average, 15th and 85th percentiles speeds, as well as the difference between the various percentile speeds of vehicles heading eastbound on the R45. Figure C.5 in Appendix C is a visual representation of the information provided in this table. The average difference between the 85th and 15th percentile speeds for the various time periods, was 24.44 km/h, while the difference between the 85th percentile and average speeds for the various time periods was 17.26 km/h.

The highest 85th percentile speed was recorded during the base set, which was 8,2 km/h faster than during any other time period. The time period that produced the highest average and 15th percentile speeds on the other hand, was 18:00 - 19:00. The slowest 85th percentile speeds were recorded during 10:00 - 11:00, while 16:00 - 17:00 and 13:00 - 14:00 produced the slowest average and 15th percentile speeds respectively. The time period during which the largest difference between the various percentile speeds were recorded, was the base set, with a difference of 23.83 km/h between the 85th percentile and average speeds and 35.59 km/h between the 85th and 15th percentile speeds.

Table 4.12: R45 Eastbound Percentiles Comparison

Eastbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	68,26	80,01	103,85	35,59	23,83
7:00-8:00	68,33	75,59	94,46	26,13	18,87
10:00-11:00	68,08	74,71	88,56	20,49	13,86
13:00-14:00	67,92	75,06	89,13	21,21	14,06
16:00-17:00	68,64	72,61	91,03	22,38	18,42
17:00-18:00	69,26	74,94	92,90	23,64	17,96
18:00-19:00	74,03	81,86	95,67	21,64	13,81

Figure 4.8 shows the 85th percentile speeds of vehicles which were travelling eastbound on this road section. All seven time periods mentioned previously were once again represented in this figure in order to compare the speeds of vehicles along the route during different times of the day. It was therefore possible to identify possible troublesome areas along the route, which was most often represented by an radical decrease or increase in speed. As with the R44, it is important to note that figure 4.8 does not represent continuous speeds of vehicles, but rather the speed at certain points along the route. This roadway section had the highest density of points at which the speeds were measured and therefore the points were the closest to one another on this section. The high density of points therefore increased the accuracy of the speed profile, as it decreased the estimation needed of speeds between the various points.

The results as displayed in figure 4.8 show that speeds recorded during the base set were significantly higher than any other periods at all points along the route. Speeds recorded during the remaining periods were relatively close to one another, as they all fell within a 10 km/h range. The figure also showed that the two periods that produced the slowest speeds were 10:00 - 11:00 and 13:00 - 14:00. Furthermore, speeds recorded during the base set were above the posted speed limit for the majority of this section, only being below it for the first 200 metres of the section.

The speed profile took the same form for all time periods, indicating that the road layout influenced the speeds of vehicles travelling at different times in the same manner, but to a varying degree. The profile shows a steep increase in speed for the first 1000 metres, after which speeds decrease slightly before levelling out. A significant decrease in speed occurred from 3500 to 4000 metres, where after it levelled out again with only minor fluctuations occurring between 4000 and 5800 metres. Speeds once again decreased from 5800 to 6200 metres, after which a steady increase in speed occurred between 6200 and 7800 metres. The average increase in speed on this section was 7 km/h for all time periods. A decrease of the same magnitude and slope immediately followed from 7800 to 9500 metres, after which the speeds seemed to remain constant for the remainder of the section.

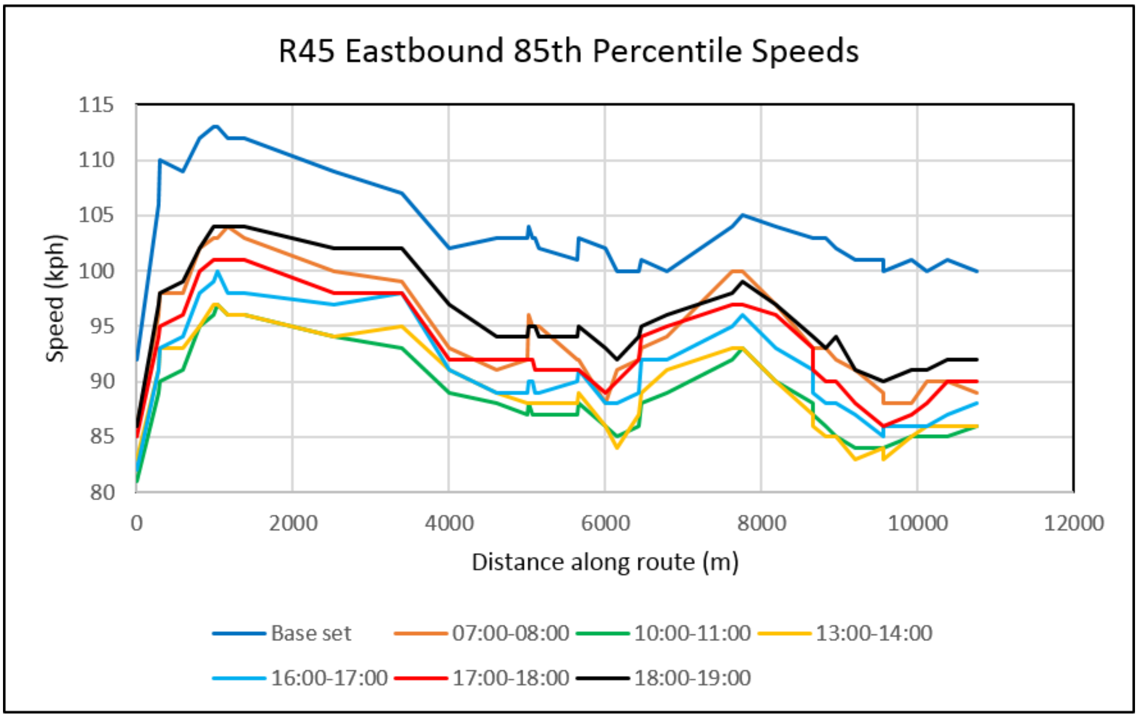

Figure 4.8: R45 Eastbound 85th Percentile Speeds Along Route

The comparison between the 85th and 15th percentile speed profiles showed that the two speed profiles had approximately the same layout with a few noticeable differences between the two. The first was that the 15th percentile speeds recorded during the base set were not higher than the other time periods, while the 85th percentile speeds recorded during the base set were much higher than during the other periods, showing that a larger difference in speed between vehicles were recorded at night than during the day. The difference in speed between the various periods was also smaller for the 15th than the 85th percentile speeds. A further difference was that the 15th percentile profile indicated a large decrease of speed from 5800 to 6200 which was most likely due to the R304 intersection, whereas the 85th percentile only had a slight decrease of speed on this section. Furthermore, the 15th percentile profile showed a large decrease in speed for periods 07:00 - 08:00, 16:00 - 17:00, and 17:00 - 18:00 from 9000 to 9500 metres, whereas the 85th percentile profile had no such decrease on this section.

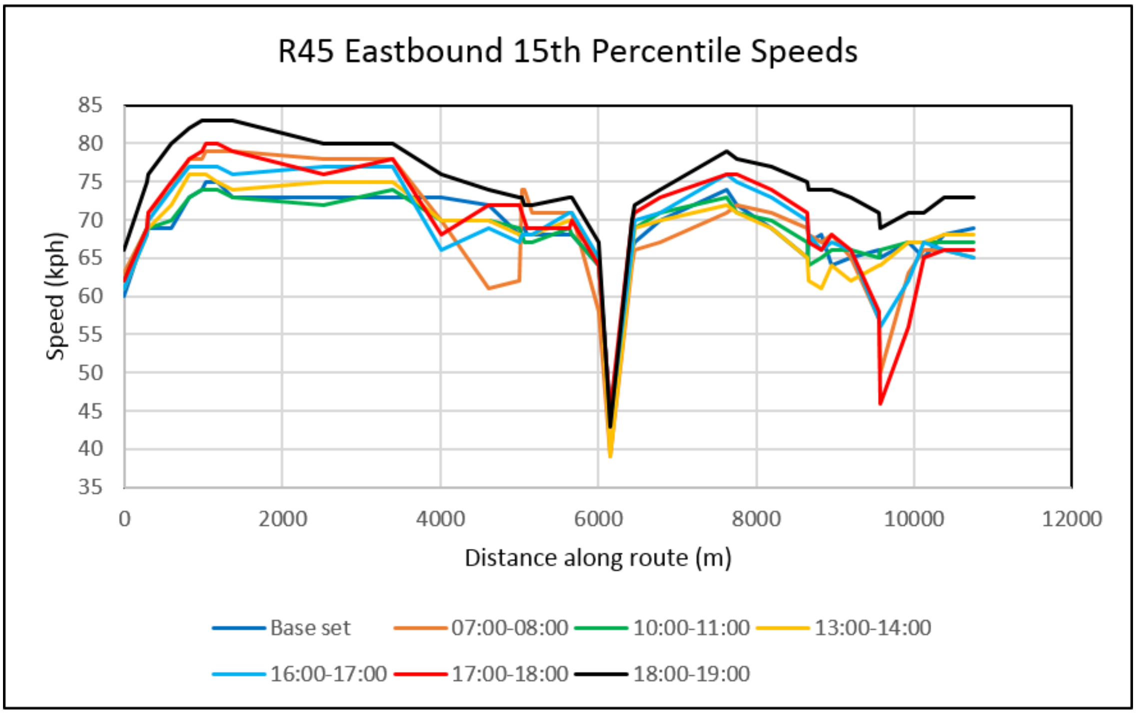

Figure 4.9: R45 Eastbound 15th Percentile Speeds Along Route

4.2.3.2 R45 Westbound Speeds

Motorists travelling westbound on the R45 were moving away from Franschhoek, while the destination for these trips had numerous possibilities. Vehicles travelling westbound on this road section produced the highest 85th percentile speeds in comparison with all the other road sections under consideration. Of particular concern was the speeds during the base set, which had a 85th percentile speed of 111.62 km/h.

Table 4.13 shows the average, 15th and 85th percentiles speeds, as well as the difference between the various percentile speeds of vehicles heading westbound on the R45. A visual representation of the information provided in this table may be seen in figure C.6 in Appendix C. The difference between the 85th and 15th percentile speeds for the various time periods was 24.95 km/h, while the difference between the 85th percentile and average speeds for the various time periods was 17.13 km/h. Comparing these results with that recorded for vehicles travelling eastbound indicated that vehicle speeds were slightly higher for vehicles travelling westbound than ones travelling westbound, while the difference between the various percentile speeds was approximately equal in both directions.

The highest 85th percentile and average speeds were recorded during the base set, which was respectively 12,5 km/h and 4,1 km/h faster than during any other time period. On the other hand, the time period that produced the highest 15th percentile speeds was 18:00 - 19:00. The slowest average, 15th, and 85th percentile speeds were all recorded during 13:00 - 14:00. The period which produced the largest difference in speed between the various percentiles was the base set, with a difference of 24.46 km/h between the 85th percentile and average speeds and 37.38 km/h between the 85th and 15th percentile speeds.

Table 4.13: R45 Westbound Percentiles Comparison

Westbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	74,24	87,16	111,62	37,38	24,46
7:00-8:00	74,50	81,94	99,12	24,62	17,18
10:00-11:00	70,05	76,63	93,21	23,17	16,58
13:00-14:00	69,98	76,20	91,48	21,50	15,27
16:00-17:00	71,95	79,26	94,93	22,98	15,67
17:00-18:00	73,52	80,16	95,81	22,29	15,65
18:00-19:00	75,48	83,09	98,19	22,71	15,10

Figure 4.10 shows that base set speeds recorded for vehicles travelling westbound were the highest for all the roadway sections. It also shows that speeds recorded during the base set were significantly higher than any other time period at any given point along the route, with the largest difference being as high as 17 km/h. The speeds of the remaining time periods were relatively close to one another, falling within a range of 7 km/h from one another for the majority of this section. The figure also showed that the two periods that produced the slowest speeds for the majority of this section were 10:00 - 11:00 and 13:00 - 14:00.

Furthermore, speeds recorded during the base set were above the posted speed limit for the majority of this section and the only section on which the base speed was equal to the speed limit was on the first 200 metres, while the speeds were never below the posted speed limit.

The highest day time speeds were recorded during both 07:00 - 08:00 and 18:00 - 19:00, with speeds recorded during these two periods being near to one another for the first half of the roadway, while speeds recorded during 07:00 - 08:00 were significantly higher than 18:00 - 19:00 during the second half of the roadway.

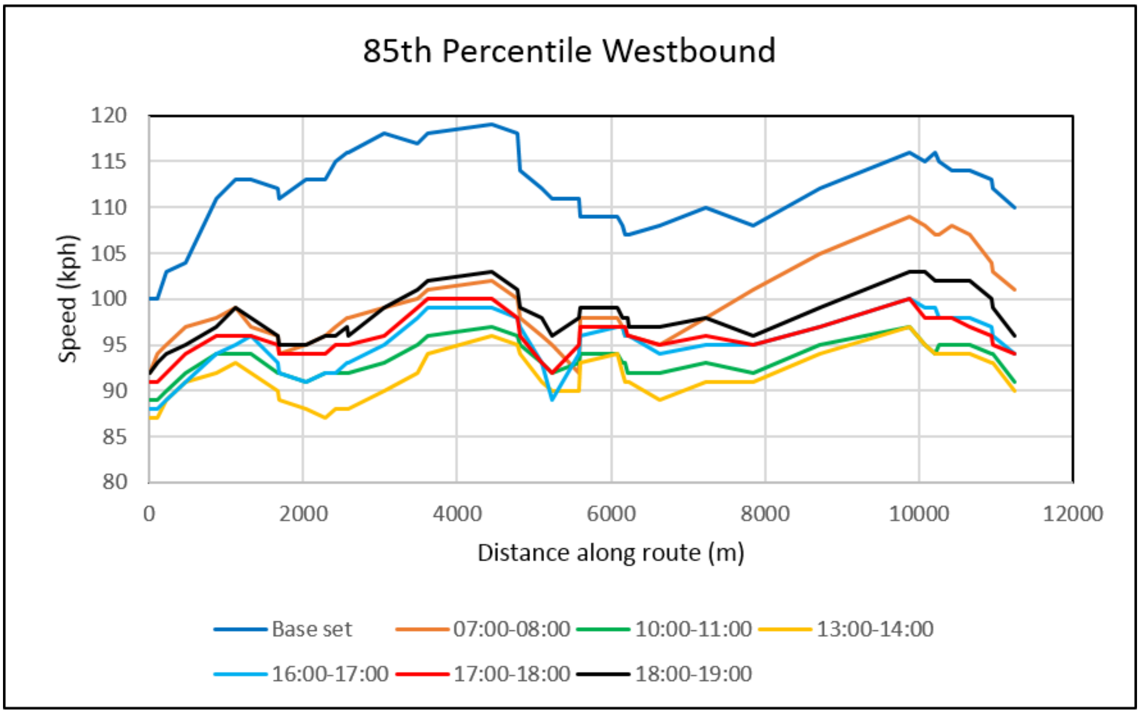

Figure 4.10: R45 Eastbound 85th Percentile Speeds Along Route

Results as shown in figure 4.11 indicated that, as with the eastbound speed profiles, the base set 15th percentile speeds were not higher than the other time periods, whereas the 85th percentile speeds recorded during the base set was much higher than the other time periods. The 15th percentile speeds also indicated a large decrease in speed at approximately 5000 metres which was caused by vehicles wanting to either join or leave the R45 at the R310 intersection.

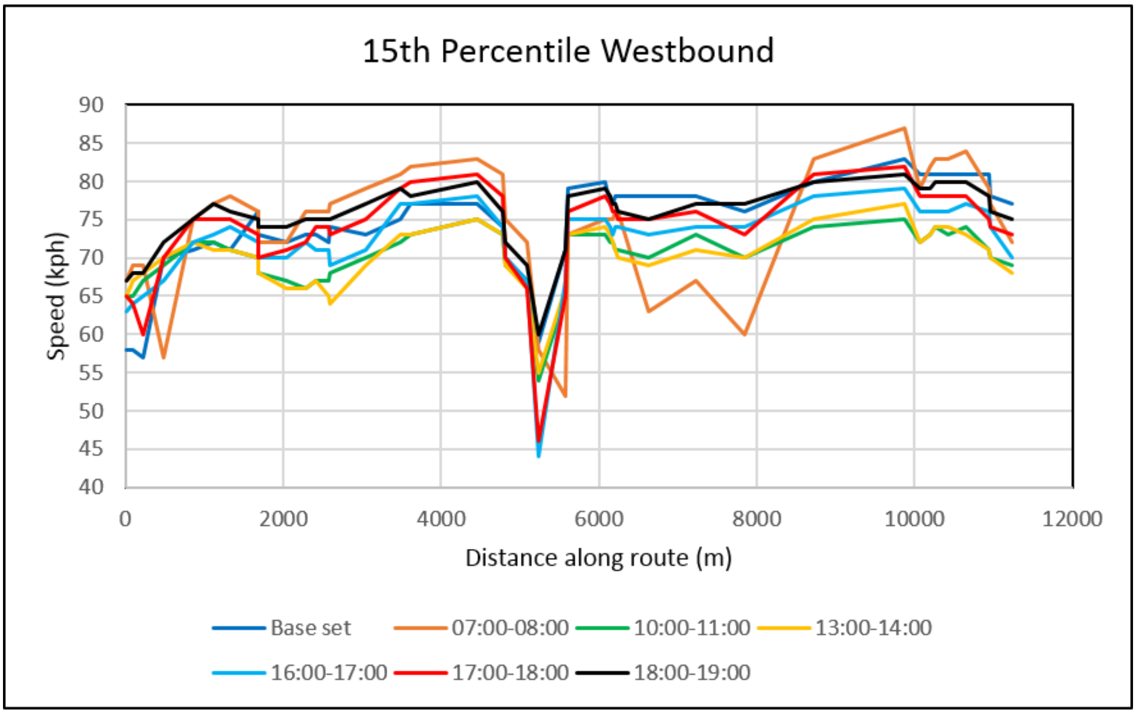

Figure 4.11: R45 Eastbound 15th Percentile Speeds Along Route

4.3 N2 Characteristics

4.3.1 N2 Geometric Characteristics

The N2 is a two-lane highway (major arterial), providing two main functions. The first and primary function is that it connects two medium sized towns, namely Knysna and Plettenberg Bay. The current population for Knysna, according to 2017 statistics, is around 75 000 people living in an around the town. The most recent census completed for Plettenberg Bay took place in 2011, which indicated an estimated number of 31 800 people living in an around the town. These two towns also serve as major holiday destinations during certain times of the year, especially from the middle of December to the middle of January each year. The second function is that this road also serves as a through road for vehicles travelling either from a different origin, or to a different destination. The second function becomes increasingly apparent during the holidays, as road users make use of this road to travel to other holiday destinations.

From the information mentioned, it is clear that this road will have the highest volume of road users making use of it during the holiday period, spanning from the middle of December to the middle of January each year. During the rest of the year, however, the road still serves as a major arterial, only carrying slightly less traffic than during the peak monthly period of the year.

The total length of the road section between the centres of these two towns spans approximately 30 km, but this includes road sections which are more urban than rural, as the road passes through the outskirts of Plettenberg bay and the centre of Knysna. This entire road section was initially considered for the study, but the section on which analysis was finally done with regards to driver behaviour, was the rural section of road which only start outside of the two towns as indicated in chapter 3. The section that was investigated intensively, was thus 18,5 km in length.

The elevation profile of this road section, as portrayed in figure 4.12, shows a large number of uphill and downhill sections encountered by motorists as they travel along this roadway. Considering the elevation profile as well as the horizontal layout of the road indicated that the western half of the N2 resembled much of the same layout characteristics as that of the R44, with a large number of crests, troughs, and horizontal curves, while the eastern half of the N2 resembled the R45 layout, which was flatter and straighter. The average gradient of slopes on this roadway for vehicles travelling eastbound, is 3,2% during inclinations and -2,8% during declinations, which is not that steep, but the presence of crests, troughs, and horizontal curves on the western half made overtaking difficult and dangerous. For this reason the road design, as well as the road markings, do not permit overtaking on the western half of this road section.

It should be noted that the gradient of the slopes as indicated in figure 4.12 may appear steeper in the figure than it is in actuality, as the difference in height and length is not in proportion to one another.

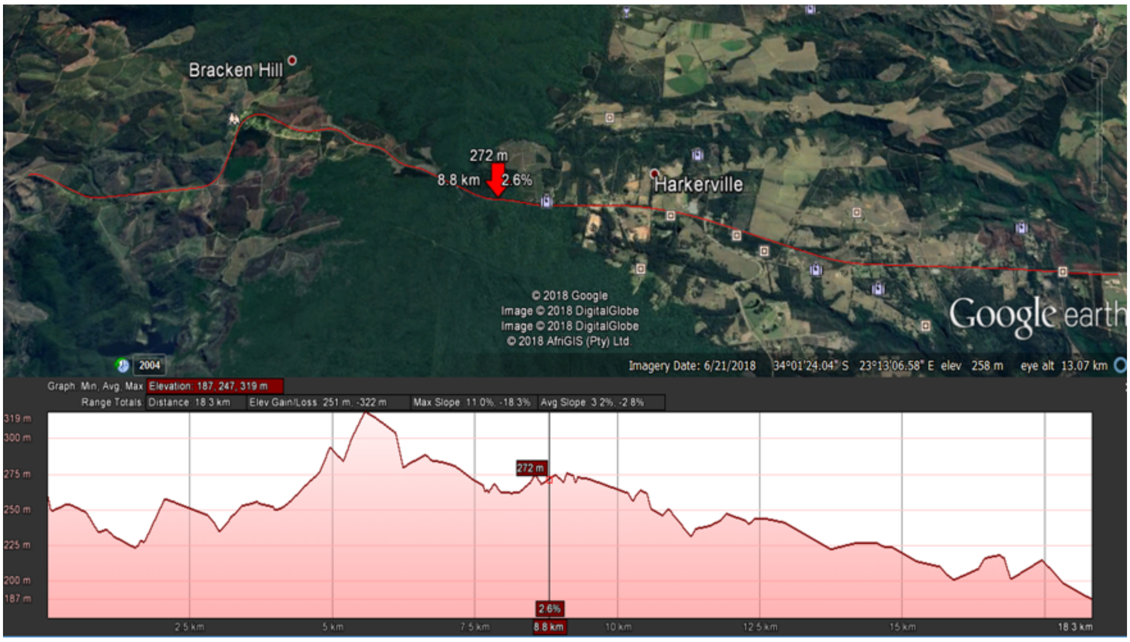

Figure 4.12: N2 Elevation Profile

The longest consecutive section of road on which overtaking is prohibited by the road markings is 11 km, which is the case in both directions. The 11 km stretch of road that prohibits overtaking starts at the most western point of the 18,5 km road section, spanning more than halfway into the entire section and was named the 'western half' of the roadway for the purpose of this study. The design and layout of the remaining 7,5 km, which was named the 'eastern half' of this roadway, is much more suited for attempting overtaking safely, and thus over a total of 5 km of this section, road markings permit attempting overtaking manoeuvres in both directions. Even though the locations at which the road markings permit overtaking manoeuvres differ for the two opposing flow directions, the total length of road sections on which overtaking is permitted, was recorded as equal for both travel directions.

Travelling Eastbound, the road markings permit drivers to attempt overtaking manoeuvres on seven possible sections, while drivers travelling westbound are permitted to attempt overtaking manoeuvres on eight possible sections. The length of these sections for vehicles travelling eastbound, range from 280 to 1 500 metres, while it ranges from 250 to 1 680 metres for vehicles travelling westbound. Interestingly, the total length on which road markings permit overtaking was measured to be equal in both directions and therefore the average length of sections permitting overtaking was longer for vehicles travelling in an eastbound direction as compared to westbound. Table 4.14 shows the length of every section for both directions on which overtaking is permitted by the road markings. These sections are ordered in the sequence that drivers would encounter them as they moved along this roadway in their respective directions.

Table 4.14: Overtaking Section Lengths on the N2

Overtaking Section Lengths		
Overtaking Section	Eastbound (m)	Westbound (m)
1	280	380
2	280	1680
3	700	700
4	750	450
5	1150	450
6	1500	800
7	300	250
8	-	250
Total	**4960**	**4960**

The posted speed limit of this roadway was predominantly 100 km/h, with one section in each direction having a posted speed limit of 80 km/h. Vehicles travelling eastbound were faced with a 1050 metre section during which the speed limit was 80 km/h, located 10,1 - 11,15 km from the western end of the section, while vehicles heading westbound were faced with a 1300 metre section during which the speed limit was 80 km/h, located 9,6 - 10,9 km from the western end of the section. The location of these sections were confirmed from an on-site data collection, imagery from Google, as well as data obtained from TomTom. Figure 4.13 shows the 80 km/h zones for both vehicles travelling eastbound and westbound.

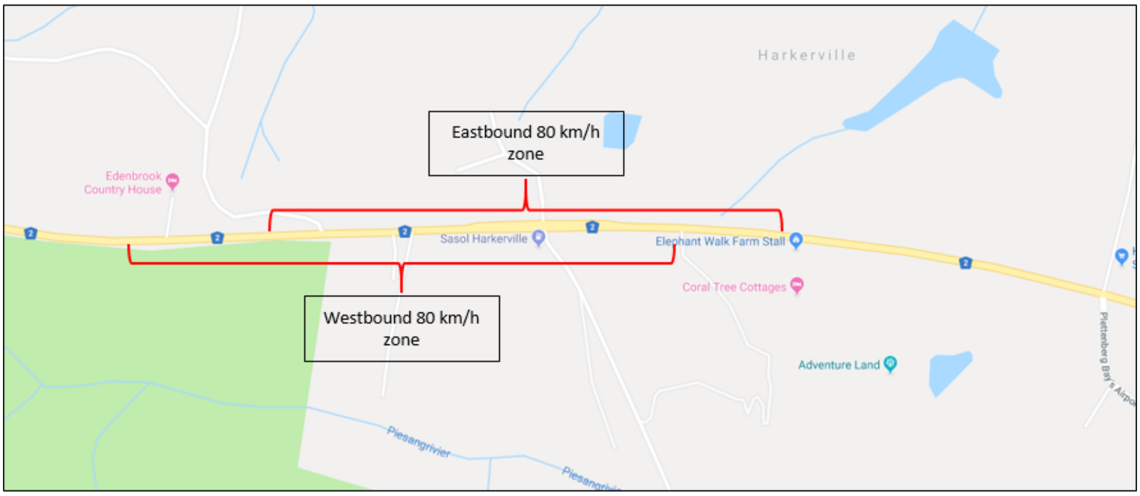

Figure 4.13: N2 zones on which the posted speed limit is 80 km/h

The lane width for both directions were measured as 4 m, while the shoulder width was consistently 2 m on both sides of the road. The shoulder was paved for the entire road section, thus the total width of the paved roadway was 12 m. The pavement condition of the road was quite good, with good maintenance of road surface along the roadway. The road reserve, which was measured on-site, as well as using Google Earth, was measured as 40 m in total.

According to the Committee of Transport Officials (2012), an access is any public, or private road, driveway, ramp, or path which crosses or is connected to a public road. An intersection is a point at which two public roads cross or join, thus being a specific type of access. From these definitions, it was assumed that in order to classify a road as private, some means of access management would be present, therefore roads that did not have any access management were assumed to be public.

All of the intersections and accesses that were present on this road section, were T-junctions, giving priority to vehicles travelling on the N2, which corresponds with the design standards as specified by the Committee of Transport Officials (2012). There are a total of 2 paved and 8 unpaved intersections on the Northern side of this roadway, while the Southern side has a total of 3 paved and 12 unpaved intersections. Furthermore there are a total of 17 accesses on either side of this roadway and therefore 34 accesses in total. Of the 17 accesses on the Northern side, 12 are to single properties, 4 accesses to multiple properties, and 1 access to a shop. On the Southern side, there are 11 accesses to single properties, 3 accesses to multiple properties, and 3 accesses to shops.

Table 4.15 is a summary of the geometric roadway characteristics mentioned.

Table 4.15: Summary of the Characteristics of the N2

Description	**Eastbound**	**Westbound**
Total length of section	18.5 km	
Length on which passing not permitted	13,5 km	13.5 km
Length on which passing is permitted	5 km	5 km
Longest section on which passing is prohibited	11 km	11 km
Length on which speed limit is 100 kph	17,45 km	17.45 km
Length on which speed limit is 80 kph	1.05 km	1.05 km
Lane width	4 m	4 m
Shoulder width	2 m	2 m
Roadway width	12 m	
Road reserve width	40 m	
Paved Intersections on the Northern side	2	
Paved Intersections on the Southern side	3	
Unpaved Intersections on North side	8	
Unpaved Intersections on South Side	12	
Total number of accesses on the Northern side	17	
Total number of accesses on the Southern side	17	

As mentioned in section 4.1.1, it is important to consider the roadway conditions immediately preceding and following the roadway under consideration. When travelling in an eastbound direction, drivers would probably have travelled through a large portion of Knysna which has a 60 kph speed limit and also have traffic signals present which would lead to an increase in travel time for drivers. After exiting the centre of Knysna, the road widens, having two-lanes per direction with a 70 kph speed limit. The road section heading out of Knysna has an average incline gradient of 5% with the speed limit remaining at 70 kph.

The slope flattens out for the first time right at the point at which the roadway starts to merge from a four-lane highway to a two-lane highway. The point of merger is also the point at which the 18,5 km investigated section started. The majority of vehicles travelling in the fast lane coming up the hill were observed travelling at speed above the speed limit, while numerous dangerous manoeuvres were also recorded in the vicinity of the point at which the road merged. The factor which most probably contributed the most to this type of behaviour at this point, was the fact that drivers travelling eastbound will be prohibited to conduct any overtaking manoeuvres and will therefore need to follow behind any slower moving vehicle ahead of them.

4.3.2 N2 Traffic Volume

A lot of vehicles were observed to travel in queues/platoons on the western 11 km of the carriageway, which was primarily due to overtaking being prohibited for the entire 11 km and therefore faster moving vehicles caught up to slower ones without having an opportunity to overtake them. Due to the large number of platoons, the traffic volume were not distributed evenly along the route, but were rather wavelike, which resulted in small congestion peaks occurring within the two towns on either side of this roadway section.

The N2 was the road section with the lowest traffic volume of the three roads that were inspected. Even though the total number of vehicles were lower than the R44 and R45, the number of trucks were the highest on the N2, therefore producing a very high percentage of trucks on the road, which was a major concern. Interestingly, the results did not show clear morning and afternoon peak periods, but rather the highest volume was recorded from 10:00 - 11:00 for all weekdays other than Fridays, which was from 14:00 - 15:00.

Figure 4.14 is an example of a platoon of vehicles travelling along the N2, unable to overtake one another due to the road marking. The vehicles in this image were travelling westbound.

Figure 4.14: Platoon of vehicles moving along the N2

Table 4.16 is a summary of the results for the period 2016/01/27 - 2016/02/23. The average daily traffic of was 4 287 and 4 269 vehicles per lane travelling eastbound and westbound respectively. The percentages of trucks were 11,7% and 11,1% eastbound and westbound respectively, with a truck split of (40 : 16 : 44) and (43 : 16 : 41) for the respective directions.

The day time traffic accounted to 3 863 and 3 872 vehicles per lane and therefore the percentages of traffic during hours of darkness amounted to 9,9% and 9,3% eastbound and westbound respectively. The highest hourly volumes in each direction were 440 and 483 eastbound and westbound respectively.

The results indicated that 25,8% and 23,4% of vehicles travelling eastbound and westbound respectively were less than 2 seconds behind the leading vehicle, indicating that a high number of vehicles travel at relatively short following distances behind the leading vehicle.

Table 4.16: Traffic Volumes for N2 for the Period 2016/01/27 - 2016/02/23

Description	Eastbound	Westbound
Total number of vehicles (counted)	115 048	114 563
Average daily traffic (ADT)	4 287	4 269
Average daily truck traffic (ADTT)	500	472
Percentage of trucks	11,7 %	11,1 %
Truck split (short : medium : long)	(200 : 80 : 220)	(203 : 75 : 194)
Nighttime traffic volume (20:00-06:00)	424	397
Daytime traffic volume	3 863	3 872
Highest hourly volume (veh/h)	440	483
% vehicles less than 2s behind vehicle ahead	25,8	23,4

Table 4.9 is a summary of the results for the period 2017/10/26 - 2017/11/23. The results showed a slight reduction in daily traffic in both directions, with an average daily volume of 4 248 and 4 174 vehicles per lane for the eastbound and westbound directions respectively. The percentages of trucks were 13,0% and 12,6% eastbound and westbound respectively, with a truck split of (36 : 16 : 48) and (39 : 17 : 44) for the respective directions.

The day time traffic accounted to 3 823 and 3 836 vehicles per lane and therefore the percentage of traffic during hours of darkness amounted to 10,0% and 9,3% eastbound and westbound respectively. The highest hourly volumes in each direction were 436 and 461 eastbound and westbound respectively.

Furthermore, the results indicated that 23,5% and 20,2% of vehicles travelling eastbound and westbound respectively were less than 2 seconds behind the leading vehicle.

Table 4.17: Traffic Volumes for N2 for the Period 2017/10/26 - 2017/11/23

Description	Eastbound	Westbound
Total number of vehicles (counted)	84 634	83 144
Average daily traffic (ADT)	4 248	4 174
Average daily truck traffic (ADTT)	553	524
Percentage of trucks	13,0 %	12,6 %
Truck split (short : medium : long)	(199 : 89 : 265)	(204 : 89 : 231)
Nighttime traffic volume (20:00-06:00)	425	388
Daytime traffic volume	3 823	3 836
Highest hourly volume (veh/h)	436	461
% vehicles less than 2s behind vehicle ahead	23,5	20,2

As mentioned previously, this roadway did not produce any evident peak periods, but a large increase in volume did occur at 08:30 and remained constant for most of the day until a large decrease at approximately 16:30. The volume of the two flow directions also differed for varying times of the day, with more vehicles travelling eastbound during the course of te morning, whereas more were travelling westbound during the course of the afternoon.

The average vehicle distribution of weekdays for the three time periods mentioned earlier can be seen in figures B.8 and B.9 of Appendix B. The red, blue, and dotted green lines in the figures represented the total, eastbound and westbound traffic volumes respectively.

4.3.3 N2 Vehicle Speeds

As mentioned in section 4.3.1, the posted speed limit for this section of the N2 was predominantly 100 km/h. Only a 1050 and 1300 metre section of road have a posted speed limit of 80 km/h for vehicles travelling eastbound and westbound respectively. As mentioned previously, the road markings prohibited overtaking on the western 11 km of this road, while the remaining 7.5 km consisted of sections which permitted overtaking, but also sections which did not. The morning peak period were estimated to be 07:00 - 08:00, while the evening peak period were estimated to be 15:30 - 17:30 for both flow directions.

This section of the N2 proved to be the road which had the smallest difference between the the 85th and 15th percentile, as well as between the 85th percentile and average speeds of the three road sections which were considered. Furthermore, it also had the smallest difference between the speeds recorded during the base set and that recorded during the other periods.

4.3.3.1 N2 Eastbound Speeds

Motorists travelling eastbound on the N2 were moving away from Knysna, heading toward Plettenberg Bay. Due to the road markings prohibiting overtaking manoeuvres on the western 11 km of the road section, it provided an opportunity to investigate whether or not any major difference existed with regards to driver behaviour on these sections. Due to overtaking being prohibited by the road markings on the western 11 km of this section, the speeds at which vehicles were travelling should have been relatively close to one another if drivers heeded to the law as indicated by the road markings.

Table 4.18 shows the average, 15th and 85th percentiles speeds, as well as the difference between the various percentile speeds of vehicles heading eastbound on the N2. Figure C.9 in Appendix C is a visual representation of the information provided in this table. The difference between the 85th and 15th percentile speeds for the various time periods, was 18.85 km/h, while the difference between the 85th percentile and average speeds for the various time periods was 12.44 km/h.

The highest 85th percentile speed were recorded during the base set, which was 2,8 km/h faster than during any other time period. The time period which produced the highest average speeds was 18:00 - 19:00, while the highest 15th percentile speeds were recorded during 17:00 - 18:00. The slowest 85th percentile speeds were recorded during 10:00 - 11:00, while 13:00 - 14:00 and the base set produced the slowest average and 15th percentile speeds respectively. The time period that produced the largest difference between the various percentile speeds was the base set, with a difference of 16.61 km/h between the 85th and average speeds and 26.38 km/h between the 85th and 15th percentile speeds.

Table 4.18: N2 Eastbound Percentiles Comparison

Eastbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	73,81	83,58	100,19	26,38	16,61
7:00-8:00	77,60	84,61	97,40	19,80	12,79
10:00-11:00	76,44	81,31	91,50	15,06	10,18
13:00-14:00	74,64	80,23	92,64	18,01	12,41
16:00-17:00	77,60	82,49	94,09	16,49	11,60
17:00-18:00	78,06	83,46	95,17	17,11	11,71
18:00-19:00	77,60	84,89	96,69	19,09	11,80

Interestingly, the 85th percentile speed profile on this roadway section was slightly different than that of the R44 and R45, the greatest difference being that the speed difference between the base set and other time periods was much lower on the N2. The results as indicated in figure 4.15 showed that speeds recorded during the base set was only higher than other time periods for the middle section of this roadway, stretching between the 4000 and 12000 metre marks. Interestingly, the results as indicated in figure 4.15 showed that speeds during the base set was only higher than other time periods during the middle section of this roadway, stretching from approximately the 4000 metre mark to the 12000 metre mark. For the rest of the route, the periods which had the highest speeds were 07:00 - 08:00 and 18:00 - 19:00.

A concerning phenomenon that was noticed, was that the 85th percentile speeds did not once fall below 80 km/h. Even within the section that had a posted speed limit of 80 km/h (10.1 - 11.15 km), the speeds at which vehicles were travelling remained high. In fact the slowest 85th percentile speed of vehicles within the 80 km/h zone, was 95 km/h, indicating that drivers did not adhere to the posted speed limit.

Only one section was identified on which vehicle speeds were affected differently during the base set as compared with the other time periods, which was between 4000 and 5000 metres. The base set speeds remained near constant on this section whereas the other time periods indicated a large decrease, followed by an immediate increase in speed. The steep decrease was most likely caused by an uphill section combined with a sharp horizontal curve which was located at this point along the route. Following the uphill section combined with a sharp horizontal curve, the road straightened out and also entered a downhill section, the combination of which likely contributed to the steep increase in speed that followed the steep decrease.

Another steep decrease in speed occurred around the 12000 - 12300 metre mark, followed by an immediate and equally steep increase in speed. This sharp decrease and increase in speeds were most likely caused by the intersection with Plettenberg Bay's Airport Road located at approximately 12000 metres. The highest speeds were recorded to the east of this intersection between 13000 and 15000 metres, which was likely due to this section being predominantly flat and straight.

Throughout this route, the speed profiles of the various time periods, apart from the base set, took the same shape, with only slight differences in speeds. The speed profile of the base set had some resemblance to that of the other periods, but the results showed that the road layout influenced vehicles travelling during this period differently to those driving during other periods.

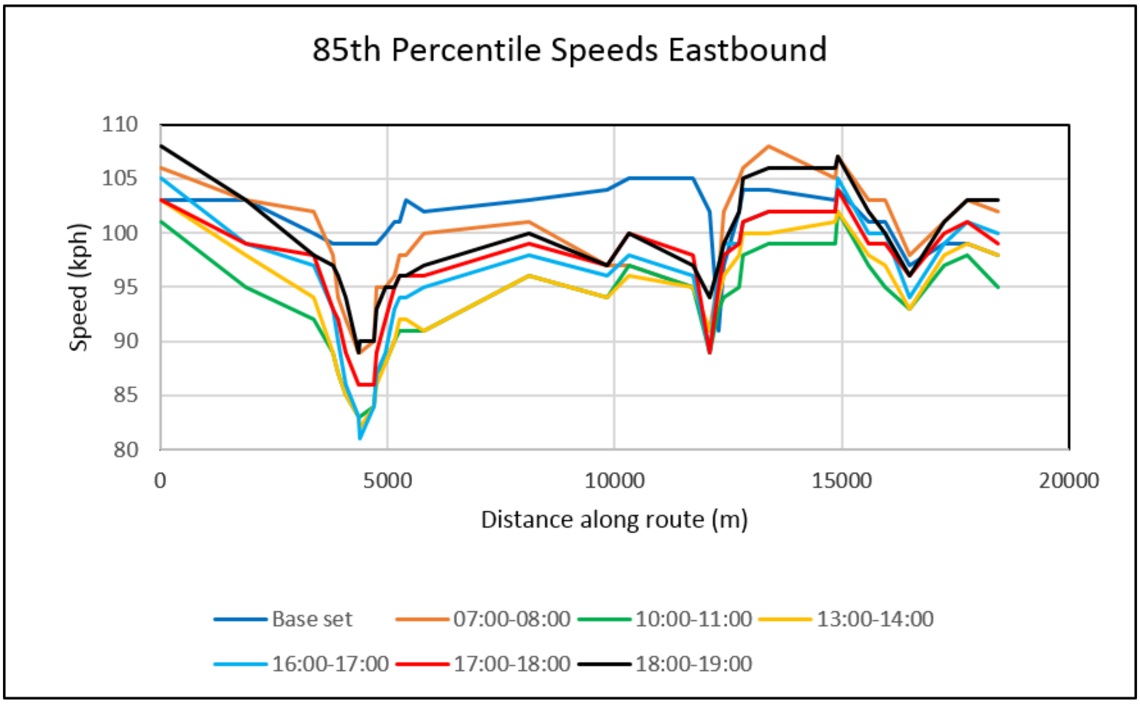

Figure 4.15: N2 Eastbound 85th Percentile Speeds Along Route

The comparison between figures 4.16 and 4.15 showed that the 15th and 85th percentile speeds profiles had approximately the same layout. That being said, three differences between these two profiles were identified along the route. The first was that the 15th percentile speeds indicate a decrease in speed from approximately 5200 to 5900 metres, while the 85th percentile speeds did not indicate any decrease in speeds on this section, but instead a slight increase. The second difference was that the 15th percentile speeds indicated a decrease in speed from 13000 to 15000 metres, while the 85th percentile speeds remained constant on this section. Finally the 15th percentile base set speeds were at no stage higher than the other time periods, while the 85th percentile base set speeds were higher than the other time periods for the middle section of this roadway.

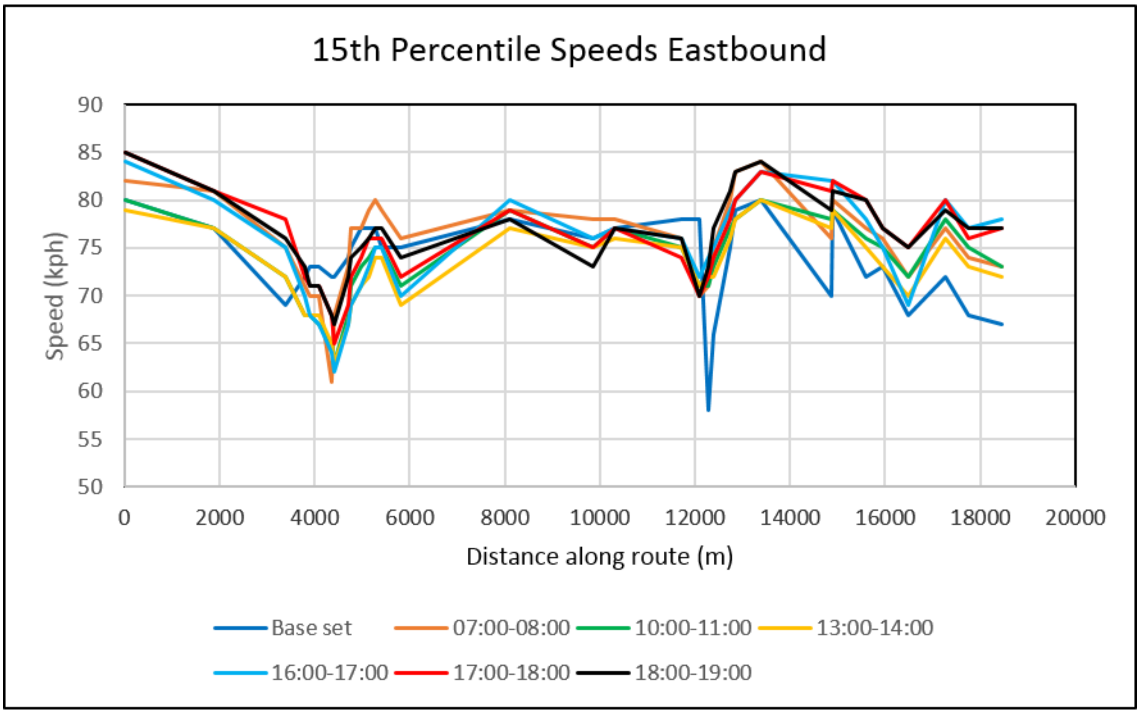

Figure 4.16: N2 Eastbound 15th Percentile Speeds Along Route

4.3.3.2 N2 Westbound Speeds

Motorists travelling westbound on the N2 were moving away from Plettenberg Bay, heading toward Knysna. The road markings were almost identical to that of the eastbound direction, with the western 11 km being identical, while the only difference was the location of section permitting overtaking on the eastern 7.5 km of the roadway.

As with previous vehicle speeds, table 4.19 shows the average, 15th and 85th percentiles speeds, as well as the difference between the various percentile speeds of vehicles heading westbound on the N2, while figure C.10 in Appendix C is a visual representation of the information provided in this table. The average difference between the 85th and 15th percentile speeds for the various time periods, were 20,24 km/h, while the difference between the 85th percentile and average speeds for the various time periods were 14,00 km/h.

The highest 85th percentile and average speeds were recorded during the base set, which was respectively 5,7 and 4,3 km/h faster than any other time period. The highest 15th percentile speeds were recorded during 13:00 - 14:00, which was only 0,3 km/h higher than during the base set. The slowest average, 15th, and 85th percentile speeds were all recorded during 10:00 -

11:00. The period that produced the largest difference in speed between the various percentiles, was the base set, with a difference of 16,5 km/h between the 85th percentile and average speeds and 26,82 km/h between the 85th and 15th percentile speeds.

This indicated that the difference in speed between the various percentiles was higher for vehicles travelling westbound than eastbound. Furthermore the 85th percentile speeds were higher for vehicles travelling westbound, while the average and 15th percentile speeds were higher for vehicles travelling eastbound.

Table 4.19: R44 Percentiles Comparison

Westbound (km/h)					
Time Set	**15th Percentile**	**Average**	**85th Percentile**	**85th - 15th**	**85th - Avg**
Base Set	76,00	86,32	102,83	26,82	16,50
7:00-8:00	75,31	81,92	97,11	21,80	15,20
10:00-11:00	74,22	79,22	91,88	17,66	12,65
13:00-14:00	76,26	80,59	93,56	17,29	12,97
16:00-17:00	75,74	81,55	94,49	18,75	12,94
17:00-18:00	75,23	81,65	95,30	20,08	13,66
18:00-19:00	75,66	82,05	96,13	20,47	14,08

Figure 4.17 shows the 85th percentile speeds of vehicles which were travelling westbound on this road section. Unfortunately no data points was recorded for the first kilometre, therefore the speed profile only started approximately 1200 metres from the start of this section.

Interestingly, a notable difference between the 85th percentile speed profile for vehicles travelling westbound and that of vehicles travelling eastbound, was that the base set speeds for vehicles travelling westbound were higher than during other time periods for the majority of this section, which was not the case for vehicles travelling eastbound. As can be seen from figure 4.17, the only section during which the base set speeds were not higher than all other time periods, was between 12000 and 12500 metres, but even here, only speeds recorded for the period 07:00 - 08:00 were higher than that of the base set. The difference between speeds recorded during the base set and that of other time periods were especially notable for the first 11 kilometres of this roadway.

The profiles of all the time periods took the same form for the majority of the roadway, indicating that the road layout influenced vehicles travelling at different times of the day in the same manner. The only exception to this was the base set speeds between 7000 and 7700 metres, which did not show the same decrease in speed on this section as during the other time periods, but remained near constant. The largest decrease in speed on this section was recorded during the period 16:00 - 17:00 with a decrease of 14 km/h.

As was the case with the speeds recorded for vehicles travelling eastbound, the 85th percentile speeds did not drop below 80 km/h for any of the time periods. This was quite concerning, as this road contained a 1300 metre section on which the posted speed limit was 80 km/h. Even though the speeds recorded within the section with a 80 km/h posted speed limit was slightly lower than the rest of this roadway, the slowest 85th percentile speeds recorded on this section was 85 km/h, which is still higher than the speed limit.

As vehicles entered the more hilly part (western half) of this roadway, as seen from approximately 12000 metres onward, vehicle speeds began to fluctuate more as compared to flatter sections. Even though the speeds fluctuated more on this section, these fluctuations all occurred within a 5 km/h range for individual time periods. Speeds recorded during all time periods decreased an average of approximately 12 km/h from 17000 to 18500 metres, at which the section under consideration ended. This decrease in speed was most likely caused by an uphill section followed by a sharp horizontal curve.

After the end of this section that was investigated, the speed of most vehicles increased dramatically, as the road diverged to a four-lane major arterial, but at the same time the speed limit lowered from 100 km/h to 80 km/h. Therefore even though the speed limit was lowered, most vehicles exhibited an increase in speed.

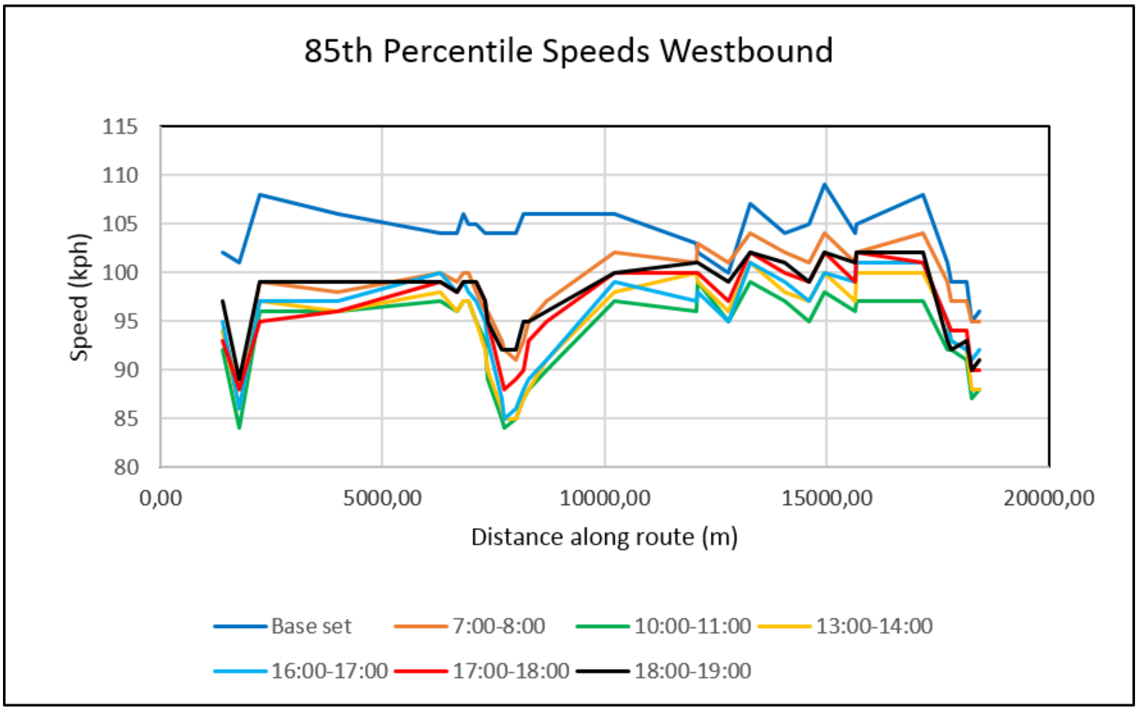

Figure 4.17: N2 Westbound 85th Percentile Speeds Along Route

Comparing the results as indicated in figure 4.18 with that in figure 4.17 showed that the two speed profiles had approximately the same layout in the sense that changes in speed occurred at the same points along the route, with only the extent of these changes differing.

One conspicuous difference between the two profiles was that the 15th percentile speeds recorded during the base set were not higher than the other time periods, while the 85th percentile speeds recorded during the base set were much higher than during the other periods. Furthermore, two occurrences were identified in figure 4.18 that were not recorded in figure 4.17. The first was that the 15th percentile speeds indicated two major drops in speed between 6000 and 8000 metres, while the 85th percentile speeds only showed one of these major drops. Secondly, the 15th percentile speeds showed a major drop of speed between 12000 and 13000 metres, whereas the 85th percentile speeds did not show this major drop. Furthermore, the steep decrease at the end of this section (17000 - 18000 metres) was much greater for the 15th percentile speeds compared to the 85th.

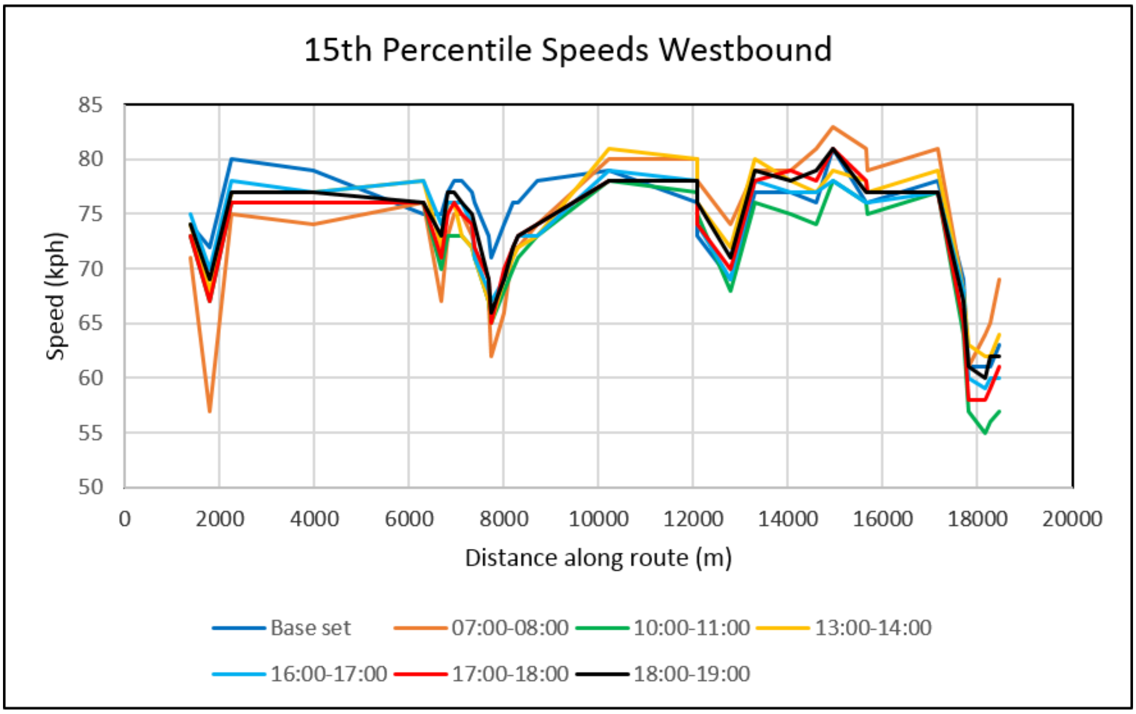

Figure 4.18: N2 Eastbound 15th Percentile Speeds Along Route

4.4 Overtaking Manoeuvres

The data that were recorded with regards to overtaking manoeuvres were all collected manually, as no such data exists electronically. For this reason, the number of overtaking manoeuvres that were used in this project was only those that were physically seen while observing driver behaviour on site, or were recorded via camera. It should therefore be that only small portions of the roadways could be monitored at a time, as physical limitations made it impossible to survey the entirety of any section at the same time. It is most likely that numerous overtaking manoeuvres occurred at other locations along the routes which were out of sight and therefore could not be recorded. For this reason the data should not be seen as the maximum number of overtaking manoeuvres that occurred, but rather the minimum. Furthermore, the number of overtaking manoeuvres that were recorded, were approximately equal in both directions and therefore the results as illustrated represents the total overtaking manoeuvres as recorded for both directions.

As mentioned in section 3.5, not all overtaking manoeuvres can be classified as containing the same level of risk, as some consists of a greater possibility to result in an accident than others. It can neither be said that all illegal overtaking manoeuvres contain a high level of risk, nor that all legal ones contain a low level of risk, in fact some illegal overtaking manoeuvres consists of a much lower level of risk than some legal ones. For this reason, the risk level involved with any type of overtaking manoeuvre was dependant solely on the nature of the manoeuvre itself; whether the manoeuvre was legal or illegal did not influence the risk level ascribed to it.

The behaviour of drivers and therefore also overtaking manoeuvres were observed on site for a total of 165 hours collectively on the three roadway sections. A total of 80 hours were spent observing behaviour on the R44, 40 hours on the R45 and 45 hours on the N2. It is important to note that these hours were spent only observing driver behaviour, collecting on site information with regards to roadway design elements occurred during other periods.

4.4.1 R44 Overtaking

As mentioned in section 4.1.1, the road markings did not permit any overtaking on the section of road which was considered. For that reason, all overtaking manoeuvres which occurred were considered to be unlawful, but not necessarily containing a high level of risk. The study on this road was done on various occasions, thus the data sampled was estimated to be a good representative of the type of behaviour which likely occurs throughout the year.

The R44 was the road section that produced the highest number of illegal overtaking manoeuvres being committed per hour, with an average of approximately 86 illegal overtaking manoeuvres being recorded per hour. This accounted to a total number of 6 888 illegal overtaking manoeuvre recorded on this roadway section. Furthermore, this section also produced the highest number of high risk overtaking manoeuvres, with a total of 246 recorded during the 80 hours spent on site. Therefore the average number of high risk overtaking manoeuvres recorded per hour, were 3.

The number of low risk overtaking manoeuvres that were recorded on this roadway, was 5 740, which accounted to an average of 71,75 overtaking manoeuvres per hour. Furthermore a total to 902 medium risk overtaking manoeuvres was recorded, which accounted to 11,3 overtaking manoeuvres per hour. The hourly overtaking rate for both low and medium risk manoeuvres were the lowest on the R44. This section therefore provided the highest high risk to total overtaking manoeuvres ratio of the three road sections, with 3,57 % of all overtaking manoeuvres recorded on this section containing a high level of risk.

It should be noted that even though the R44 was re-sealed and therefore provided an opportunity to compare driver behaviour before, during and after with one another, the overtaking manoeuvres recorded in this study were only counted after the re-seal was completed, therefore all the overtaking manoeuvres were illegal.

Comparing the number of overtaking manoeuvres before and after the reseal of the roadway and prohibiting overtaking for the entire section, it was discovered that the number of overtaking manoeuvres were nearly the same before and after, with a slight reduction in the total and especially the high risk overtaking manoeuvres since the change in the road markings. Therefore the reduction in high risk overtaking manoeuvres as well as a reduction in total overtaking manoeuvres recorded on the roadway indicated that the change in road markings brought forth a slight, but positive change in driver behaviour.

4.4.2 R45 Overtaking

The design layout of the R45 differed somewhat from that of the R44, as it was flatter and had fewer horizontal curves. Therefore this roadway consisted of both sections on which overtaking was permitted, but also others on which overtaking was prohibited by the road markings. For this reason, both legal and illegal overtaking manoeuvres were recorded on this roadway.

The total number of overtaking manoeuvres that were recorded on the R45, was 5 929, of which 4 806 consisted of a low level, 970 consisted of a medium level and 153 consisted of a high level of risk. This accounted to an average of 120,2 low risk, 24,3 medium risk and 3,8 high risk overtaking manoeuvres recorded per hour.

Furthermore this roadway had the highest ratio of legal to illegal overtaking manoeuvres recorded. This was expected to be largely due to the fact that this roadway was the only one of the three investigated on which the length of sections on which overtaking is permitted, is higher than the length on which overtaking is prohibited. The total number of legal overtaking manoeuvres that were recorded, was 4 448 and the number of illegal overtaking manoeuvres that were recorded, was 1 481. Therefore the ratio of legal vs illegal overtaking manoeuvres that were recorded, was 3:1.

4.4.3 N2 Overtaking

This road section consisted of both sections on which overtaking was permitted and others on which overtaking was not permitted. The layout of the western 11 km of this section was much like that of the R44 with regards to the horizontal and vertical alignments and that overtaking is also prohibited on this section. The eastern 7,5 km on the other hand was much like the R45 regards to the horizontal and vertical alignments and also consisting of both sections on which overtaking was permitted, but also on which overtaking was not permitted.

The number of legal overtaking manoeuvres recorded on the N2 also outweighed that of illegal manoeuvres, but not to such a degree as on the R45. The total number of overtaking manoeuvres was 6 144, of which 4 299 was legal and 1 845 was illegal. Therefore the ratio of legal vs illegal overtaking manoeuvres that were recorded, was 2,33:1.

Of the total number of overtaking manoeuvres that were recorded, 5 253, 779 and 112 consisted of low, medium and high levels of risk respectively. This accounted to an average of 116,7 low risk, 17,3 medium risk and 2,5 high risk overtaking manoeuvres recorded per hour. This roadway therefore produced the lowest number of high risk overtaking manoeuvres per hour.

Table 4.20 shows all the overtaking manoeuvres that were recorded on the various road sections, while table 4.21 shows the hourly overtaking manoeuvres per roadway section. Of all the overtaking manoeuvres that were recorded, 83,3 % were considered as low risk manoeuvres, 14 % were medium risk manoeuvres and 2,7 % were high risk manoeuvres.

Table 4.20: All Overtaking Manoeuvres Recorded on Various Road Sections

Overtaking Manoeuvres on Various Roadways					
Manoeuvre	**Risk Level**	**R44**	**R45**	**N2**	**Total**
Illegal	Low	5 740	1 199	1 620	8 559
	Medium	902	221	180	1 303
	High	246	61	45	352
Legal	Low	0	3 607	3 633	7 240
	Medium	0	749	599	1 348
	High	0	92	67	159
Combined	Low	5 740	4 806	5 253	15 799
	Medium	902	970	799	2 651
	High	246	153	112	511
Total		6 888	5 929	6 144	18 961

Table 4.21: Hourly Overtaking Manoeuvres on Various Road Sections

Hourly Overtaking Manoeuvres on Roadways				
Manoeuvre	**Risk Level**	**R44**	**R45**	**N2**
Illegal	Low	71,75	29,98	36,00
	Medium	11,28	5,53	4,00
	High	3,08	1,53	1,00
Legal	Low	0,00	90,18	80,73
	Medium	0,00	18,73	13,31
	High	0,00	2,30	1,49
Combined	Low	71,75	120,15	116,73
	Medium	11,28	24,25	17,31
	High	3,08	3,83	2,49
Total		86,10	148,23	136,53

4.4.4 Types of Overtaking Manoeuvres

Only Medium and high risk overtaking manoeuvres will be discussed in depth in this section. The exact type of low risk overtaking manoeuvres were not dotted down for all the occurrences (for there were many) and therefore no correlation within this field was drawn. The low risk involved in these manoeuvres meant that these were not the concern and therefore not the area of focus for this study, but rather manoeuvres containing a higher level of risk.

4.4.4.1 High Risk Overtaking Manoeuvres

As mentioned previously, overtaking manoeuvres consisting of a high level of risk are the most likely to result in an accident and poses a real possibility that an accident can indeed occur from such manoeuvres. Even though all these manoeuvres posed a very real possibility of resulting in an accident, it does not mean that all of them did lead to accidents. In fact only two very small accidents were observed during the entire period spent on the various roadways.

The road section on which the highest number of high risk overtaking manoeuvres were recorded, was the R44, with a total of 246 high risk manoeuvres recorded on this roadway, all of which were illegal. The second highest was recorded on the R45, with a total of 153 high risk overtaking manoeuvres, 61 of which were illegal and 92 were legal, while the least number of high risk overtaking manoeuvres were recorded on the N2, with a total of 112, of which 45 were illegal and 67 were legal. Therefore the total number of high risk overtaking manoeuvres that were recorded, were 511, of which 352 were illegal and 159 were legal.

Only four manoeuvres which was classified as containing a high level of risk, were recorded on the various roadway sections, as previously mentioned in section 3.5. Firstly considering the illegal overtaking manoeuvres, 198 were recorded as overtaking manoeuvres being conducted with insufficient sight distance, 79 were fly by overtaking manoeuvres in the face of oncoming traffic, 17 were overtaking three or more vehicles at once without being certain of being able to complete the overtaking manoeuvre before encountering a conflict point with oncoming traffic, and 58 were overtaking one vehicle directly behind another vehicle also conducting an overtaking manoeuvre without being able to see oncoming traffic and therefore containing uncertainty of completing the manoeuvre before encountering a conflict point with oncoming traffic. Table 4.22 show the information with regards to these overtaking manoeuvres and also shows which percentages that each manoeuvre contributed to the total number of illegal overtaking manoeuvres.

Table 4.22: Types of Illegal High Risk Overtaking Manoeuvres

High Risk Manoeuvre Types (Illegal)		
Manoeuvre Type	**Number of occurrences**	**Percentage**
Insufficient sight distance	198	56,25 %
Fly by in the face of oncoming traffic	79	22,44 %
Overtaking 3 or more	17	4,83 %
Immediately behind another vehicle	58	16,48 %

Considering the legal high risk overtaking manoeuvres, 79 were recorded as fly by overtaking in the face of oncoming traffic, 29 were overtaking three or more vehicles without certainty of completing the manoeuvre, and 51 were overtaking one vehicle directly behind another without being able to see oncoming traffic. Therefore the total legal overtaking manoeuvres consisting of a high level of risk were 159. Therefore the total number of fly by overtaking manoeuvres in the face of oncoming traffic, overtaking three or more vehicles at once, and overtaking one vehicle immediately behind another, were 158, 46, and 109 respectively.

The only type of overtaking manoeuvre that only consisted of illegal overtaking manoeuvres and not legal ones as well, was overtaking with insufficient sight distance, whereas the other three consisted of both legal and illegal manoeuvres. Of the 198 overtaking manoeuvres being conducted with an insufficient sight distance, 95 occurred at left-hand curves, 69 occurred at right-hand curves, and 34 occurred at crests. Furthermore, of the overtaking manoeuvres occurring at horizontal curves, a total of 147 were recorded at the end of flat, straight sections on which numerous lower risk overtaking manoeuvres were recorded.

The majority of the overtaking manoeuvres that did not occur with insufficient sight distance were recorded on straight, flat road sections. Of the total of 158 fly by overtaking manoeuvres that were recorded, 113 occurred either near the end of a section on which the road markings permitted overtaking, or toward the end of a flat, straight on which the road markings prohibited overtaking.

Manoeuvres during which motorists attempted to overtake 3 or more vehicles at once without being sure whether or not they could complete the manoeuvre before being faced with a conflict point with oncoming traffic, most often occurred on the first half of either a section permitting overtaking, or a straight, flat section on which overtaking is prohibited; these manoeuvres very seldom occurred toward the end of such sections. These manoeuvres were most often recorded after numerous vehicles have been travelling in a queue behind a slower moving vehicle for an extended period of time.

When vehicles were travelling in a queue and there is sufficient provision and room to conduct an overtaking manoeuvre, it was observed that approximately 80 % of the time, the second vehicle conducted the overtaking manoeuvre (meaning only 1 vehicle needed to be overtaken), which was classified as a low risk overtaking manoeuvre. 16 % of the time, the third vehicle in the queue conducted the overtaking manoeuvre (meaning 2 vehicle needed to be overtaken), which was classified as a medium level of risk, and 4 % of the time were either the fourth vehicle of further back in the queue.

Furthermore the type of vehicles involved in the overtaking manoeuvres were also recorded in order to estimate whether or not the capabilities of the vehicle itself played in role in affecting the drivers' choice of action. Three vehicle brands stood out in particular as contributing to the number of high risk overtaking manoeuvres being conducted; these were Mercedes, BMW, and Audi, which contribute to approximately 69 % of all high risk overtaking manoeuvres.

Of the 198 overtaking manoeuvres that were conducted with insufficient sight distance, 66 were Mercedes, 42 were BMW, 36 were Audi, and 54 were other vehicle brands.

Of the 158 fly by overtaking manoeuvres in the face of oncoming traffic, 37 were Mercedes, 34 were BMW, 31 were Audi, and 56 were other vehicle brands.

Of the 46 manoeuvres during which vehicles overtook 3 or more vehicles at once, 11 were Mercedes, 10 were BMW, 16 were Audi, and 9 were other vehicle brands.

Of the 109 overtaking manoeuvres that were conducted immediately behind another vehicle also conducting an overtaking manoeuvre, 22 were Mercedes, 30 were BMW, 20 were Audi, and 37 were other vehicle brands.

4.4.5 Medium Risk Overtaking Manoeuvres

The road section on which the highest number of medium risk overtaking manoeuvres were recorded was the R45, with a total of 970 medium risk manoeuvres recorded on this roadway, 221 of which were illegal and 749 were legal. The second highest number of medium risk overtaking manoeuvres were recorded on the R44, with a total of 902 (all of which were illegal). The lowest number of manoeuvres consisting of medium level of risk, were recorded on the N2, with a total of 779, of which 180 were illegal and 599 were legal. Therefore a total of 2 651 medium risk overtaking manoeuvres were recorded, 1 303 of which were illegal and 1 348 were legal.

As mentioned in section 3.5.2, four manoeuvres consisting of a medium level of risk were identified. Of the total of 1 303 illegal overtaking manoeuvres that were recorded, 175 were overtaking 2 or 3 vehicles at once, 192 were overtaking one vehicle immediately behind another vehicle that were also conducting an overtaking manoeuvre, 504 were when drivers conducted an overtaking manoeuvre, knowing that the manoeuvre will not be completed in time, but expecting the oncoming traffic to give way and 432 were high speed fly by overtaking manoeuvres.

Considering the legal medium risk overtaking manoeuvres that were recorded: of the total of 1 3484, 217 were overtaking 2 or 3 vehicles at once, 212 were overtaking one vehicle immediately behind another vehicle that were also conducting an overtaking manoeuvre, 525 were when drivers conducted an overtaking manoeuvre, knowing that the manoeuvre will not be completed in time, but expecting the oncoming traffic to give way and 394 were high speed fly by overtaking manoeuvres.

The majority of cases when vehicles overtook 2 or 3 vehicles at once, or overtaking immediately behind another vehicle were recorded at two type of locations. The first was at the beginning of a section that permitted overtaking after vehicle have been travelling along in a queue (regardless of how large or small) for a while. Therefore drivers conducted such manoeuvres in order to get out of the queue. The second, which was predominantly recorded on the R44 and N2, was at the beginning of a flat and straight section on which overtaking is prohibited. These types of manoeuvres unfortunately occurred numerous times and the motive was much the same as in the case where overtaking is permitted.

4.5 Accident Data Analysis

As mentioned previously, the locations of the accidents that occurred on the N2 could not be identified and therefore the data could not be used for this study. For this reason, only the accident data of the R44 and R45 were analysed.

4.5.1 R44 Accidents

The R44 contained a higher number of accidents, but these resulted in less fatalities than that recorded on the R45. The total number of accidents that occurred on the R44, was 110. This resulted in 3 fatalities, 6 serous injuries, 15 slight injuries and 179 did not suffer any injury, which is a total of 203 people.

The point along the route at which the highest number of accidents were recorded, was in the vicinity of the intersection with Kromme Rhee Rd. Figure 4.19 indicates some of the accidents that occurred on the R44. The accidents portrayed in this figure is only at locations where multiple accidents occurred.

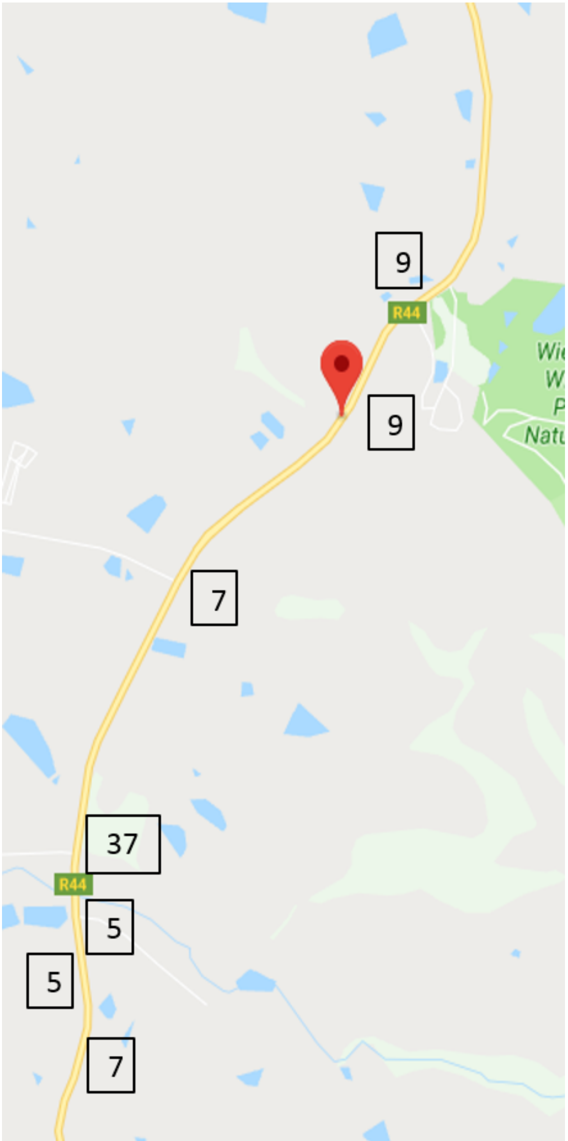

Figure 4.19: Accidents on the R44

4.5.2 R45 Accidents

The R45 had slightly less accidents than the R44, yet it resulted in more fatalities than the R44. The total number of accidents that occurred on the R45, was 91. This resulted in 5 fatalities, 8 serous injuries, 27 slight injuries and 126 did not suffer any injury, which is a total of 166 people.

The point along the route at which the highest number of accidents were recorded, was in the vicinity of the intersection with R304. Figure 4.20 indicates some of the accidents that occurred on the R45. The accidents portrayed in this figure is only at locations where multiple accidents occurred.

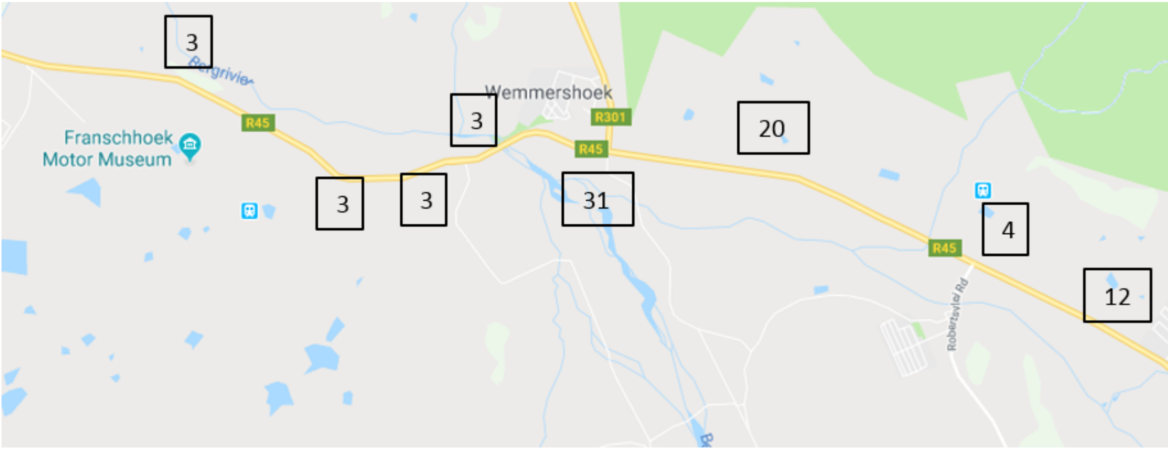

Figure 4.20: Accidents on the R45

4.6 Questionnaire Results

All the answers of the questionnaire will not be indicated in this section, but rather will be indicated and drawn upon when discussing topics pertaining the the same type answers as were obtained from the questionnaire.

Chapter 5

DISCUSSION

5.1 Driver Behaviour and Travel speeds

According to both Shinar (2007) and Abele & Møller (2011), speed is a significant factor in contributing to road safety. Even though this was not the focus point of this study, it did provide an opportunity to observe the behaviour of vehicle from a speed point of view.

The recorded 85th percentile speeds were lower than the posted speed limit for the majority of the time periods except for the base set. This is a good indication that the speed limit is too high and that it is a good opportunity to lower it. The only concern with a reduction in speed is the R45 section, for the results of the base period indicated that drivers felt comfortable travelling at very high speeds and even though a lower speed limit may serve to lower these as well, it may have a slight negative effect on the psychological state of drivers in the short term.

Slower speeds during daytime compared to the base set were attributed to two major factors. The first was that more trucks made use of this road during daytime than during hours of darkness; trucks were unable to travel at the same speeds as passenger cars and therefore caused a reduction in overall speeds of vehicles. The second was that traffic volumes were higher during daytime than at during hours of darkness.

The traffic volumes resulted in an increase in density and therefore the headway between following vehicles decreased, which resulted in vehicles having less freedom to drive at desirable speeds due to the presence of slower moving vehicles in the same direction. The second consequence was that the volume of oncoming traffic was also higher, which caused overtaking to be difficult. Thirdly, the slower speeds and difficulty of overtaking caused queues to form behind slower moving vehicles. The presence of queue meant that drivers had to spend more time behind slower moving vehicles as most vehicles decided rather to wait until all the vehicles in front of them had passed the leading vehicle before he/she overtook the leading vehicle.

It was discovered that when considering the speed profiles, the majority of the time a decrease in speed was accompanied by an uphill section and an increase by a downhill section. Furthermore the presence of horizontal curves brought forth a slight reduction in vehicle speeds.

All of the roadways portrayed a large difference between the 85th and 15th percentile speeds, indicating that there was a large difference in the speed of vehicles travelling in the same direction. This posed a significant threat according to past research (Shinar, 2007).

5.1.1 R44 Speed Observations

The 85th percentile speeds on the R44 were the slowest of the three roadways and therefore indicating both the limitations that the road design places on vehicle speeds, as well as the effect that the traffic volume have on the vehicle speeds. The greatest difference between the 85th and 15th percentile speeds were also recorded on the R44, meaning that slower moving vehicles were travelling at very low speeds.

This is likely to pose a problem for motorists, for the large difference in vehicle speeds, combined with the large volume and the length of the roadway, meant that it was likely that faster moving vehicles will caught up to slower moving vehicles. If this happened, faster moving vehicles were posed with two options, the first is to follow behind the slower moving vehicle for the remainder of the length of this roadway, or to conduct an illegal overtaking manoeuvre and continue along at their desired speed.

By observing the driver behaviour, it was clear that approximately 95 % of motorists, when faced with the circumstances described previously, chose to overtake the slower moving vehicle as soon as traffic circumstances allowed. The large difference in speed and the very low speed of slower moving vehicles were also estimated to be contributory factors to the number end severity of dangerous overtaking manoeuvres which was recorded on this roadway.

5.1.2 R45 Speed Observations

The most concerning observation with regards to speed on the R45, is the magnitude of the speed and the large difference between the base set speed and the speed of other time periods. The highest speeds of the three roadways were recorded on the R45, with the highest speeds reaching even as high as 130 km/h. Such high speeds are likely to have a repercussion on the safety of the road (Abele & Møller, 2011) and cause perception to be more difficult, as it is more difficult to accurately perceive situations at faster speeds (Shinar, 2007). The high speeds also posed a concern at the R310 intersection, where numerous accidents have occurred, many of which have high speeds to blame.

The difference between the 85th and 15th percentile travel speeds were not as high as the

R44, but was still significant. It was interesting to note that the highest hourly overtaking rate accompanied these high speeds. It was therefore possible to attain such high speeds because there was sufficient chance to overtake slower moving vehicles without losing too much time or speed. Even though sufficient providence was made to overtake slower moving vehicles legally, numerous illegal overtaking manoeuvres were still recorded.

5.1.3 N2 Speed Observations

The N2 had the most consistent speed range from all three the road sections. It had the smallest difference between the 85th and 15th percentile speeds and the difference between the base period speed and that of other time periods were also small. Driver behaviour on this road section was also the most reserved. Furthermore, he speeds for all the time periods were relatively close to one another and also close to the speed limit.

The large difference in speed between fast moving and slow moving vehicles at the point where lanes merged is a great concern and results in dangerous behaviour at this point. This is something that should be addressed if future accidents want to be avoided.

5.2 Driver Behaviour and Overtaking

According to Damasio (1994), man's deepest and most fundamental motive is survival and therefore all drivers will behave in such a manner as to preserve their own lives. Accordingly, Näätänen & Summala (1974) stated that drivers will behave in such a manner as to experience no risk. Both of these agree that drivers will behave in such a manner as to preserve their own lives rather than put it at risk, or at least will not purposefully put their lives at risk, but can it be said that this is always the case, and if so, why are so many cases of drivers exhibiting dangerous behaviour reported?

The results obtained in this study with regards to overtaking manoeuvres, as shown in section 4.4, indicated that numerous high risk overtaking manoeuvres were recorded within the time spent on the three road sections. These driver behaviour observations therefore either indicate that some drivers did not accurately perceive the level of risk involved in certain manoeuvres, or they accurately perceived the risk involved and yet still chose to conduct a manoeuvre(s) that posed the possibility of resulting in an accident.

The results obtained from the questionnaire pertaining directly to the topic of drivers conducting dangerous manoeuvres (questions 7 and 10) indicated that most drivers do indeed consider the risk involved in their behaviour, yet some mentioned that from time to time they are willing to take more risks. From questions 7 and 10, a total of 112 out of 112 indicated that the thing that they consider before conducting an overtaking manoeuvre or what governs their behaviour, is their own safety. This agrees then with what Damasio (1994) said, that a person will act in such a way as to aim to preserve his/her own life.

What might serve as a slight contradiction to this, is that in these same questions, 42 also indicated that they take more risks when late for work. This then serves to show that the two things governing one's behaviour is firstly the desire for safety, but also time.

A common phenomenon that occurs on South African roads is drivers regularly driving on the hard shoulder indicated by the yellow lines. Vehicles moving at slower speeds do this in order to give more room for faster vehicles to overtake them more easily. Participants of the questionnaire were asked in which way they would respond when a faster moving vehicle came up behind them (see question 15 of questionnaire); of the 112 participants, 92 indicated that they would give way and move more to the left (drive on the hard shoulder) if possible, 12 indicated that they would either try to give way or drive faster due to feeling pressured by the faster vehicle, only 8 of the participants indicated that they would not give way and drive at a constant speed. Furthermore, of all the overtaking manoeuvres that were recorded, approximately 58 % involved the leading vehicle driving on the hard shoulder to some extent.

Although hard shoulder driving allowed for more opportunities to complete lower risk overtaking manoeuvres on straight/flat sections, it posed a problem at crests and horizontal curves. According to Abele & Møller (2011), vehicles move more toward the centre of the road when going around a curve than when driving on straight roads. This was also confirmed from the observation made while on site and therefore any vehicle driving on the hard shoulder moved more toward the middle of the road, leaving less room for other faster moving vehicles to overtake it. For this reason, it was observed that there was not sufficient room for vehicle to overtake slower moving vehicles around horizontal curves. Furthermore, of the 198 high risk overtaking manoeuvres conducted with an insufficient sight distance, 186 occurred while the leading vehicle were driving on the hard shoulder.

The concern therefore is not with hard shoulder driving in itself, but the risk that is holds when coming nearer curves and crests. Therefore it is not the high quantity of low risk overtaking manoeuvres that is the concern, but rather the medium and high risk manoeuvres accompanied the low risk manoeuvres from the results obtained on site. Reason (1990), Stanton & Salmon (2009) and Bucchi *et al.* (2012) all agree that your current behaviour is based on your past experiences and therefore if a driver successfully execute an overtaking manoeuvre, it causes the driver to grow in confidence with regards to that specific manoeuvre, which in turn encourages the driver to attempt more such manoeuvres. With every successfully completed overtaking manoeuvre, the driver grows more confident and eventually more bold, leading to more dangerous overtaking manoeuvres being attempted. Individuals with a higher cognitive capacity, however, are more likely to be able to restrain their behaviour to a more moderate level (Hirsh *et al.*, 2008).

Vehicles that are not willing to drive on the hard shoulder also poses some other difficulties. When a vehicle is driving close to the speed limit, it did not lead to any repercussions that were recorded, but when vehicles were driving more than 15 km/h slower than the speed limit, a queue began to form behind that vehicle. Such cases resulted in numerous high and medium risk overtaking manoeuvres recorded and therefore it was concluded that drivers became more agitated due to the low speeds that they were forced to travel by and therefore conducted more dangerous manoeuvres.

5.3 Driver Behaviour and Roadway Characteristics

Various roadway elements may have an effect on the psychological state of drivers and as mentioned previously, it is likely to affect some individuals different than others (Hirsh *et al.*, 2008) and may even influence the same individual differently depending on their initial state of mind. For this reason the various roadway elements of the three roadways were inspected in order to draw the most accurate conclusion with regards to the affect that the various roadway elements may have on the psychological state of drivers.

When considering an individual roadway without taking the immediate preceding and following conditions into considerations, one may come to wrong conclusions with regards to driver behaviour, as the preceding conditions would have undoubtedly affected the psychological state of drivers. For instance a driver may have grown increasingly agitated due to a single or multiple events that happened elsewhere within the roadway system, but only acted upon that agitation later on. Therefore if the action upon the agitation took place and was recorded within the section under inspection while the events leading to the agitation took place in another section, one may come to an inaccurate conclusion in identifying the cause of that agitation.

A factor that may not seem to have anything to do with the characteristics of the roadway, is the presence of queues. Queues are not necessarily road characteristics in itself, but are nevertheless a resultant consequence of road characteristics, due to the characteristics of the road not providing sufficient opportunity for faster vehicles to overtake slower moving vehicles safely. For this reason the effects that queues have on driver behaviour were also approached as a roadway characteristic, as it is the subsequent result of insufficient provision provided for low or no risk overtaking manoeuvres. As stated previously, all overtaking manoeuvres of two-lane highways contain some level of risk, therefore no risk overtaking manoeuvres involves two lanes going in the same direction.

The behaviour of drivers when in a queue was not the concerning factor, but rather the behaviour of drivers after coming out the front of the queue (after overtaking the vehicle that caused the queue). When drivers were faced with the circumstances described here, between 70-75 % of all vehicles were observed to travel at speeds faster than the speed limit immediately following. The results obtained from the questionnaire (see question 13) also pointed to the same, with 84 of the participants indicating that they would travel at speeds higher than usual after being stuck in a queue and 34 indicated that they will also be willing to take more risks in order to attempt to make up lost time.

As mentioned in section 4.4.4.1, when vehicles were travelling in a queue, 80 % of the time the vehicle that conducted the overtaking manoeuvre were second in the queue and therefore drivers mostly waited their turn to overtake the leading vehicle, yet once again, after they have overtaken the leading vehicle, their behaviour took the form as described previously.

Considering the driver behaviour and overtaking manoeuvres of the three roads indicated that drivers more illegal, as well as more dangerous overtaking manoeuvres on the R44 than on the other two roadways. Even though the hourly rate of the total number of overtaking manoeuvres that were recorded were the least on the R44, it was still high considering that all the manoeuvres were illegal. The total of 86 illegal overtaking manoeuvres being conducted per hour indicated that the road markings were very ineffective.

When asked about the perceived effectiveness of the road markings that prohibit overtaking (question 19 of the questionnaire), 53 of the participants indicated that they did not think it is always a good indication of where to pass and where not, for sometimes it prohibits overtaking on areas where overtaking is possible. Four of the participants further noted that when overtaking is prohibited on a section where it is perceived that overtaking can easily be completed, it results in them starting to doubt the effectiveness and accuracy of the road markings on other sections.

Comparing the R44 with the western 11 km of the N2, it was discovered that the primary difference in roadway elements were the presence of law enforcement on the N2 and the lack thereof on the R44. Even when drivers on the N2 conducted illegal overtaking manoeuvres on this 11 km stretch of road, the majority of these manoeuvres contained a very low level of risk and high risk overtaking manoeuvres were recorded very seldom.

Even though the law enforcement controlled the behaviour of drivers on this road section, the effect of law enforcement is temporal (Abele & Møller, 2011) and when it is approached incorrectly and with a bad attitude, it may even serve to achieve the opposite as intended (Shinar, 2007). That being said, the presence of law enforcement on the N2 were observed to bring forth a reduction in dangerous behaviour. When law enforcement officers correctly apply their purpose and are present and visible on the roadways on a constant basis, the long term effect is likely to be very positive in bringing forth a reduction in hazardous behaviour (Abele & Møller, 2011).

This was observed from the difference in driver behaviour on the different roadways. During all the time spent on site on and next to the R44, not a single law enforcement vehicle or officer were observed on this road, only two were seen on the R45, but numerous law enforcement vehicles were seen daily on the N2 (some driving on it and other stationary). The results of this was evident when considering the number of high and medium risk overtaking manoeuvres recorded on the various roads. The N2 produced the least number of high and medium risk overtaking manoeuvres. This then confirms that law enforcement correctly applied might very well have a positive long term effect.

5.3.1 R44 Road Characteristics and Driver Behaviour

Two characteristics that were immediately notable on this section were the posted speed limit and the presence of the no-passing solid line (RM1). Furthermore, the reseal of the R44 provided an opportunity to inspect the manner in which the road markings affected the drivers.

During roadway conditions before the road markings were changed, more medium and high risk overtaking manoeuvres were recorded on the R44 as compared to after the change in road markings. The results recorded before the change of road markings indicated that the most dangerous behaviour was observed toward the end of a section permitting overtaking. After the change in road markings, this problem was not completely gone, but rather shifted from on area to the next, as the results showed that the most dangerous behaviour was observed toward the end of flat, straight sections.

When the road markings still permitted overtaking, it was observed that drivers exhibited dangerous behaviour closer to horizontal curves especially as compared to after the change in road markings. This slight change in behaviour may give a clue to how to approach such a problem. It is unlikely to think that drivers on the R44 will all of a sudden change their behaviour and suddenly stop overtaking on this road and therefore eliminating such manoeuvres are improbable, but the best solution would be to move the point at where this behaviour is recorded so that it is further away from any crest of horizontal curve, which would allow drivers more time to react when fact with unwanted circumstances.

In the past, the most dangerous behaviour was exhibited toward the end of sections permitting overtaking, but since the change in road markings, that has changed to near the end of straight and flat sections, yet the point at which this behaviour was recorded, was further away from curves and crests than before the change in road markings. What then brought forth this change and can it be used elsewhere? This change in behaviour can be attributed to the drivers' change in perception at these locations and the change in road markings enabled drivers to perceive more accurately the danger of their past behaviour, which they have since adapted, as agrees with the view of both (Damasio, 1994) and (Vaa, 2014).

The danger of the manoeuvres were in the insufficient sight distance that drivers had when conducting overtaking manoeuvres, but in shifting this point further away from the crest or horizontal curve will increase their sight distance. The only difference between the two mentioned cases, is the road markings. The change in road markings therefore brought forth a change in the perception and experience of drivers on this section, which in turn brought forth a change in feeling or emotion (Vaa, 2014), which brought forth a change in behaviour (Bucchi *et al.*, 2012). Therefore wisely adjusting the road markings at certain locations at which drivers are prone to exhibit dangerous behaviour (not only this road section, but throughout), should have a positive effect on the behaviour of drivers.

Another factor that influenced the risk of an overtaking manoeuvre, was the extent to which slower moving vehicles were willing to give way and drive within the hard shoulder. As discussed in section 5.2, vehicles driving on the hard shoulder is common in South Africa, but not all give way to the same extent as others. Due to this road being resealed, it was possible to compare the extent to which drivers were willing to give way and drive on the hard shoulder when all the road markings were present to that of drivers when only the RM1 line were present and therefore no hard shoulder were indicated yet.

The results indicated that drivers were willing to give way to a greater extent when no hard shoulder was indicated compared to when it was indicated. During the time when only the RM1 line was present, most drivers drove as far to the left of the carriageway as possible and therefore making it easier for faster moving vehicles to overtake them. During the time when all the road markings were present and the hard shoulder was clearly indicated, the displacement of vehicles giving way to faster moving vehicles were approximately 0.6 - 0.8 metres more toward the centre of the road compared to when only the RM1 line was present, therefore making it more difficult for faster moving vehicles to overtake them. Therefore the time during which the hard shoulder was indicated, drivers acknowledged it a bit more as a separate space, but still felt compelled to give way to faster moving vehicles.

Due to vehicles driving further to the left when no shoulder was indicated, faster moving vehicles were able to complete overtaking manoeuvres without having to cross the centre line and therefore never entered the lane of the opposing flow. Even though this helped in assisting faster moving vehicles to complete overtaking manoeuvres at relatively low levels of risk, it also posed a problem when vehicles entered bends on the road. On straight sections, two vehicles travelling in the same direction could fit comfortably next to one another without one having to cross the centreline, but this was not the case for bends.

Due to drivers not feeling comfortable to drive as close to the edge of the carriageway around bends as on straight sections, most vehicles drove a bit more to the right on bends. Furthermore drivers also did not want to pass to close to other vehicles on bends, as handling were more difficult than on straight sections. This combination therefore meant that the risk of overtaking manoeuvres increased dramatically around curves. Most drivers in the curve seemed to perceive overtaking as containing high levels of risk and therefore did not attempt to overtake, but the problem area was at the point where vehicles entered a curve coming from a straight section, as some drivers perceived the level of risk as being low enough, but did not seem to account for the approaching curve. Therefore the perception that the driver had in thinking he/she could complete an overtaking manoeuvre without having to cross the centreline were inaccurate and often led to vehicles overtaking in dangerous circumstances.

Furthermore, what was interesting to note was the type of vehicles involved in the of high risk manoeuvres. The majority of vehicles were either Mercedes, BMW, or Audi, which indicates that the capabilities of vehicles also influenced the behaviour of drivers, in this case individuals driving more expensive vehicles with better capabilities overestimated the capabilities of their vehicle.

One of the most concerning things that were noticed, was the lack of law enforcement on this road section. Not one single law enforcement vehicle or officer were ever observed on this road section for the entire period when on-site inspections were conducted. The mere presence of law enforcement is known to affect both the speeds at which vehicles travel, but also the type of overtaking manoeuvres that drivers are willing to attempt. Most commuters seemed to be well aware of the lack of law enforcement on this road section, as very little hesitation were observed before conducting overtaking manoeuvres, whereas a slight and major hesitation were observed for drivers making use of the R45 and N2 respectively when considering whether to conduct an illegal overtaking manoeuvre or not.

The most troublesome area that were identified with regards to driver behaviour, was approximately 1 km north of the Muldersvlei Rd intersection. The layout of the roadway is a slight left hand horizontal curve with the vertical slope of the road also increasing to approximately 4,5 % at this point. Numerous vehicles travelling northbound were observed attempting high risk overtaking manoeuvres at this location. The accident data also showed that 9 accidents had occurred at this location since January 2015. When investigation was conducted with regards to the cause of these manoeuvres, the preceding roadway environment was considered to contribute the most to the causation.

A large reduction in speed occurred between 1000 and 700 metres before this point, after which the road was straight and levelled out which allowed vehicles to gain some speed, but the straight section also allowed numerous faster moving vehicles to overtake slower moving ones. Due to smaller vehicles gaining more speed and queue lengths becoming shorter, numerous vehicles were observed to conduct high risk overtaking manoeuvres at the end of this straight section, where the sight distance is not sufficient to conduct an overtaking manoeuvre.

Although it was no fully clear why no law enforcement were present on this roadway, numerous law enforcement officers and vehicles were observed investing a large amount of time in enforcing parking within Stellenbosch.

It should be noted that the R44 is close to capacity and the accident rate is therefore expected to increase as drivers are expected to attempt more and more hazardous overtaking manoeuvres. Therefore a major upgrade in this roadway should be considered.

5.3.2 R45 Road Characteristics and Driver Behaviour

The R45 was the only roadway on which the length of road sections that permitted overtaking was longer than non-overtaking sections. This was possible due to the layout being predominantly favourable for overtaking manoeuvres, as this roadway had a lot of flat and straight sections, which was not the case with the other two roads. For this reason, the number of legal overtaking manoeuvres recorded greatly outweighed that of illegal ones as mentioned previously. Even though the R45 did not produce as many illegal overtaking manoeuvres as the R44, numerous legal ones contained relatively high levels of risk. Therefore it was not only the illegal overtaking manoeuvres that were problematic and concerning on this road section, but also numerous legal ones.

Furthermore, the flatter, straighter roads meant that vehicles could drive at faster speeds. This was also evident in the speed data provided in chapter 4. Secondly, this also brought forth a large difference in speed between faster and slower moving vehicles, and it is this combination of excessive speeding and the difference between vehicle speeds that increase the chance of an accident (Shinar, 2007). This section also produced numerous fly by and high speed fly by overtaking manoeuvres, which from the results, seem to be a direct result of the high speeds attained by some vehicles.

The flatter, straighter roads also meant that the slower moving vehicles were moving nearer to the speed limit, which meant that overtaking manoeuvres require a longer distance to be completed. Furthermore the high speeds recorded on this road section also made accurate perception of situations more difficult for drivers, especially with regards to judgement of distance of oncoming traffic (Shinar, 2007).

One factor that was more prominent on this section than on the R44 and N2, was the presence of pedestrians and cyclists making use of the hard shoulder. This caused hard shoulder driving to be more dangerous, as it increased the risk of vehicles colliding with either pedestrians or cyclists. A concerning phenomenon that was observed numerous times, was that some drivers that were driving on the hard shoulder, even when seeing pedestrians on the hard shoulder ahead of them, did not take action to get out of the hard shoulder, but rather stayed their course and expected the pedestrians to get out of the way. This resulted in numerous near miss events that could easily have ended in an accident.

On the other hand, less high risk overtaking manoeuvres were observed on flat, straight road sections, as drivers were capable of assessing situations more accurately. Even though drivers struggled to accurately determine the distance of oncoming traffic, hazardous were less likely to occur on such roadway conditions, as less perception and decision errors occurred on flatter, straighter sections as compared to sections containing vertical and horizontal curves. Therefore a more forgiving road design decreased the amount of high risk overtaking manoeuvres.

5.3.3 N2 Road Characteristics and Driver Behaviour

The layout and design of the N2 served as a near combination of that of the R44 and R45 and therefore provided an opportunity to inspect driver behaviour when faced with such a difference in road layout. The layout and design of the western half were close to that of the R44, with vertical and horizontal alignments causing overtaking to be difficult, while the eastern half had many flat and straight sections.

The behaviour of drivers on the N2 were of a safer nature than that observed on the R44 and R45. This can also be seen from the results recorded with regards to the risk levels involved in the overtaking manoeuvres on the various road sections. The least medium and high risk overtaking manoeuvres were both recorded on the N2. That being said, a slight difference were observed in driver behaviour between the western and eastern halves of the roadway.

The majority of illegal manoeuvres were recorded on the western half, while the majority of the high and medium risk overtaking manoeuvres were recorded on the eastern half. Furthermore, the majority of illegal overtaking manoeuvres that were recorded on the western half consisted of a low level of risk, proving that even though drivers did conduct illegal overtaking manoeuvres, most of the drivers waited for an appropriately safe opportunity to do so. The low number of medium or high risk overtaking manoeuvres that were recorded on the western half of this roadway as compared to the eastern half confirmed that drivers were more prone to dangerous behaviour on the eastern half of the roadway, yet even the behaviour that were recorded here was more reserved than both the R44 and R45. Therefore the main difference between the behaviour observed on the N2 and that of the R44 and R45, was not necessarily the amount of illegal or legal overtaking manoeuvres observed, but rather the level of risk involved in the overtaking manoeuvres. This served to emphasise the effect of the preceding psychological state of road users as well as the effect that correctly applied law enforcement have on driver behaviour.

Furthermore, a slight change in behaviour were also noted to the west of this roadway where the road diverges or merges, depending on the direction one is driving. The location of the point where the road merges from a four-lane to two-lane highway should possibly be move to a different point along the road. The location at which the road currently merges pose a lot of risk for motorists, as it is located at the crest of the uphill section, but at the same time also in the middle of a horizontal curve. The location therefore contributed to a lot of the dangerous behaviour exhibited by drivers at this point. The point of divergence is not the concern, but the point of merger, therefore, even though it is not part of this study, it would be suggested to move the point of merger for vehicles travelling eastbound should be moved 200 metres more to the east, which will allow drivers to more accurately perceive the situation and therefore avoid exhibiting dangerous behaviour.

The effect that the preceding psychological state had on drivers may be seen by comparing the risk level of overtaking manoeuvres with one another. Even when it was legal to conduct overtaking manoeuvres and no law enforcement were in the vicinity, the type of behaviour observed on the N2 contained less risk than that of the R44 and R45. What exactly caused this difference in the preceding psychological state of drivers in not known however.

The effect of law enforcement on the psychological state of drivers were easily observed between the difference in behaviour on the N2 as compared to the R44 and R45. Even though the preceding psychological state did affect driver behaviour on the roadway sections, so too did law enforcement. The presence of law enforcement on a daily basis served to assist in drivers attempting less, and less-hazardous overtaking manoeuvres on the N2, whereas the lack of law enforcement on the R44 and R45 failed to assist in producing the same type of behaviour.

The effect of the road markings on the psychological state of drivers can also be seen from the difference in behaviour between the western and eastern halves of the roadway. Either drivers exhibited their natural behaviour on the eastern half and it was only the presence of law enforcement that caused them to be more conservative on the western half, or the long time spent following slower moving vehicles on the western half so influenced the psychological state of drivers as to contribute to them conducting more dangerous behaviour on the eastern half.

This study is in favour of the latter, but it cannot be known for certain.

Furthermore, the active presence of law enforcement provided an opportunity to observe what type of behaviour was fined and what was allowed without receiving a fine. For clarity, the student conducting this study did not test the patience of the law enforcement by conducting illegal or dangerous overtaking manoeuvres, but rather simply observed what behaviour of other motorists was viewed as worthy of a fine by the law enforcement officers. From this, it was observed that law enforcement officers allowed the majority of motorists conducting low risk, illegal overtaking manoeuvres to go without giving them a fine, while the majority of motorists conducting medium risk illegal overtaking manoeuvres were indeed fined for their actions. It therefore served as a confirmation that the law enforcement officer also perceived some manoeuvres more dangerous than others.

5.4 Identified Problematic Characteristics

One of the most prominent problems identified, was the posted speed limit. The posted speed limit was predominantly 100 km/h for all the road sections. Even though this is meant to indicate to drivers which speed they may not exceed, it also has the effect of indicating to drivers at which speed they should aim to drive at. Therefore the majority of drivers on the roads aimed to driver at speeds either close to the posted speed limit, which in the case of these road sections were estimated to be too high. The majority of vehicles were not able to drive at the posted speed limit as indicated previously. The lower speeds in themselves were positive, but most drivers tend to compare his/her speed with that of the posted speed limit and when he/she is unable to drive at speeds close to the posted speed limit, it may very well have the effect of increasing the individual's frustration and agitation levels. This may in turn influence the individual's attitude and therefore behaviour on the road.

Therefore the effect of having a relatively high speed limit was twofold. Firstly it encouraged drivers to travel at higher speeds during off peak periods and secondly it added to the agitation and frustration of drivers in the peak periods when it was not possible to travel at speeds close to the posted speed limit. The safety of the road sections can therefore be increased by bringing forth a decrease in the posted speed limit. It is suggested to lower the speed limits from 100 km/h to 90 km/h. In a previous study, it was estimated that a 5% decrease in speed leads to an approximate decrease of 10% in injury accidents and 20% decrease in fatal accidents (Centre *et al.*, 2006).

Two elements that produced the same type of hazardous behaviour from drivers that needs to be addressed was the location at which overtaking sections ended, as well as the location at which two lanes merged into one. At both these scenarios, drivers were observed to increase speed and attempt hazardous overtaking manoeuvres in order to pass one last vehicle or make up as much time as possible. The majority of high risk overtaking manoeuvres and the most hazardous behaviour were recorded during the above mentioned scenarios.

Firstly addressing the location at which overtaking sections ended. The primary reason for the road markings not permitting overtaking, was due to the road layout not allowing a long enough sight distance for completing a successful overtaking manoeuvre at crests, troughs or horizontal curves along the route. It was observed that sections permitting overtaking manoeuvres ended too close to crests, troughs and horizontal curves. Numerous vehicles were observed to attempt overtaking manoeuvres in the last 50 metres of such sections, knowing that the manoeuvre will not be completed before entering a section on which overtaking is prohibited. The greatest concern with these manoeuvres, was that they often took place near horizontal curves and crests and the sight distance were not sufficient to conduct such a manoeuvre. For this reason, numerous of such cases almost ended in an accident.It was therefore at these locations that the greatest amount of perception and decision errors were recorded, almost as if drivers did not consider the likelihood of oncoming traffic in the opposite lane. By moving the point at which overtaking is no longer permitted to a point further away from the crest, trough or horizontal curve is estimated to decrease the occurrence of overtaking manoeuvres being conducted too close to crests, troughs and horizontal curves.

Having two lanes in the same direction provide safe opportunities for vehicles to pass one another without much risk and is often provided at long uphill sections in order to provide faster moving vehicle to overtake slower ones without much risk involved. The concern was therefore only at the point at which the two lanes merged, which was often just before a crest, at the crest point itself or just after the crest. When the lanes merged either before or on the crest, it presented the situation of drivers conducting high risk overtaking manoeuvres, but when the two lanes merged after the crest, drivers were more conservative in their behaviour. Therefore the best solution with regards to this issue would be to move the point at which the lanes merge to after the crest, and therefore decreasing the occurrence of hazardous behaviour being exercised at the point where two lanes merge.

The main cause for drivers to attempt such high risk manoeuvres at these locations, was primarily attributed to the lack of capability of drivers to think ahead and therefore failed to consider the probability of oncoming traffic on the other side of the crest. Therefore the inability to physically see the risk caused a failure in accurately assessing the consequences of their actions. The majority of high risk overtaking manoeuvres were therefore attributed to perception and decision errors of drivers, but this failure was likely to be assisted by some sort of failure within the roadway design.

Furthermore, the affect of speeds on the psychological state of drivers seemed to pose a major problem - when the road design is of such a kind as not to encourage high speeds, the speeds of slower moving vehicles will decrease as well, which in turn will influence a further decrease in speeds of faster moving vehicles and therefore adding to the frustration of drivers. This seemed to leave only two options, either design the road to discourage faster speeds and risk drivers growing more frustrated and agitated due to the loss of time, or design the road as to allow drivers to travel at faster speeds in order to minimize frustration and risk causing more accidents due to higher speeds. These scenarios therefore seemed to leave very little room for optimism, but this was not the case.

When only considering the short term psychological state of motorists, there seemed to be little hope, but when considering the long term affect of roadway elements on the psychological state of drivers, the situation became more hopeful. A decrease in the speed limit may seem to have a negative immediate affect on the psychological state of drivers, but it is likely to serve as a positive influence in the long term. A decrease in the posted speed limit may have a very positive affect on the psychological state of drivers, as at the current stage, drivers are attempting to drive at speeds close to the posted speed limit, which often leads to drivers being agitated, as they fail to achieve such speeds. Therefore, contrary to what may be believed, a decrease in the speed limit may serve to decrease the frustration and agitation levels of drivers. That being said, the presence of law enforcement may also serve to assist in insuring that drivers adhere to the change in speed limit.

Chapter 6

CONCLUSION

When aiming to improve the road safety of any given roadway section, it is important to always take into consideration both the preceding psychological state of drivers in that area as well as the effect that the roadway elements will have on the current psychological state of drivers.

From the results obtained in this study, it was concluded that a total of three roadway and environmental elements contributed to dangerous overtaking manoeuvres being conducted, with an additional factor having the capability of assisting in the reduction in dangerous behaviour. Environmental in this sentence refers to anything that is not the individual self, nor part of the roadway design. Therefore roadway elements refers to roadway design elements.

The first roadway design element that contributed to dangerous overtaking manoeuvres being conducted, was the speed limit. This may seem a strange one, but it has been noted that drivers consider the posted speed limit more as an indication of the speed that they should be travelling, rather than the actual speed limit above which you should not travel. For this reason drivers compare their own speeds to that of the posted speed limit and aim to attain that speed. It was often found that vehicles were not capable of driving at speeds close to the posted speed limit due to the presence of slower moving vehicles on the road. The end result in numerous of such cases, were driver attempting dangerous overtaking manoeuvres in order to drive at higher speeds, or at least close to the posted speed limit.

The second roadway design element was the road markings and overtaking either being permitted or prohibited by it. During the course of this study, it was observed that numerous drivers to not adhere to the law as stipulated by the road markings and this can be attributed to two major reasons: firstly, the law enforcement very seldom enforces this law in South Africa and secondly, poor positioning of sections on which overtaking is prohibited result in drivers losing their confidence in the road markings as a good indication of where to overtake. As mentioned previously, some participants of the questionnaire also confirmed this. Therefore drivers should be able to perceive why overtaking is prohibited at certain areas, otherwise they will stop adhering to it.

The third element, and the first environmental elements, was the behaviour of other motorists in the vicinity. It was discovered that some actions of drivers encouraged, and other discouraged other drivers to drive behave more dangerously or not. As an example would be when a leading vehicle drives on the hard shoulder to give way for a faster moving vehicle, the leading driver is encouraging the following driver to conduct an overtaking manoeuvre. In the same manner, when an individual perceives others conducting and completing certain manoeuvres, it may serve to encourage that individual to attempt the same.

Every one of the above mentioned factors is likely contribute to dangerous overtaking manoeuvres, but it is when these three factors all happen at once when it results in the greatest contribution to dangerous overtaking manoeuvres. This can be seen by considering the difference in behaviour recorded on the N2 and the R44. The difference in design and also social norm are two major contributing factors to more dangerous behaviour being recorded on the R44 than the N2.

6.0.1 Recommendations

The first suggestion would be to lower the speed limit of all three roadways to 90 km/h. This will serve to bring down the absolute speeds of faster moving vehicle and also lower the difference in speed between faster and slower moving vehicles. A further result will be that it will decrease the desire for drivers to increase their speeds in order to drive at speeds close to the speed limit due to the speed limit being lower, which will assist in decreasing any negative effect of the road design on the psychological state of drivers.

A second suggestion is to move the point where the road markings change from permitting overtaking to prohibiting further away from horizontal curves or crests. It is likely that the kind of behaviour currently exhibited at these locations will continue in the future. Therefore moving this point further away from the curve or crest will give drivers more time to respond to any unforeseen events.

Thirdly is that there is a large need for the accurate application of law enforcement in South Africa. If this can be improved as it was seen on the N2, this could hold great advantages to the safety of South African roads.

How to best approach each of these points were not addressed in great detail and it is recommended that future research be conducted with regards to this.

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Appendix A

Elevation Profiles

A.1 R44 Elevations

The first two parameters of table A.1, (starting km and end km), are the measurements along the x-axis at which every uphill section starts and ends. The measurements were taken from the southern most point of the carriageway section. The starting and end heights are the vertical height above sea level at the beginning and end of each uphill section. From these measured parameters, the length of each uphill section, the difference in height from the beginning to the end of each section, as well as the gradient of each incline were calculated.

Table A.1: R44 Northbound Uphill Sections

Incline	**1**	**2**	**3**	**4.1**	**4.2**	**4.3**	**5**
Starting km	1.09 km	2.8 km	3.88 km	5.78 km	6.57 km	7.35 km	9.33 km
End km	2.57 km	2.97 km	5.25 km	6.57 km	7.35 km	7.98 km	9.64 km
Starting height	157 m	210 m	171 m	199 m	239 m	252 m	208 m
End height	214 m	218 m	209 m	239 m	252 m	279 m	214 m
Length	1480 m	170 m	1370 m	790 m	780 m	630 m	290 m
Height	57 m	8 m	38 m	40 m	13 m	27 m	6 m
Gradient	3.85 %	4.71 %	2.77 %	5.06 %	1.67 %	4.29 %	2.07 %
Length'				2200 m			
Height'				80 m			
Gradient'				3.64 %			

Figure A.1 indicates the locations of the various uphill sections when travelling in a southbound direction, while table A.2 is the summary of the characteristics of these sections. The parameters found in this table has the same characteristics as in table A.1, with the only difference being that vehicles moving southbound is moving from right to left in on the elevation profile, thus the x-coordinate of the beginning of an uphill section will be greater than the x-coordinate at the end.

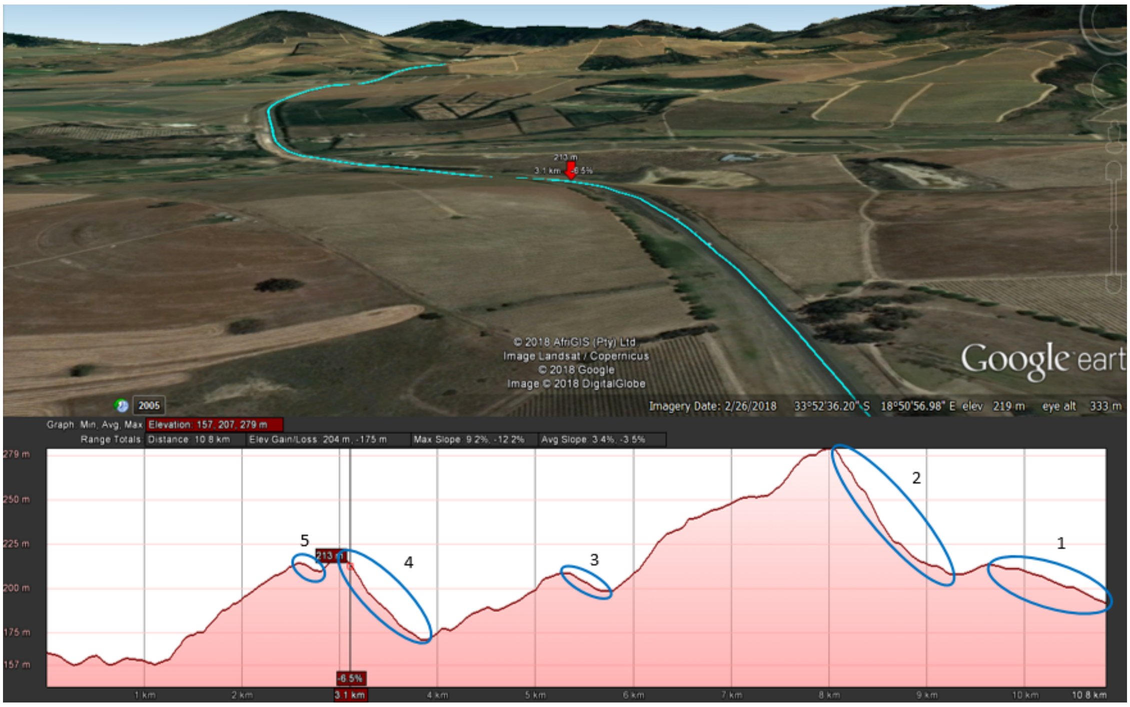

Figure A.1: R44 Southbound Uphill Sections

Table A.2: R44 Southbound Uphill Sections

Incline	**1**	**2**	**3**	**4**	**5**
Starting km	10.8 km	9.25 km	5.67 km	3.83 km	2.75 km
End km	9.63 km	8 km	5.31 km	2.98 km	2.58 km
Starting height	192 m	208 m	199 m	171 m	210 m
End height	214 m	279 m	209 m	218 m	214 m
Length	1170 m	1250 m	360 m	850 m	170 m
Height	22 m	71 m	10 m	47 m	4 m
Gradient	1.88 %	5.68 %	2.78 %	5.53 %	2.35 %

A.2 N2 Elevations

Table A.3: N2 Uphill Sections for Motorists Travelling Eastbound

Incline	X1 (km)	X2 (km)	H1 (m)	H2 (m)	L (m)	H' (m)	Gradient
U1	0.07	0.31	249	253	240	4	1.67%
U2	0.9	1.01	234	236	110	2	1.82%
U3	1.53	2.08	224	257	550	33	6.00%
U4.1	3.02	3.44	235	253	420	18	4.29%
U4.2	3.44	3.67	253	256	230	3	1.30%
U5	4.01	4.97	250	293	960	43	4.48%
U6	5.18	5.57	284	319	390	35	8.97%
U7	6.24	6.63	280	288	390	8	2.05%
U8	7.74	7.84	262	268	100	6	6.00%
U9	8.26	8.55	262	274	290	12	4.14%
U10	8.66	8.98	268	274	320	6	1.88%
U11	9.05	9.12	269	275	70	6	8.57%
U12	10.3	10.45	256	263	150	7	4.67%
U13	10.85	10.95	246	250	100	4	4.00%
U14.1	11.3	11.4	231	237	100	6	6.00%
U14.2	11.4	11.9	237	247	500	10	2.00%
U15	12.3	12.4	240	244	100	4	4.00%
U16	13.8	14.2	222	237	400	5	1.25%
U17.1	15.95	16.35	201	208	400	7	1.75%
U17.2	16.35	16.5	208	217	150	9	6.00%
U18	16.9	17.5	201	214	600	13	2.17%

Table A.4: N2 Uphill Sections for Motorists Travelling Westbound

Incline	X1 (km)	X2 (km)	H1 (m)	H2 (m)	L (m)	H' (m)	Gradient
D1	18.35	17.40	187	215	950	28	2.95%
D2	16.9	16.65	201	218	250	17	6.8%
D3.1	15.95	15.65	201	211	300	10	3.33%
D3.2	15.65	14.85	211	224	800	13	1.63%
D4	14.70	14.55	224	227	150	3	2.00%
D5	13.80	12.68	222	244	1120	22	1.96%
D6	12.30	11.90	240	247	400	7	1.75%
D7	11.30	10.95	231	250	350	19	5.43%
D8.1	10.85	10.55	246	261	300	15	5.00%
D8.2	10.55	10.45	261	263	100	2	2.00%
D9.1	10.30	10.20	256	262	100	6	6.00%
D9.2	10.20	9.34	262	273	860	11	1.28%
D10	9.25	9.12	269	275	130	6	4.62%
D11	9.05	8.92	269	274	130	5	3.85%
D12	8.66	8.55	268	274	110	6	5.45%
D13	7.95	7.84	262	268	110	6	5.45%
D14.1	7.67	6.89	263	284	780	21	2.69%
D14.2	6.78	6.63	284	288	150	4	2.67%
D15.1	6.24	6.08	280	304	160	24	15.00%
D15.2	6.08	5.57	304	319	510	15	2.94%
D16	5.18	4.97	284	293	210	9	4.29%
D17	4.00	3.67	250	256	330	5	1.82%
D18.1	3.02	2.80	235	246	220	11	5.00%
D18.2	2.80	2.08	246	257	720	11	1.53%
D19	1.53	1.02	224	236	510	12	2.35%
D20.1	0.90	0.66	234	248	240	14	5.83%
D20.2	0.66	0.37	248	254	290	6	2.07%

Appendix B

Traffic Volume Figures and Tables

Figure B.1 is a representation of the level of service for the various roads indicated in figure 3.8.

on some of the roads within the Stellenbosch municipal region. Different colours have been provided for differing ranges of traffic volumes travelling on the various roads. Table 3.1 shows the different volume ranges for the colours represented in figure 3.8.

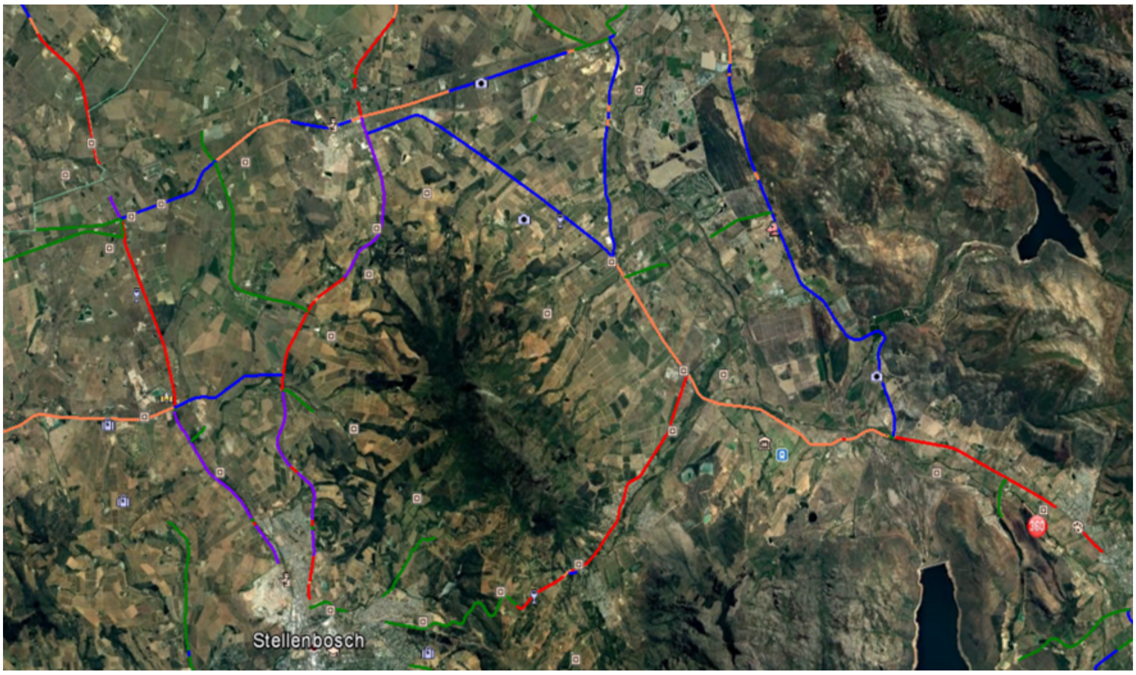

Figure B.1: Stellenbosch Municipal Roads Level of Service

Table B.1: Level of Service Colours

Colour	Level of Service
	A
	B
	C
	D
	E

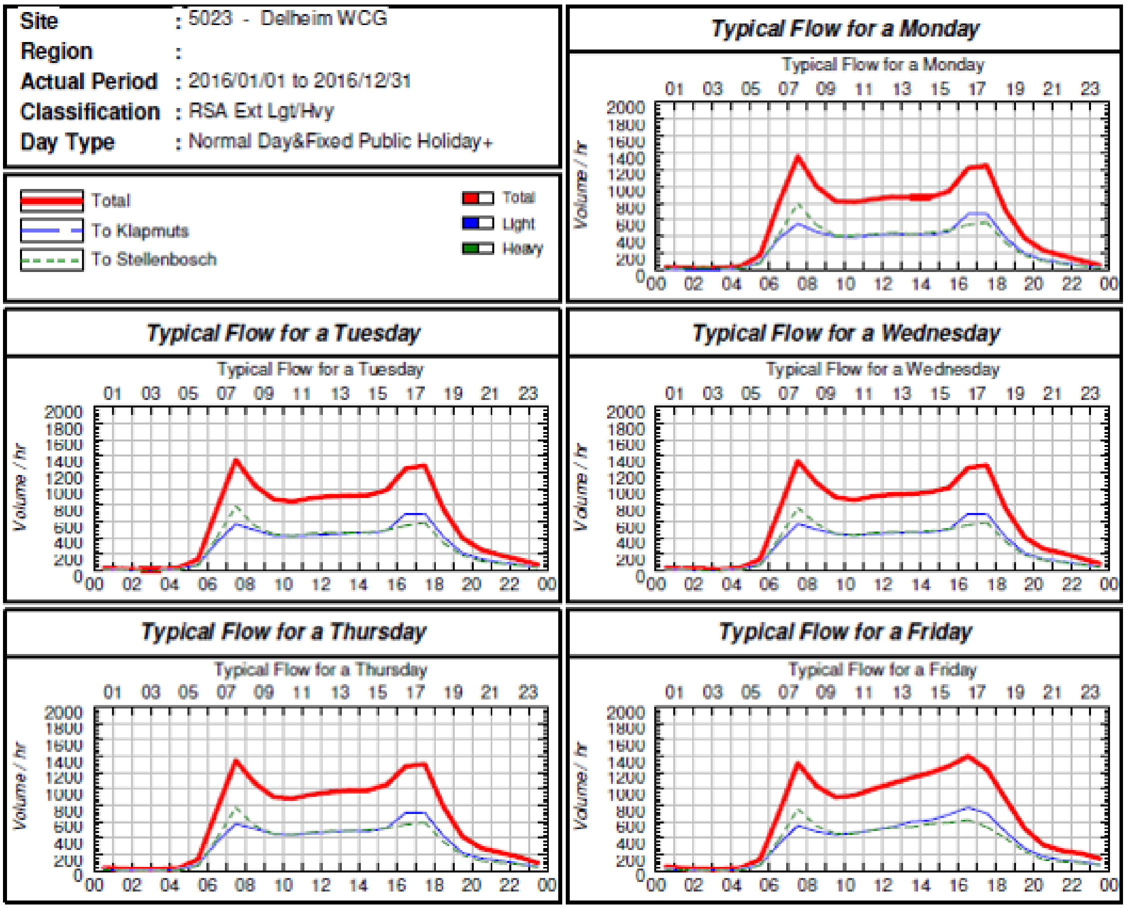

Figure B.2: Average Weekly Volumes on the R44 for 2016

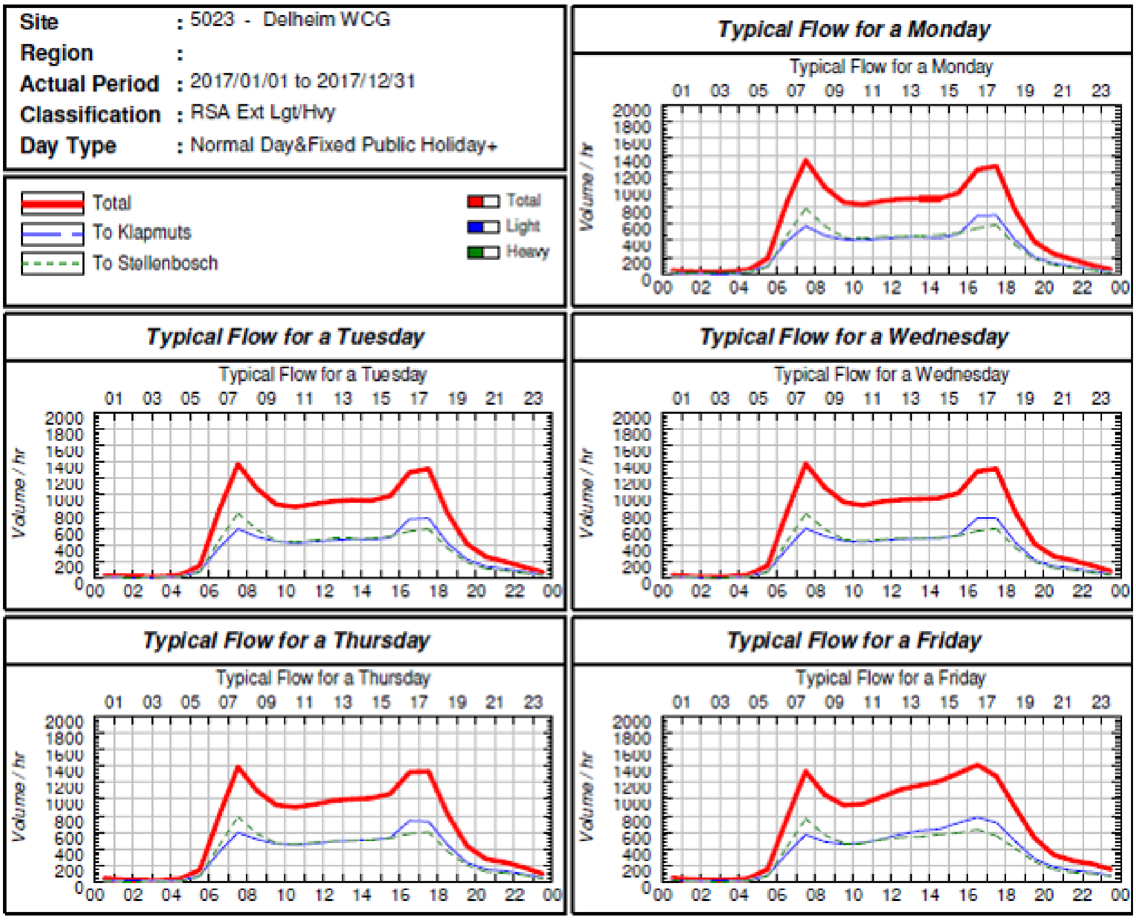

Figure B.3: Average Weekly Volumes on the R44 for 2017

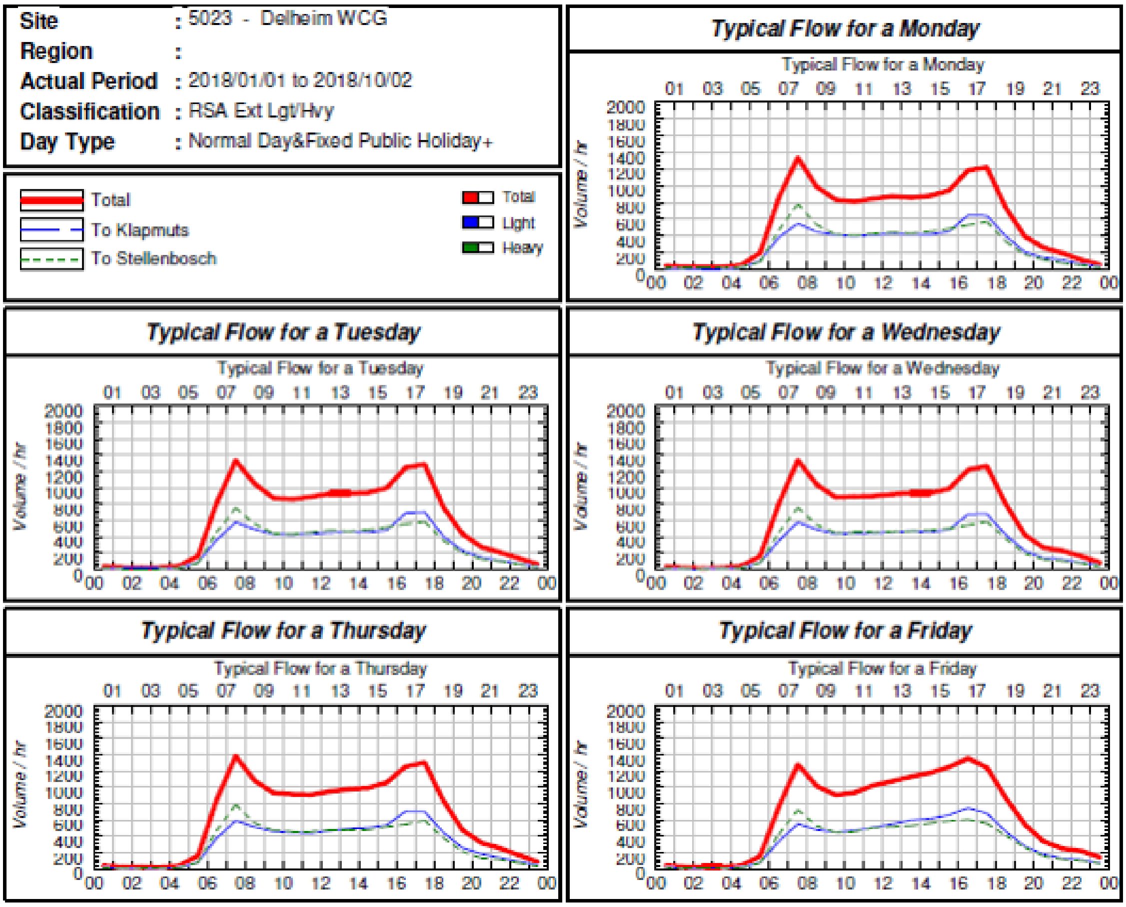

Figure B.4: Average Weekly Volumes on the R44 for 2018

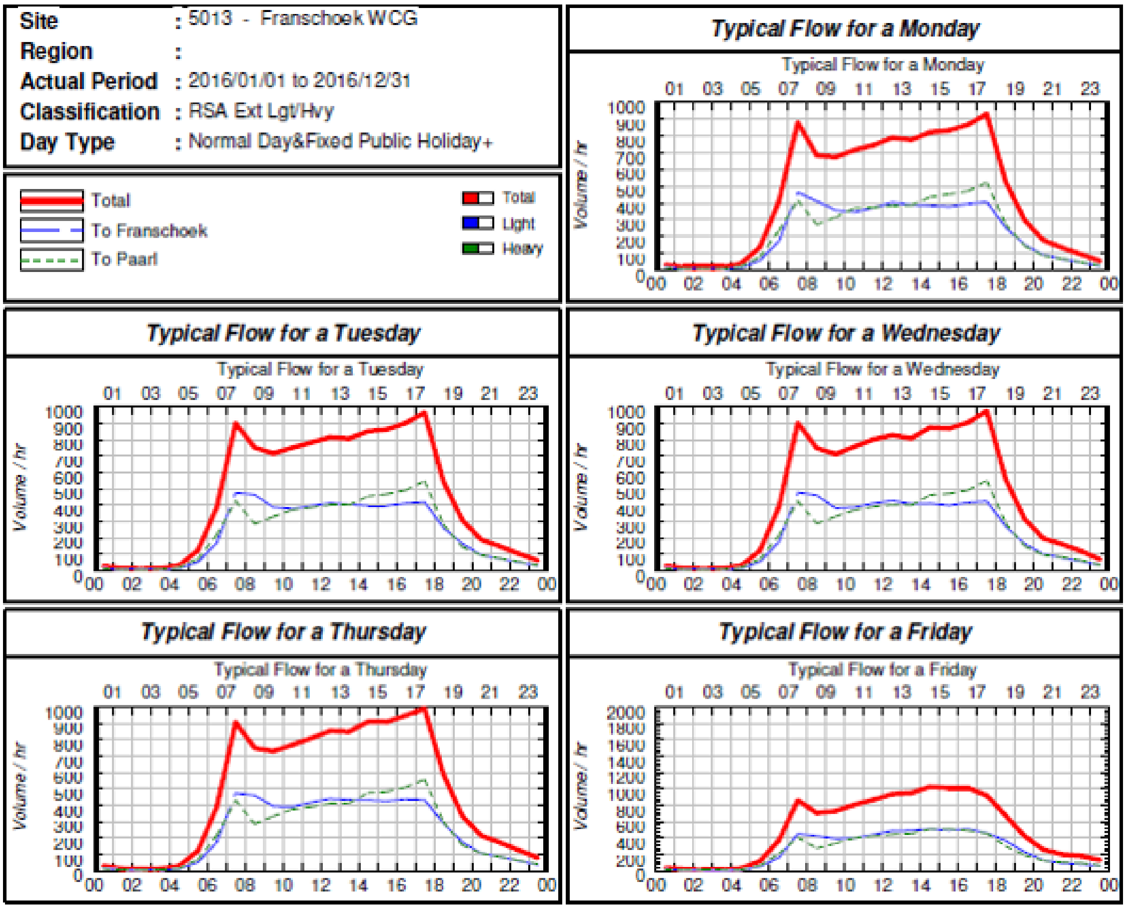

Figure B.5: Average Weekly Volumes on the R45 for 2016

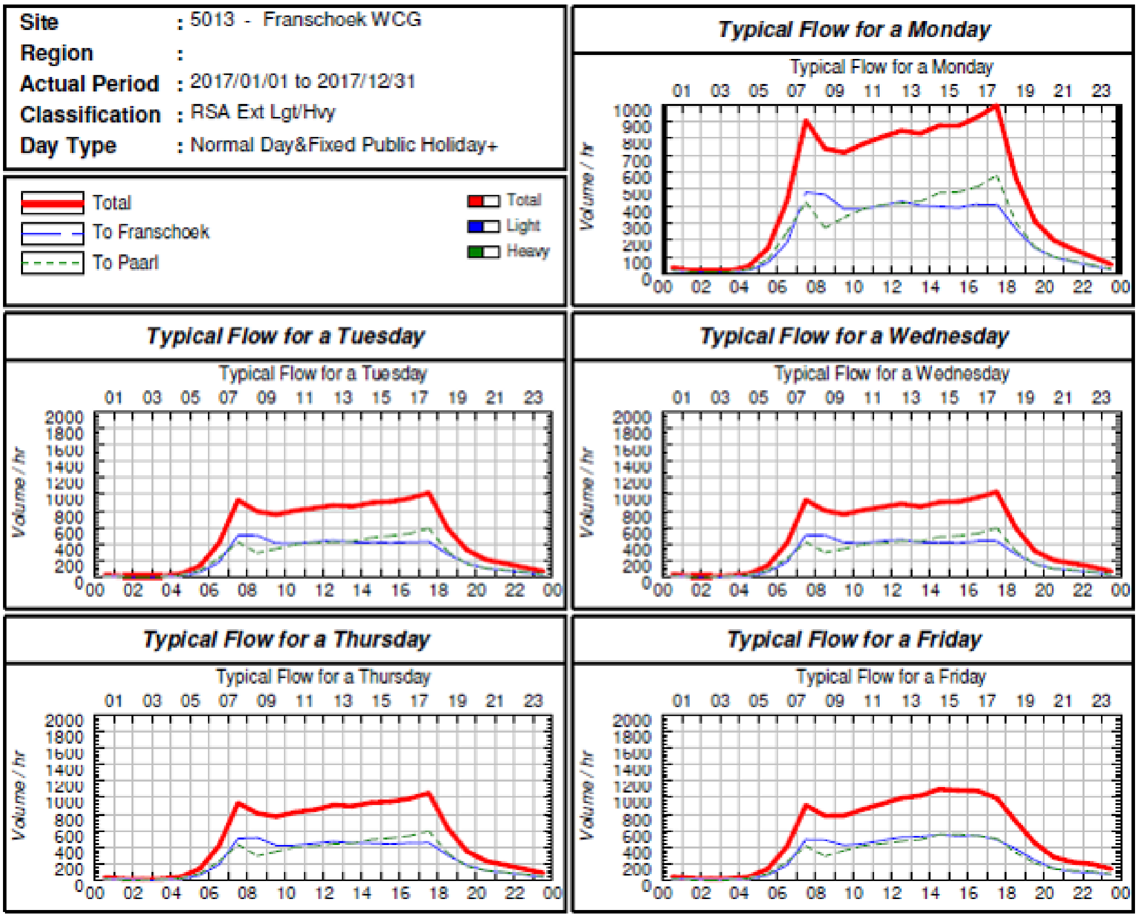

Figure B.6: Average Weekly Volumes on the R45 for 2017

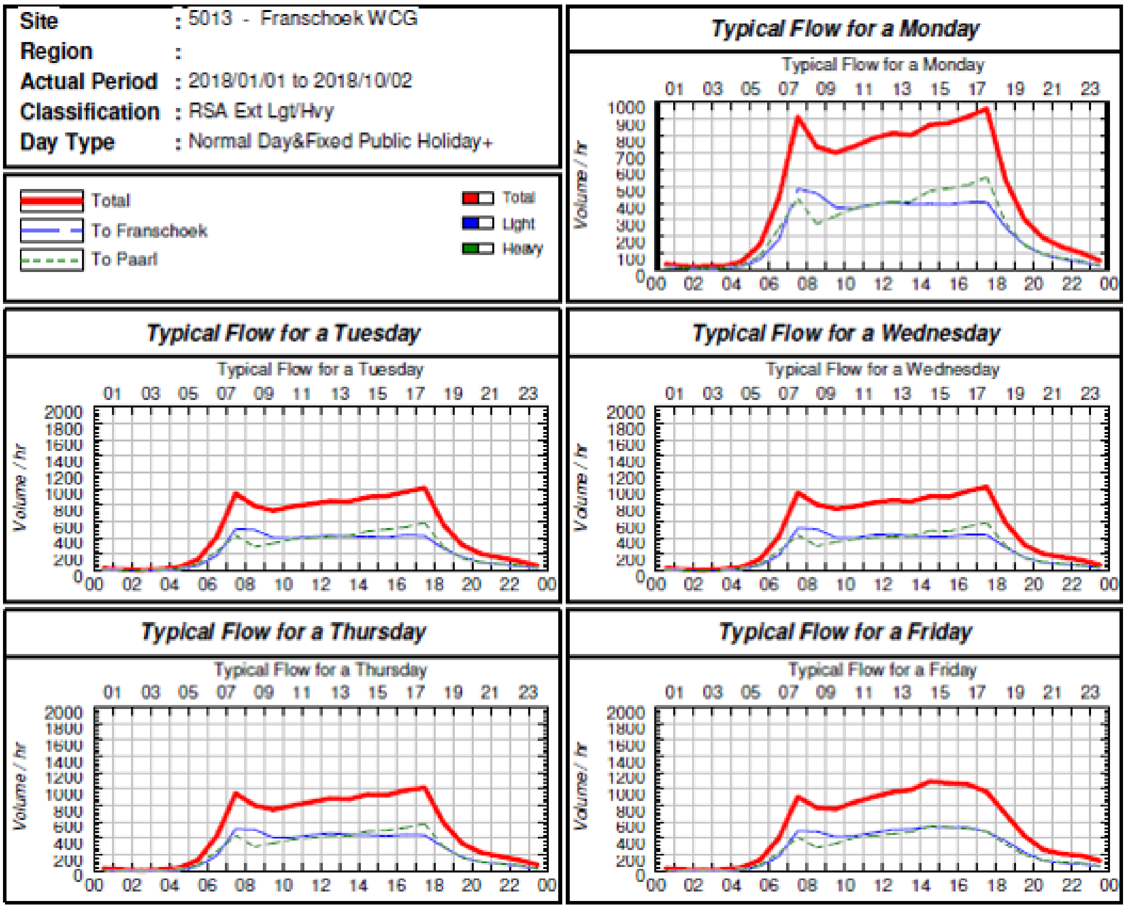

Figure B.7: Average Weekly Volumes on the R45 for 2018

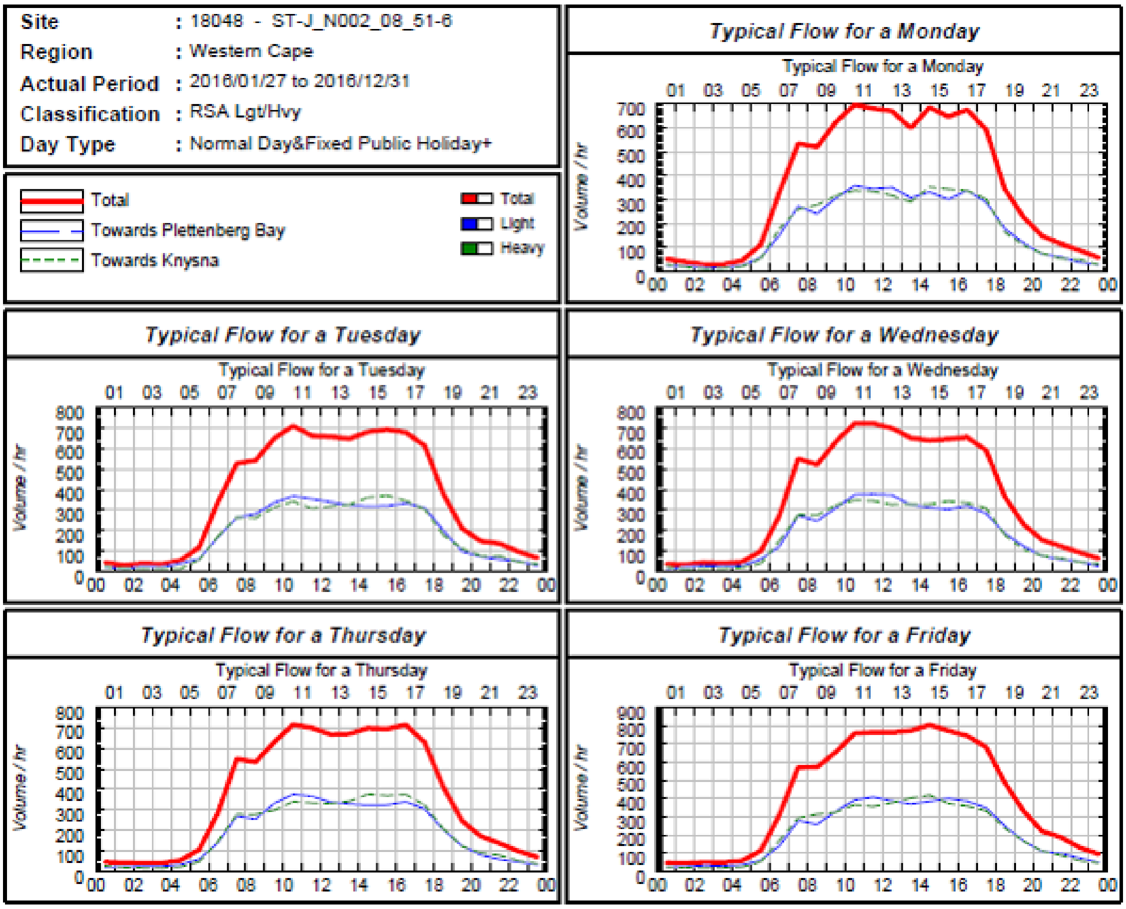

Figure B.8: Average Weekly Volumes on the N2 for the 2016 period

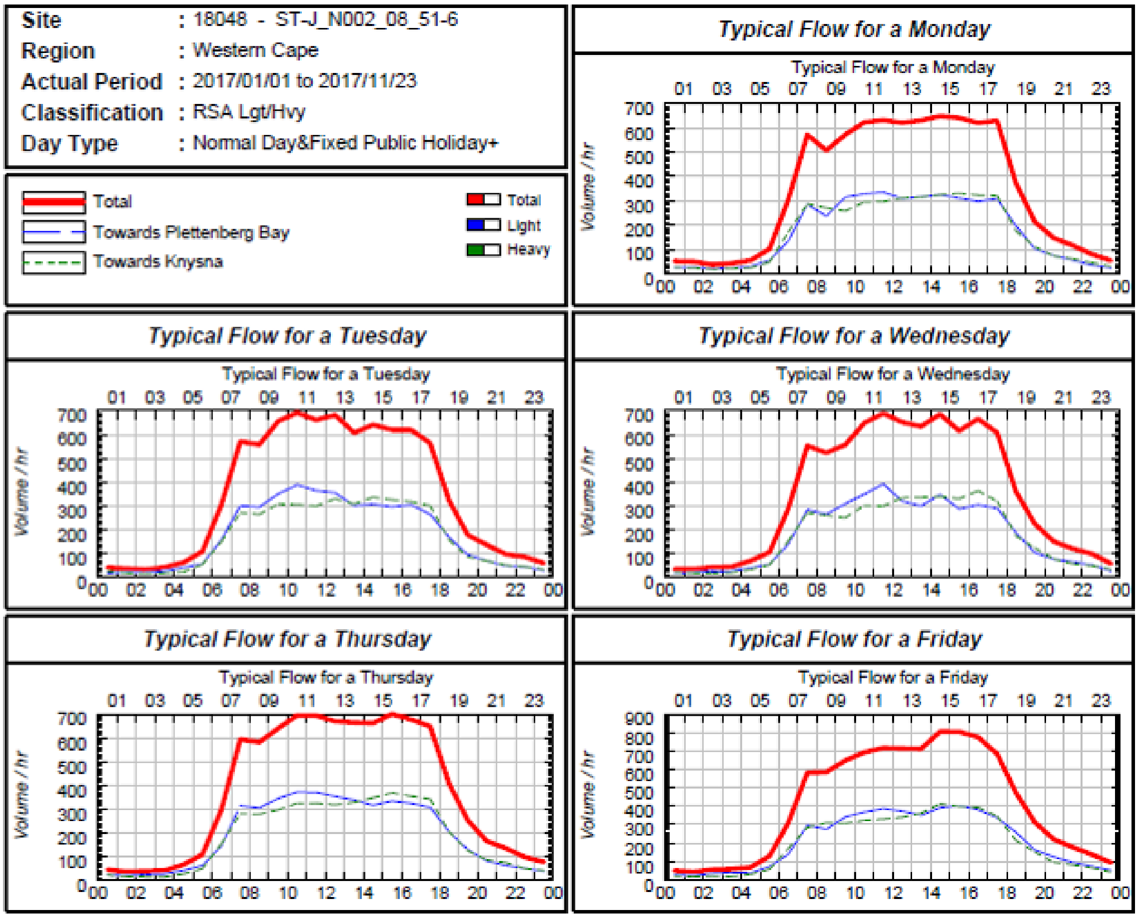

Figure B.9: Average Weekly Volumes on the N2 for the 2017 period

Appendix C

Vehicle Speed Figures

C.1 R44 Speed Figures

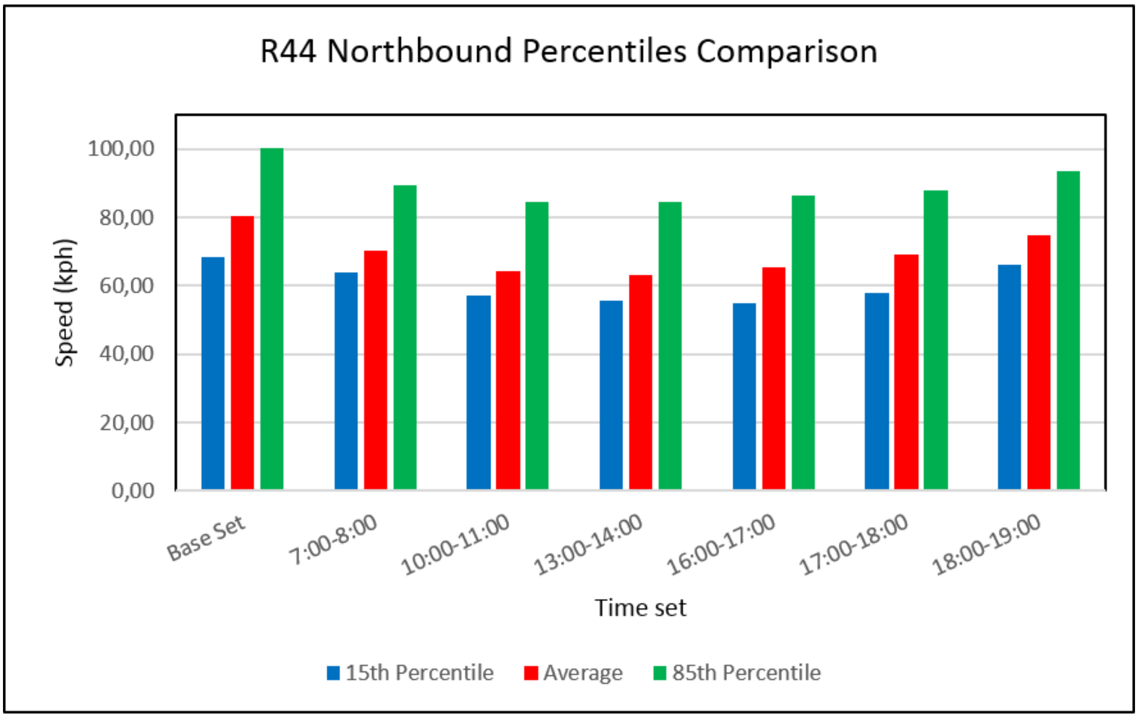

Figure C.1: R44 Northbound Percentiles Comparison

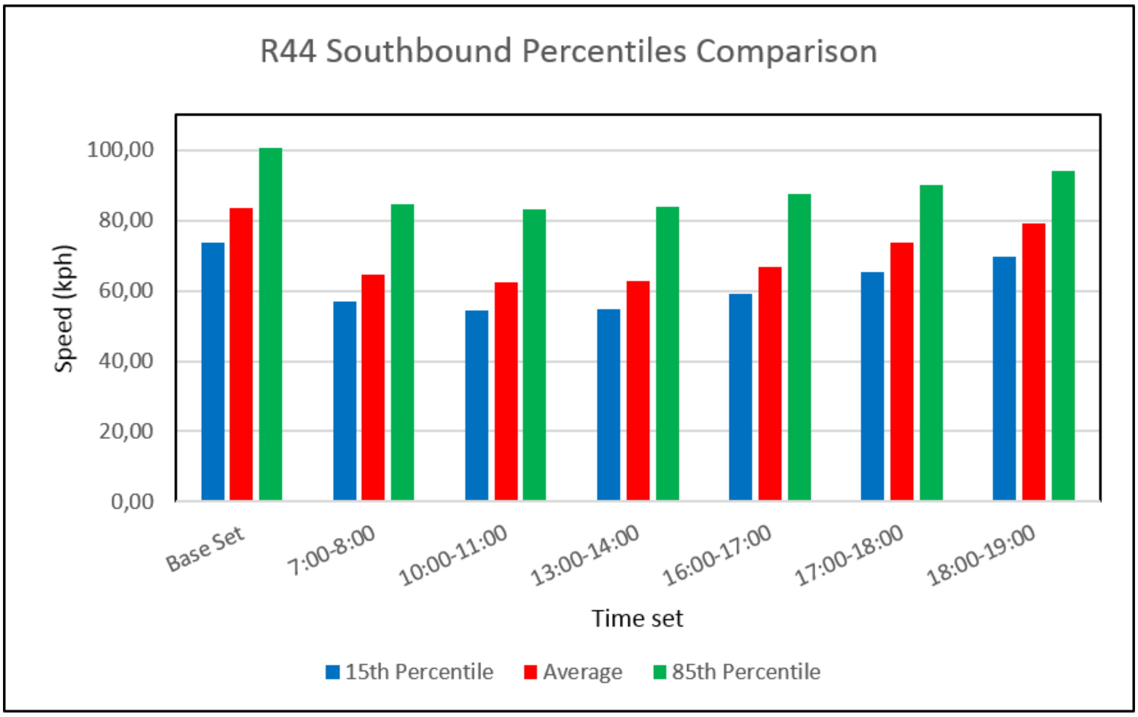

Figure C.2: R44 Southbound Percentiles Comparison

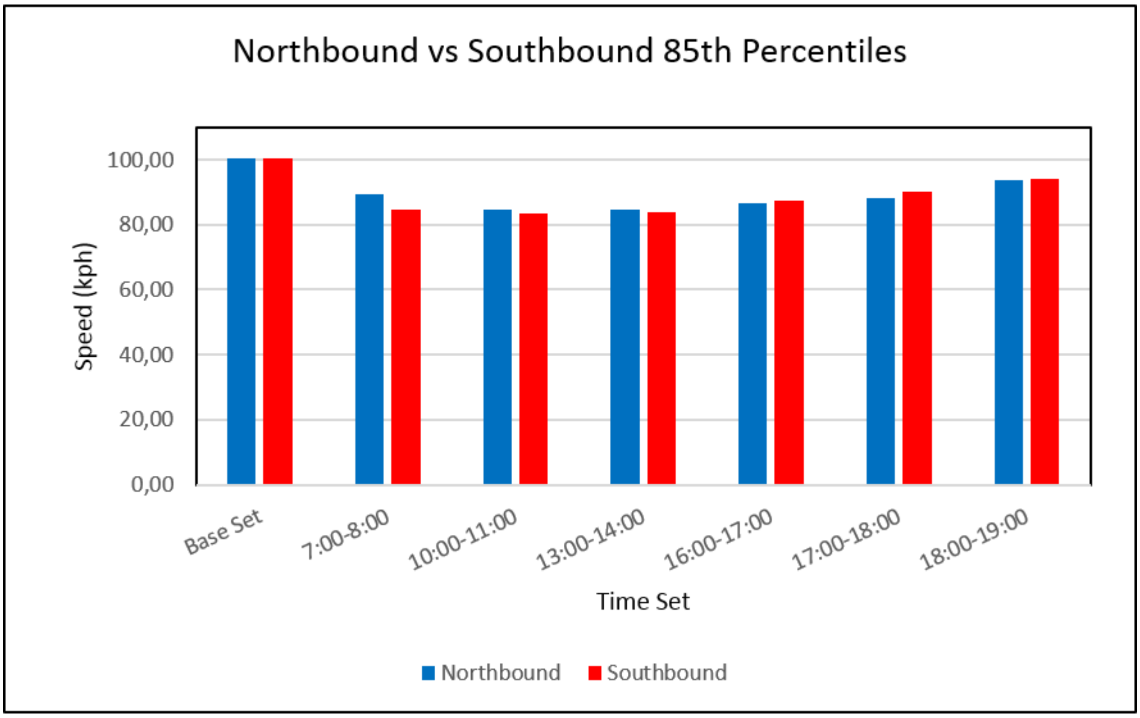

Figure C.3: R44 Northbound vs Southbound 85th Percentile Speeds

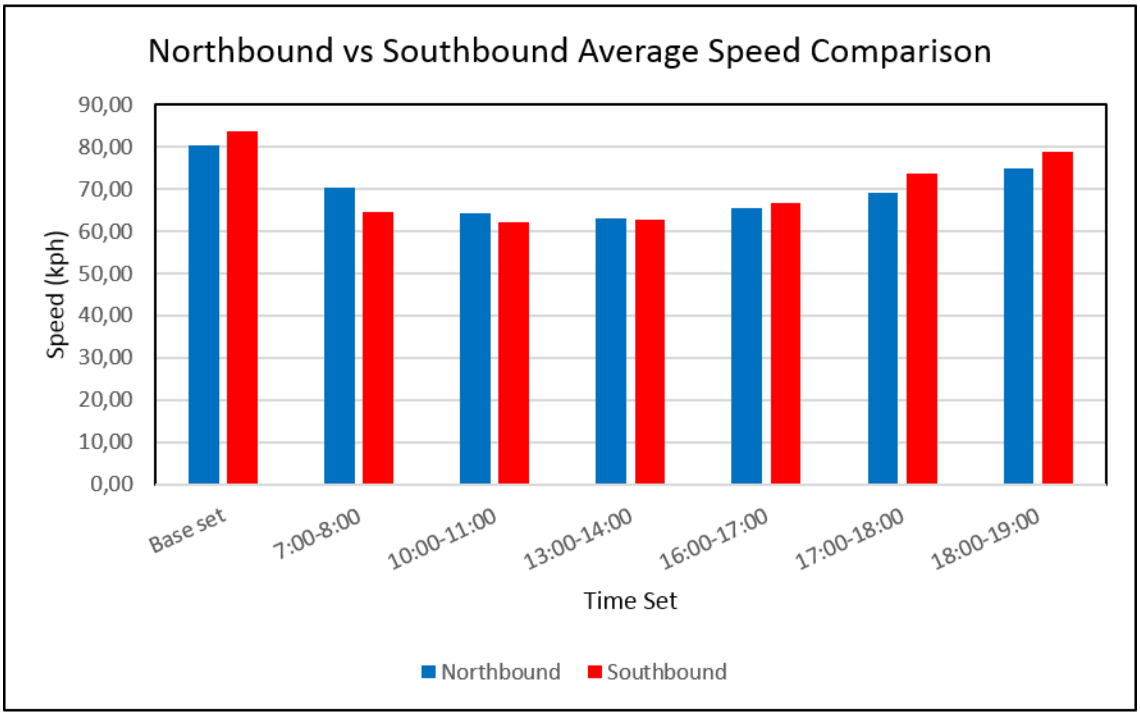

Figure C.4: R44 Northbound vs Southbound Average Speeds

C.2 R45 Speed Figures

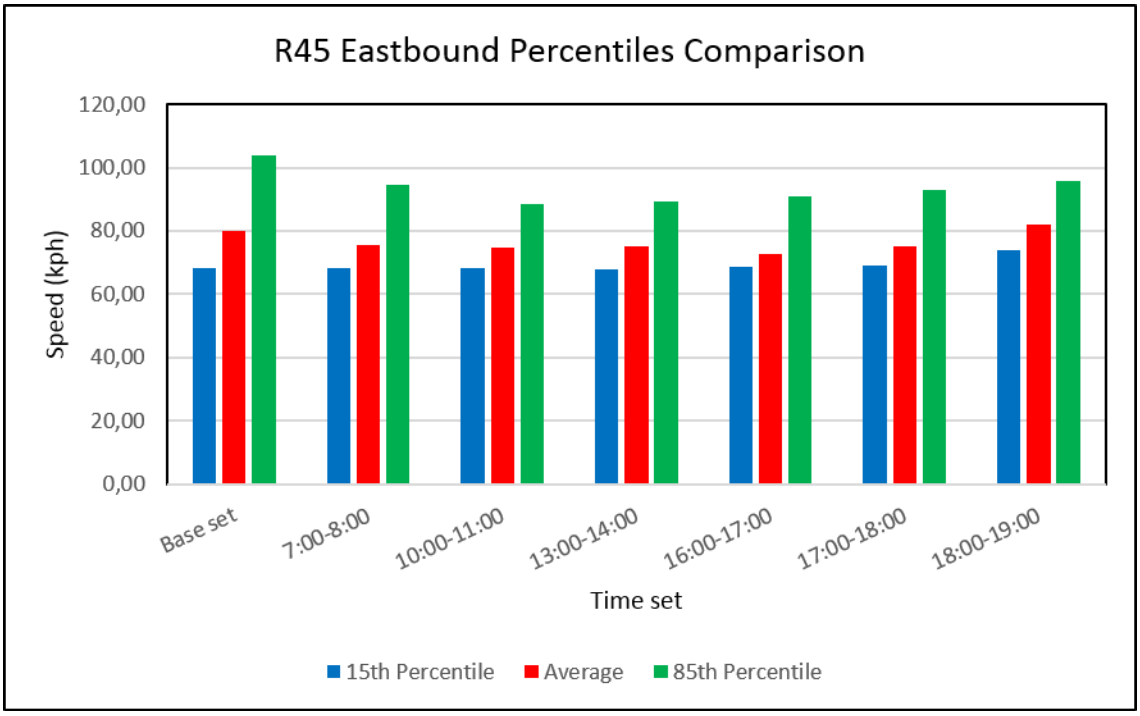

Figure C.5: R45 Eastbound Percentiles Comparison

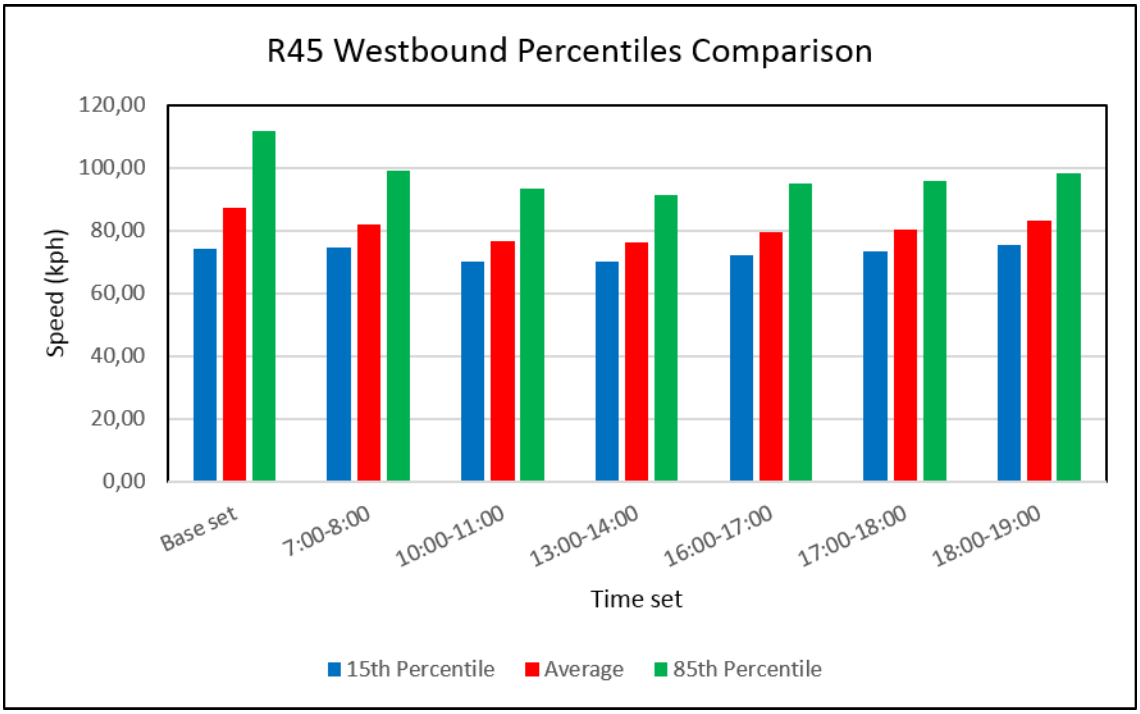

Figure C.6: R45 Eastbound 85th Percentile Speeds Along Route

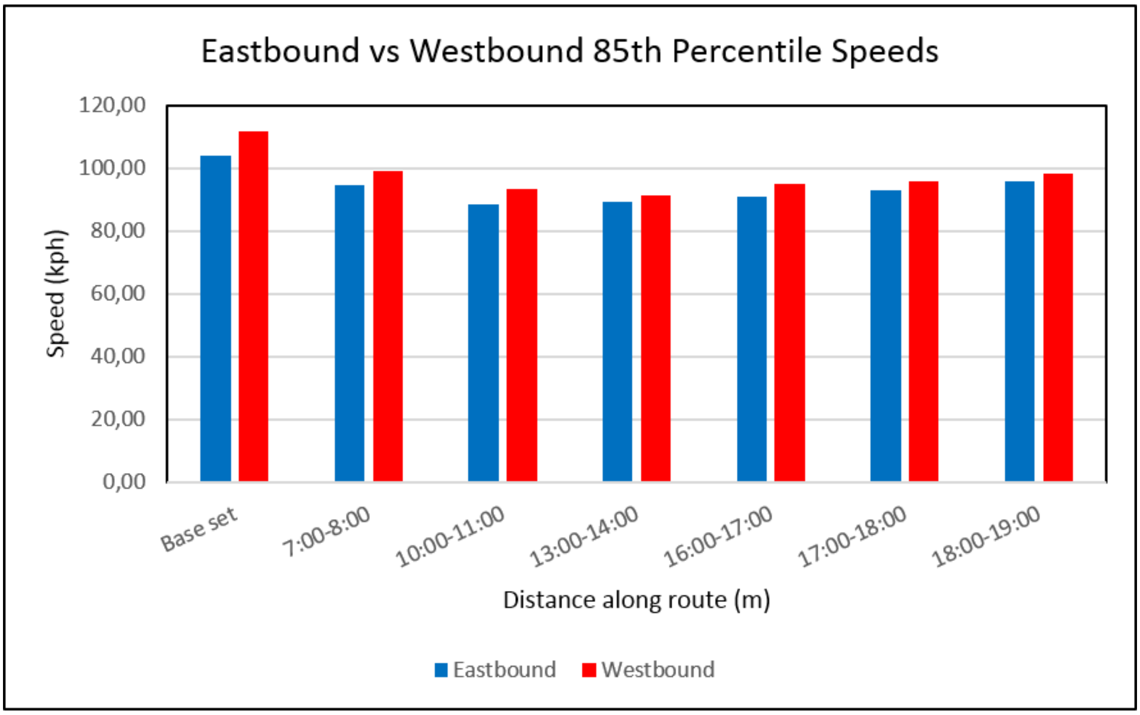

Figure C.7: R45 85th Percentile Speeds Comparison for Eastbound vs Westbound

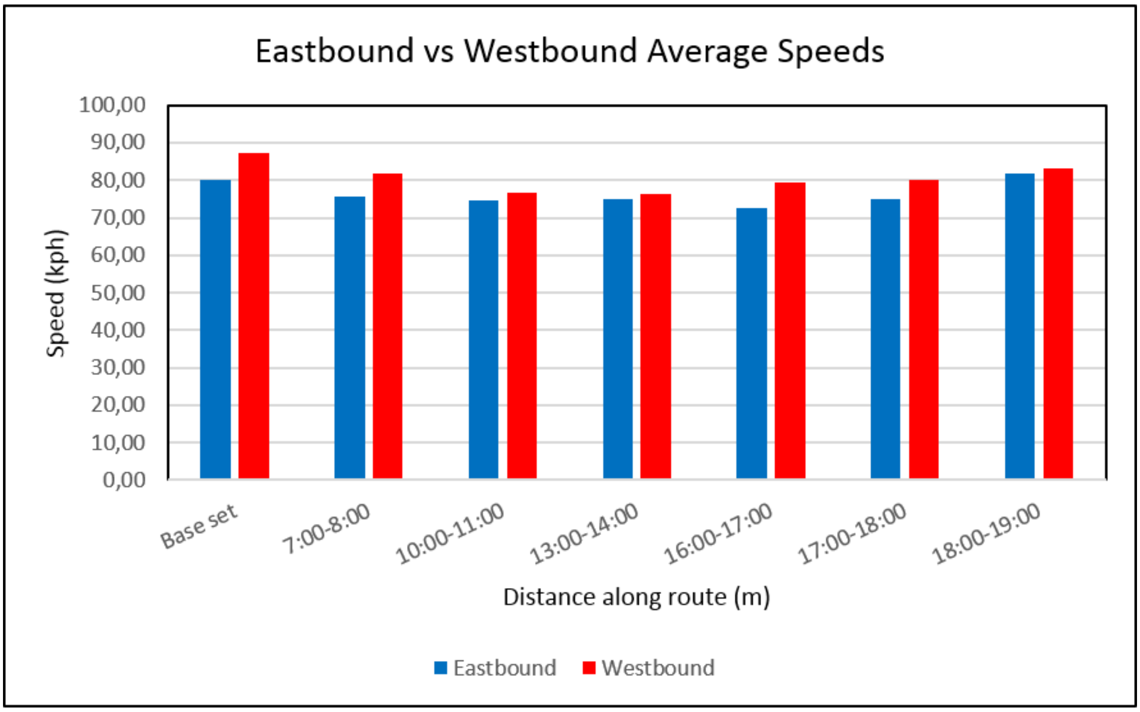

Figure C.8: R45 Average Speeds Comparison for Eastbound vs Westbound

C.3 N2 Speed Figures

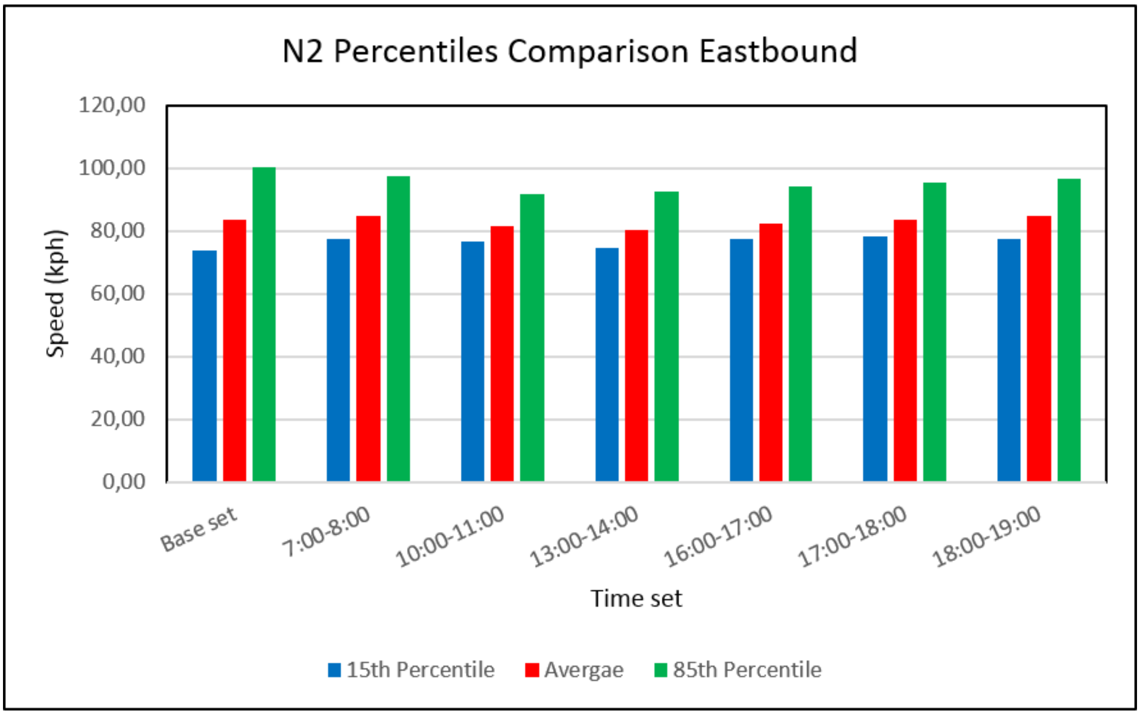

Figure C.9: N2 Eastbound Percentiles Comparison

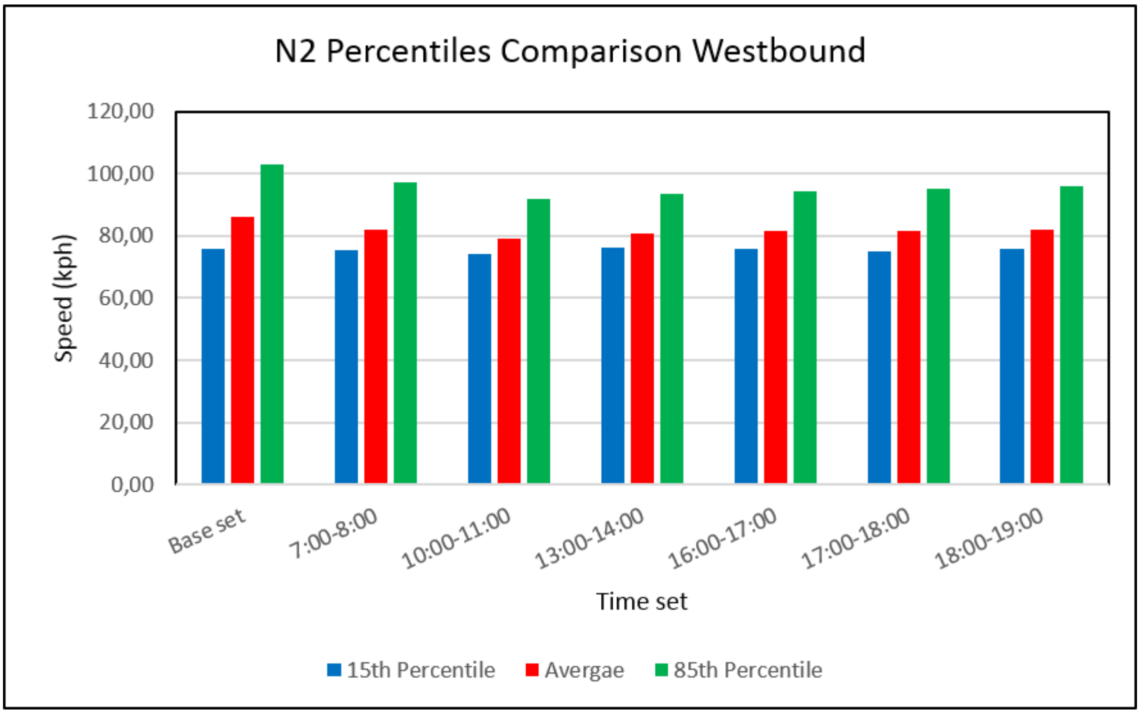

Figure C.10: N2 Eastbound 85th Percentile Speeds Along Route

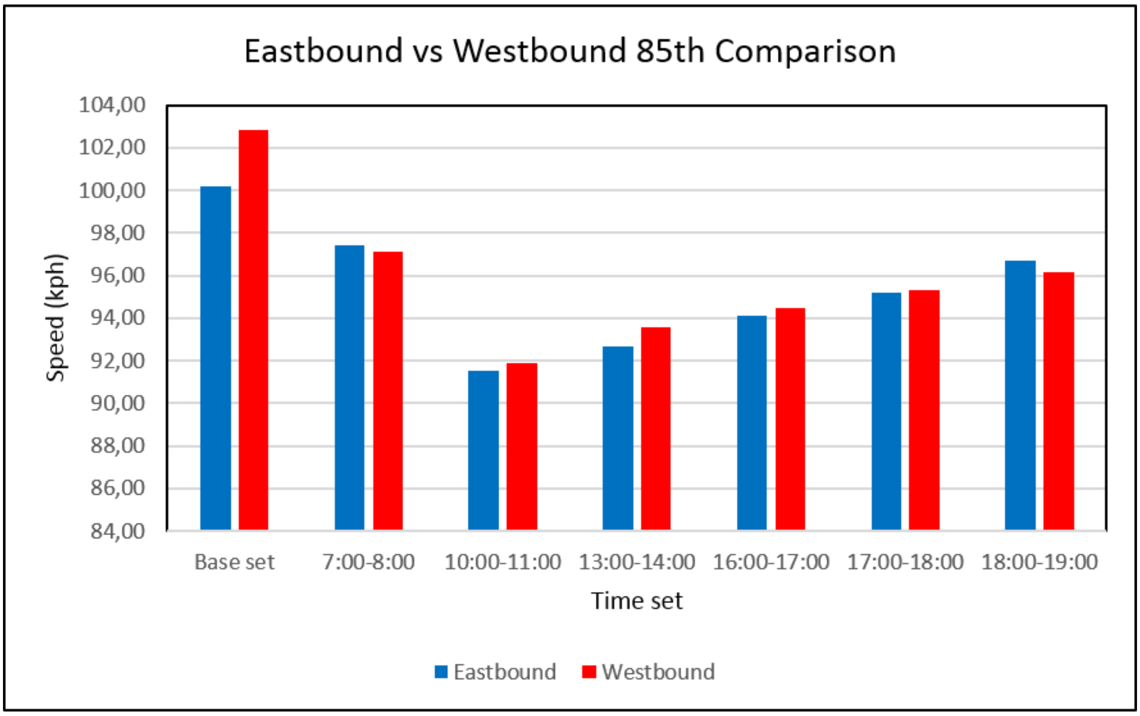

Figure C.11: N2 85th Percentile Speeds Comparison for Eastbound vs Westbound

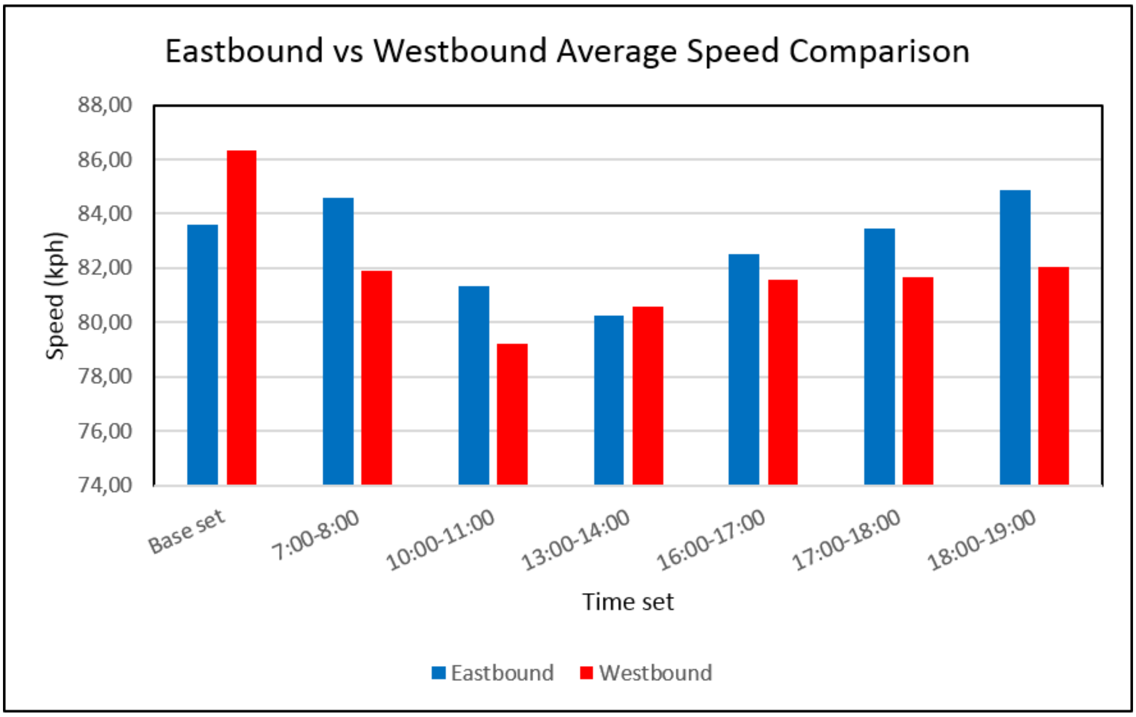

Figure C.12: N2 Average Speeds Comparison for Eastbound vs Westbound

Appendix D

Questionnaire