Restricting freight traffic in urban areas:

The economic and traffic impact of banning heavy vehicle movement in Stellenbosch during peak periods

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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

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"Research is formalised curiosity. It is poking and prying with a purpose"

- Zora Neale Hurston

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.

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ABSTRACT

Whenever new traffic regulations are proposed for implementation, it is crucial to investigate the effects that they will have on the operations of the transportation network. In this study, the potential impact of heavy vehicle restrictions in urban areas, as proposed by the South African Department of Transportation in 2015, was investigated. No evidence could be found to indicate that there had been any research performed into the effects of such restrictions before, or since, this proposal was made. Therefore, this study aimed to fill this gap. Although the regulations were proposed in an attempt to improve road safety, the focus of this study lies on the potential impact of the regulations on traffic conditions and the economy.

Two main areas of research were addressed in this study; the first being the investigation of the current heavy vehicle movement patterns in Stellenbosch, and the second being the assessment of the impact of heavy vehicle bans on the traffic operations on the town's road network. It was determined that almost no research had been performed in the past regarding the movements of freight vehicles in Stellenbosch and, therefore, this study aimed to fill this gap. Fleet management data from MiX Telematics and vehicle movement surveys were analysed for this purpose. From the analysis of fleet management data, the temporal and spatial distribution patterns of freight vehicles in Stellenbosch were determined. It was found that the majority of freight vehicles in Stellenbosch travel during the day and that the R44 and Bird Street are two of the most used roads for freight trips. The vehicle movement surveys found that the majority of freight trips in the town originate locally or in nearby towns.

The potential impact of heavy vehicle bans on traffic conditions were investigated with the use of a microscopic traffic model constructed in PTV Vissim. The model examined the potential effects of the proposed bans on the transportation network of Stellenbosch in both the cases that latent demand was present in the town and the case where it was not. It was found that traffic conditions generally improved when latent demand was not present, but it worsened when latent demand was present. Even when traffic conditions improved, the changes were small, with no traffic condition improving by more than 10%.

A high-level economic evaluation was performed in order to determine the economic impact of the proposed bans. It was found that passenger car drivers would experience economic losses if latent demand were present in Stellenbosch. In the absence of latent demand, passenger car drivers have the potential of saving R23 109.81 during the six banning hours, but it is believed that these benefits would be far outweighed by the cost of implementation of the bans and the losses experienced by the freight industry.

The proposed heavy vehicle restrictions were not deemed feasible for implementation and more research would have to be performed into the effects of the bans on a national level.

OPSOMMING

Wanneer nuwe verkeersregulasies voorgestel word vir implementasie, is dit hoogs noodsaaklik om die effekte daarvan op die werking van die verkeernetwerk te ondersoek. In hierdie studie word die potensiële impak van swaar voertuig beperkings in stadsgebiede, soos voorgestel deur die Suid-Afrikaanse Departement van Vervoer in 2015, ondersoek. Geen bewyse kon gevind word wat aangedui het dat enige navorsing na die effekte van sulke beperkings uitgevoer is voor, of sedert, dit voorgestel is nie. Daarom het hierdie studie gemik om die gaping te vul. Alhoewel die regulasies voorgestel is in ’n poging om padveiligheid te verbeter, lê die fokus van hierdie studie op die potensiële impak wat die regulasies op verkeer en die ekonomie kan hê.

Twee hoof areas van navorsing is aangespreek in hierdie studie; die eerste daarvan is die ondersoek na die huidige swaar voertuig bewegingspatrone in Stellenbosch en die tweede is die assessering van die impak van swaar voertuig beperkings in die dorp se padnetwerk. Dit is vasgestel dat daar amper geen navorsing in die verlede gedoen is oor die bewegings van vragvoertuie in Stellenbosch nie en daarom mik hierdie studie om die gaping te vul. Vloot bestuur data van MiX Telematics en voertuig bewegingsopnames is geanaliseer vir hierdie doeleinde. Deur die analise van vloot bestuur data is die temporale en ruimtelike verspreidingspatrone van vragvoertuie in Stellenbosch vasgestel. Dit is gevind dat die meerderheid van vragvoertuie in Stellenbosch gedurende die dag reis en dat die R44 en Bird Straat twee van die mees benutte paaie vir vrag-ritte is. Die voertuig bewegingsopnames het bevind dat die meerderheid van vrag-ritte in die dorp plaaslik of in nabye dorpe ontstaan.

Die potensiële impak van swaar voertuig beperkings op verkeerkondisies is ondersoek deur die gebruik van ’n mikroskopiese verkeersmodel, gebou in PTV Vissim. Die model is gebruik om te ondersoek wat die effekte van die voorgestelde verbannings sou wees op die verkeerkondisies in Stellenbosch in beide die gevalle dat daar latente aanvraag in die dorp teenwoordig was en die geval waar dit nie was nie. Dit is bevind dat verkeerkondisies oor die algemeen verbeter het wanneer latente aanvraag nie teenwoordig was nie, maar dat dit vererger het wanneer latente aanvraag wel teenwoordig was. Selfs wanneer verkeerkondisies verbeter het, was die verandering klein, met geen verkeerkondisie wat met meer as 10% verbeter het nie.

A hoë-vlak ekonomiese evaluasie is uitgevoer om die ekonomiese impak van die voorgestelde verbannings vas te stel. Dit is bevind dat passasiersvoertuig bestuurders ekonomiese nadele sou ondervind indien daar latente aanvraag teenwoordig was in Stellenbosch. Indien geen latente aanvraag teenwoordig was nie, kon passasiersvoertuig bestuurders die potensiaal hê om R23 109.81 te bespaar gedurende die ses verbanningsure, maar dit is geglo dat hierdie voordele baie kleiner is as die koste van implementasie van die verbannings en die verliese wat deur die vrag industrie gedra sal word.

Die voorgestelde swaar voertuig beperkings is nie voordelig geag vir implementasie nie en meer navorsing sal uitgevoer moet word na die effekte wat die verbannings op 'n nasionale vlak sal hê.

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PUBLICATIONS

A section of the work contained in this research document was presented as a poster at the PIARC International Seminar on Integrated Road Transport & Mobility held on 5 to 7 November 2018.

A journal article covering the research contained in this study is under preparation.

CONTENTS

FIGURES

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EQUATIONS

ACRONYMS AND SYMBOLS

ACRONYMS

BCR	Benefit-cost Ratio
CBA	Cost-benefit Analysis
CBD	Central Business District
CI	Confidence Interval
CITP	Comprehensive Integrated Transport Plan
DoT	Department of Transport
ESAL	Equivalent Single Axle Load
FCD	Floating Car Data
FTA	Freight Transport Association
GDP	Gross Domestic Product
GMT	Greenwich Mean Time
GVM	Gross Vehicle Mass
HCM	Highway Capacity Manual
HDOP	Horizontal Dilution of Precision
HGV	Heavy Goods Vehicle
HOV	High Occupancy Vehicle
ITRE	Institute for Transportation Research and Education at NC State
ITS	Intelligent Transport Systems
JCCI	Johannesburg Chamber of Commerce and Industry
JDS	Joint Delivery System
JSE	Johannesburg Stock Exchange
KIT	Karlsruhe Institute of Technology
LOS	Level of Service
MOE	Measure of Effectiveness
NEDA	National Economic and Development Authority
NMT	Non-motorised Transport
NPV	Net Present Value
NYC	New York City

OSM	OpenStreetMap
PCE	Passenger Car Equivalent
RFA	South African Road and Freight Association
RTMC	Road Traffic Management Corporation
SCC	Social Cost of Carbon
SSML	Stellenbosch Smart Mobility Laboratory
tralac	Trade Law Centre
TRB	Transportation Research Board
UAE	United Arab Emirates
UCC	Urban Consolidation Centres
VBA	Visual Basic for Applications
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometres Travelled
VMS	Vehicle Movement Survey
VOC	Vehicle Operating Costs
VOT	Value of Time
WC	Western Cape
WHO	World Health Organisation
WTO	World Trade Organisation

SYMBOLS

B_t	nominal value of benefits in year t
C_t	nominal value of costs in year t
D	vehicle depreciation in % per km
E_T	maximum tolerable error
F	fuel consumption in ml/km
L	lifetime of project in years
M	vehicle maintenance value in % per km
n_{min}	minimum required sample size
O	oil consumption in ml/km
r	nominal discount rate
RC_F	resource cost of fuel in R/l
RC_O	resource cost of oil in R/l

RC_{PC}	resource cost of an average passenger car in R
RC_T	resource cost of a set of tyres in R
s	standard deviation of Measure of Effectiveness
T	tyre wear in % per km
V	average travel speed in km/h
VOC	total VOC in R/veh.km
VOC_D	vehicle depreciation cost in R/veh.km
VOC_F	fuel consumption cost in R/veh.km
VOC_M	vehicle maintenance cost in R/veh.km
VOC_O	oil consumption cost in R/veh.km
VOC_T	tyre wear cost in R/veh.km
$z_{\alpha/2}$	critical normal deviate for a specific confidence interval
θ	allowable error (in %)
μ	average
σ	standard deviation

CHAPTER 1: INTRODUCTION

1.1. Introduction

"You can't be a nice guy and solve traffic."

- Henry A. Barnes

This quote by Henry A. Barnes, a famous American traffic engineer in the early 1900s, still rings true in the 21st century. It is impossible to solve traffic problems and, at the same time, satisfy every party involved. It is, however, in the quest to ensure fairness, crucially important to know what the impacts of proposed traffic solutions would be on all stakeholders before implementing new policies or regulations.

This study aims to investigate the potential impact of implementing new regulations regarding movement restrictions on heavy goods vehicles in the urban areas of South Africa. The restrictions investigated are based on new traffic regulations proposed in 2015 by the Department of Transportation. These regulations are discussed in much more detail later in this document, but in short, it is proposed that all heavy vehicles heavier than 9 000 kg be banned from travelling in urban areas during peak periods on weekdays. The town of Stellenbosch was selected as the study area, for reasons discussed later in this chapter. In addition to investigating the impact of the restrictions, the current movement behaviour of freight vehicles in the study area is also investigated.

This chapter, along with **CHAPTER 2**: and **CHAPTER 3:**, aim to provide the reader with the contextual background and knowledge required to apprehend the research contained in this document and the motivation therefore. This chapter contains background to the freight industry (both global and local), a brief introduction to the proposed new regulations, a description of the research conducted, and a discussion of the selected study area.

1.2. Background

1.2.1. The global freight industry

Throughout history, the movement of freight has always been an important and necessary part of a growing world economy. Without the movement of goods, trade would be nearly impossible and accessibility to important commodities could become severely limited. According to the Cambridge Dictionary, freight is defined as:

"Goods, but not passengers, which are carried from one place to another by ship, aircraft, train, or truck; or the system of transporting these goods."

The definition above is true for today's day and age, but before aeroplanes, trucks, ships and trains were invented, freight was already being moved with the use of other modes. It has been suggested that the earliest form of goods movement was by domesticated horses as far back as 4 000 BC. In 3 200 BC, goods started being transported with carts after the wheel was invented. It took more than 4 000 years, however, for these two transport modes to be combined (in the form of horse-drawn carriages) when the iron horseshoe was invented in 770 (Freightquote, 2015a). It is important to note that these modes were limited to carrying small quantities of goods over relatively short distances.

One of the earliest recorded international shipping routes was China's Silk Road, named in the 19th century by Baron Ferdinand von Richthofen, a German geologist (UNESCO, no date). Between the first and 14th century, goods like woollen products, silk, grapes, camels and military goods were traded between China and the Roman Empire on this 7 000 km long route (Freightquote, 2015b). The Silk Road played an important role in introducing different cultures and languages to each other, and the effect of this trade route can still be seen today (Freightquote, 2015b).

Up until this point in history, the movement of goods was still heavily dependent on manpower and animals. The invention of the steamboat in 1787, however, made it much easier to transport large quantities of goods over long distances (Freightquote, 2015a). Shipping goods by boat dominated freight movements until the early 1800s when rail started becoming a more popular method of freight transportation. Throughout the 19th century, significant investment was made in the construction of railroads for the movement of freight, especially in the USA, and by the beginning of the next century, rail had essentially monopolised the freight industry (Freightquote, 2015a).

In the early 1900s, cars and paved roads became more popular, but the use of trucks to transport freight only started booming in the middle of the century. Before the Second World War, rail was the main method of transporting freight over long distances and roads were used for transport over short distances (Button and Pearman, 1981). As road infrastructure improved, however, trucks became more popular to use, even for long distances, and eventually became the second-most popular mode of transporting goods in the world, carrying 28.6% of the world's freight (in ton-miles) in 2015 (Freightquote, 2015b).

Today, freight is transported via five main modes: trains, trucks, pipelines, ships and aircraft. **Figure 1.1** shows the share of global freight carried by each mode in 2015 in ton-miles. It has been found that more than 80% of inland freight volumes are carried by trucks, with 85% of road freight being transported less than 150 km (IRU, no date). This seems to contradict the previous statement that rail is the most popular form of freight transport in the world. It is important to note, however, that although trains carry more freight in terms of ton-miles, they carry significantly less freight when only considering absolute volumes. Since the majority of road freight is only transported over short distances, the amount of freight transported by road is understated when only considering the ton-miles of freight transported.

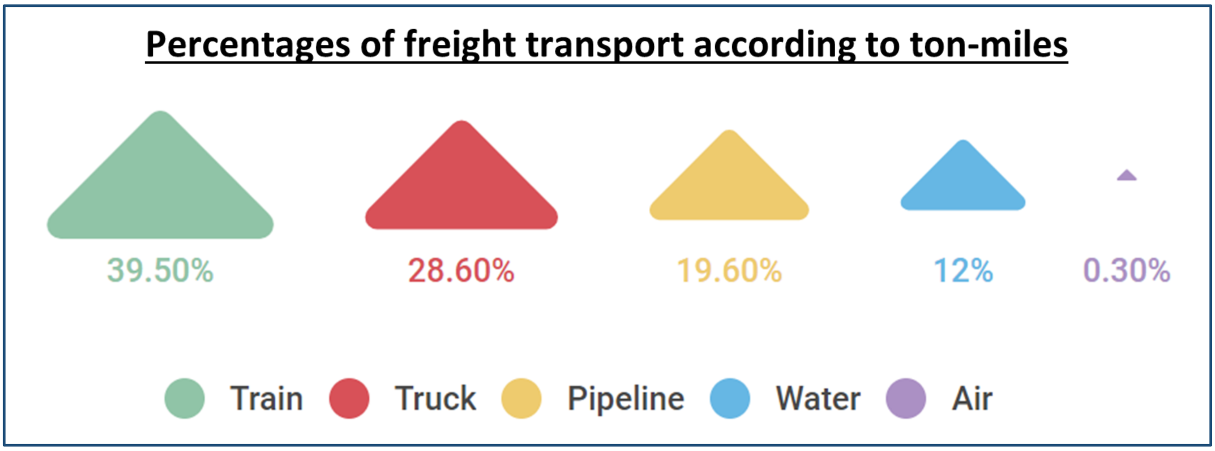


Figure 1.1. *Percentages of global freight transport according to ton-miles (after Freightquote, 2015b).*

The freight industry has struggled with many issues in recent decades, including the Great Recession between 2007 and the early 2010s. The recession caused a major oversupply of freight transportation services, leading to massive losses for freight logistics companies (The Economist Staff, 2018). Recently, a more stable economy has improved growth in the industry, with the global freight forwarding market experiencing a revenue growth of 2.7% between 2015 and 2016, and it has been predicted that the compound annual growth rate would increase to 4.1% by 2020 (Millar, 2017).

Political issues are also a major concern to the current freight industry. The refugee crisis in Europe, Brexit, and the presidency of Donald Trump in the USA have been found to pose major potential risks. The political climate has given rise to increased support of populism and protectionism, leading to countries being more protective of who they allow through their borders. Between 2008 and 2016, members of the World Trade Organisation (WTO), implemented 2 900 measures to restrict trade, while only 740 measures were removed (Millar, 2017). Additionally, travel restrictions between certain countries have been proposed and, in some cases, implemented. It is estimated that these measures could significantly increase freight transportation costs, leading to major losses for the industry (KPMG, 2017).

1.2.2. Freight in South Africa

Freight is transported within South Africa by five main methods. **Figure 1.2** shows the split for all freight transported in South Africa in 2013. As can be seen in the figure, much more freight is transported by road than any other mode. Combined, the majority of South Africa’s freight is transported over land via road and rail. For this reason, this section will mainly focus on the use of these two modes in the country.

One of the biggest challenges faced by the South African freight industry, is the disproportionate distribution of freight between road and rail for long-haul trips. In 2010, 88% of these trips were carried out via road, while the other 12% were via rail. The concerning part is that 42% to 55% of the freight transported via road was found to be suitable for rail transport (Havenga and Simpson, 2014).

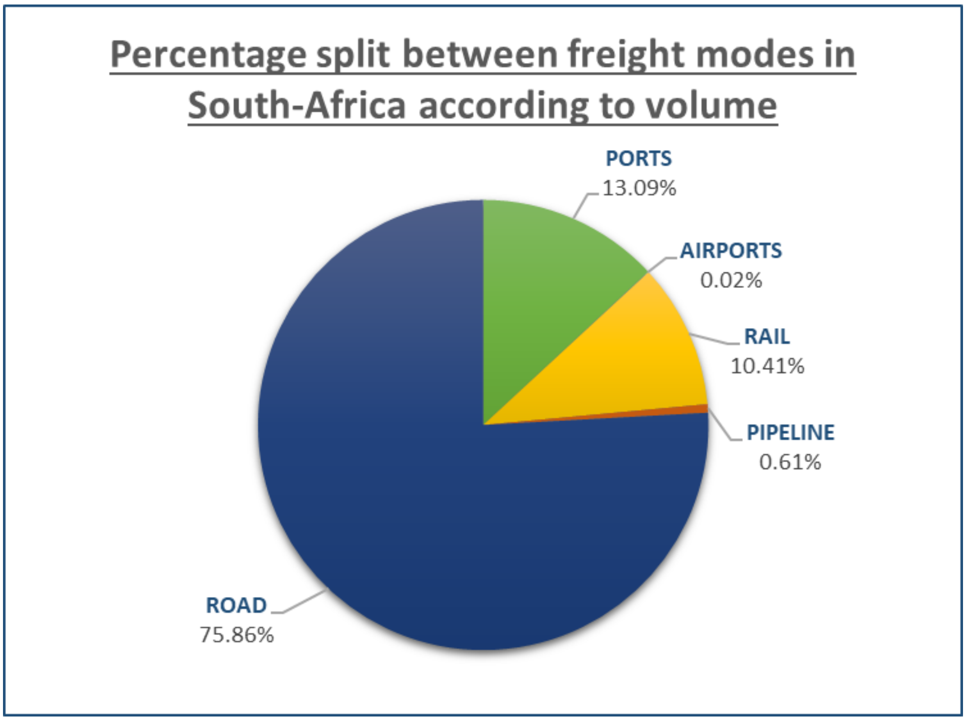


Figure 1.2. *Percentage split between freight modes in South Africa in 2013 (after Department of Transport, 2017).*

Because of the high market share of trucks in the long-haul freight industry, and especially due to the fact that a large portion of road freight is actually suitable for rail transport, South Africa's freight efficiency lacks significantly when compared to other countries. **Figure 1.3** shows the contribution of freight to the GDP of different countries per tonne-km. It is clear that the profitability of the South African freight industry far underperforms.

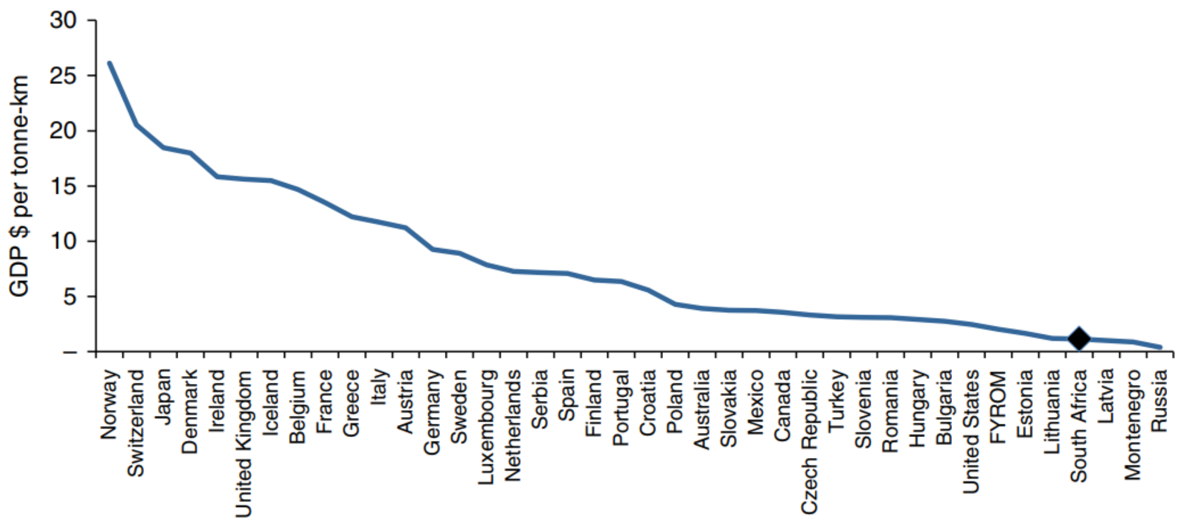


Figure 1.3. *Contribution of GDP per tonne-km in $ (Havenga and Simpson, 2014).*

It is important to note here that the low contribution of freight to the GDP of South Africa per tonne-km must also be partly contributed to the fact that South Africa's largest economic capital, namely Johannesburg, is located inland, far from any major ports. This leads to high transport costs for the freight industry, as many products need to be transported between Johannesburg and the coast. This differs from many other large cities across the globe, where economic hubs are frequently located on a coast line to have direct access to an ocean port.

In addition to this, one of the largest industries that requires freight transport in the country, namely mining, is also primarily located inland (Havenga, Le Roux and Simpson, 2016). Between 100 and 150 million tons of coal and iron ore were transported in 2015, most of which had to be transported over vast distances between mines and coastal ports. The fact that commodities need to be transported over such large distances to be exported contributes to the fact that South Africa ranks so low in **Figure 1.3**.

Most freight movements in South Africa (41% in 2014) have trip ends in either Cape Town, Johannesburg or Durban (Department of Environmental Affairs, no date). This is observable when studying **Figure 1.4**, which shows the freight movements via rail and road in South Africa in 2013. The freight movement paths shown in this figure indicate that much of the freight arriving at coastal ports is transported over large distances inland via road or rail.

In 2012, it was estimated that freight logistics costs totalled approximately 12.8% of the country's GDP (Havenga, Le Roux and Simpson, 2016). This figure is much higher than the average for most developed countries, which ranges between 8% and 10% (Department of Environmental Affairs, no date). These high costs are again partly contributed to the fact that freight must be transported such vast distances inland from the country's major ports.

Although there are potential benefits, switching from road to rail as the main freight transport mode is not an easy task. Historically, rail was actually much more preferred for the movement of goods than roads in South Africa (Department of Environmental Affairs, no date). In the 1930s, the use of roads for freight transport was severely restricted and regulated, mainly to develop the railway network in the country (Department of Transport, 2017). However, the deregulation of the freight transportation sector in the early 1980s (Havenga *et al.*, 2011) led to trucks becoming more popular than trains. This has led to many commodities that would usually be more suitable to be transported via rail, to be transported by road. Additionally, investment in rail decreased with time to such a point that rail infrastructure has deteriorated significantly (Department of Transport, 2017). This has made it very difficult to justify the costs associated with switching to rail as the main freight transport mode in South Africa. It is also important to note that the use of rail is limited in the fact that trains can only travel where rail lines are provided and very seldom travel to urban areas. Additionally, rail cannot be used to make point-to-point deliveries, something that trucks are able to do.

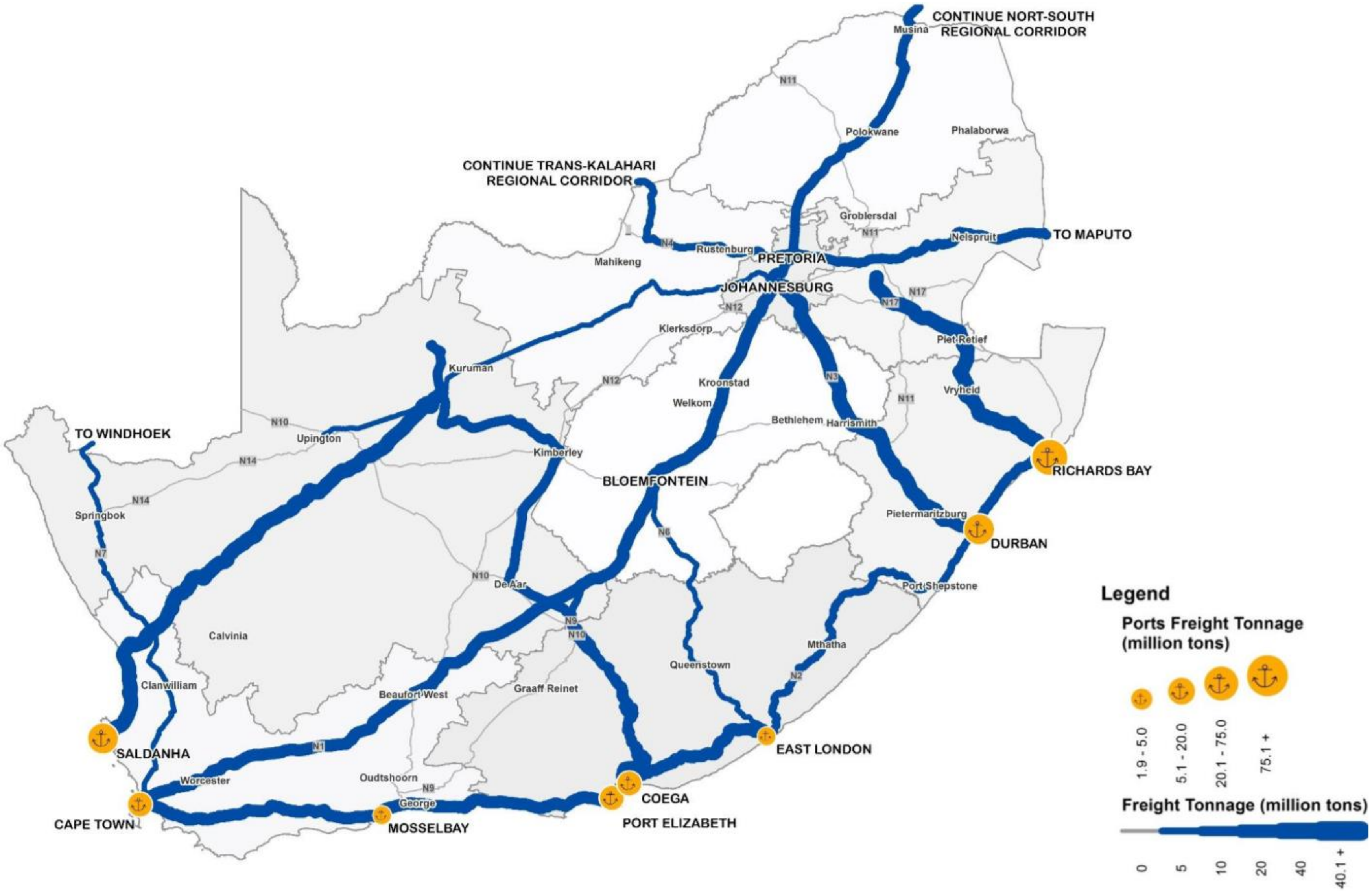


Figure 1.4. *2013 Freight tonnage movements for road and rail in South Africa (Department of Transport, 2017).*

1.2.3. The importance of freight

Freight transportation is one of the most important sectors in global economic growth. In the USA, a strong correlation has been found between the ton-miles of freight moved and the GDP for both rail and road transport (Mid-America Freight Coalition, no date). **Figure 1.5** shows the change in ton-miles of rail and road freight versus the change in GDP in the USA between 1989 and 2007. It can clearly be seen that GDP increases when more freight is moved. It has been predicted that the global transport logistics industry will have a revenue of $15 522.02 billion (approximately R215.28 trillion) in the year 2023 (PRNewswire Staff, 2016). It is clear that freight contributes to a very large part of the world's economic growth.

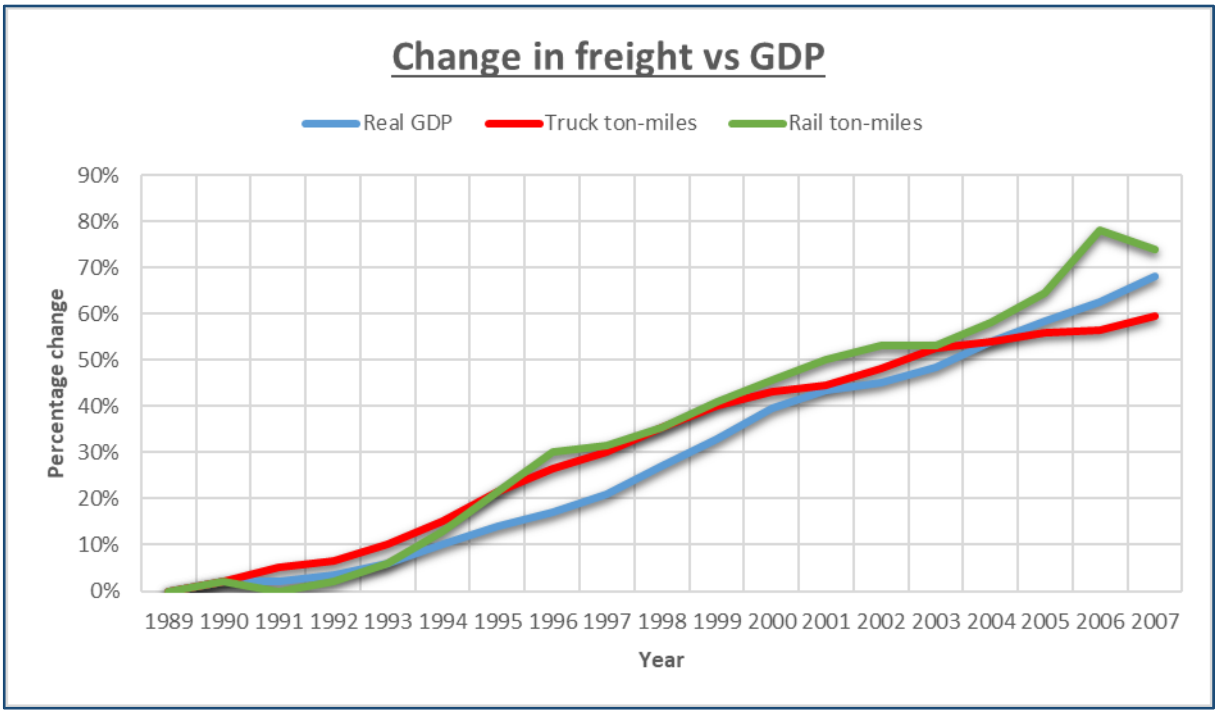


Figure 1.5. *Percentage change in freight transported vs. GDP in the USA (after Mid-America Freight Coalition, no date).*

Furthermore, freight is a significant contributor to job creation. It has been estimated that road transport of goods creates approximately 6.5 million jobs in Europe and 9 million in the USA (IRU, no date). Furthermore, it creates more than 190 000 jobs in Australia, a country that moves relatively little freight when compared to the USA, Europe and China (*Importance Of Road Freight Transport in Australia*, no date).

The movement of goods in South Africa is similarly, very important for economic growth. In only the fourth quarter of 2017 (October to December), the freight industry in South Africa generated an income of R39.829 billion (Statistics South Africa, 2017). For this period, it was found that the biggest income generators were the mining industry, the transportation of food products, the transportation of chemicals and other mineral products as well as the agriculture industry (Statistics South Africa, 2017).

Figure 1.6 shows the breakdown of the types of freight being moved on South Africa's corridors. Freight transportation ensures that these types of products are transported to the places where they are needed and used. Additionally, freight enables South Africa to partake in the world economy through its import/export industry (Belfreight Staff, 2016).

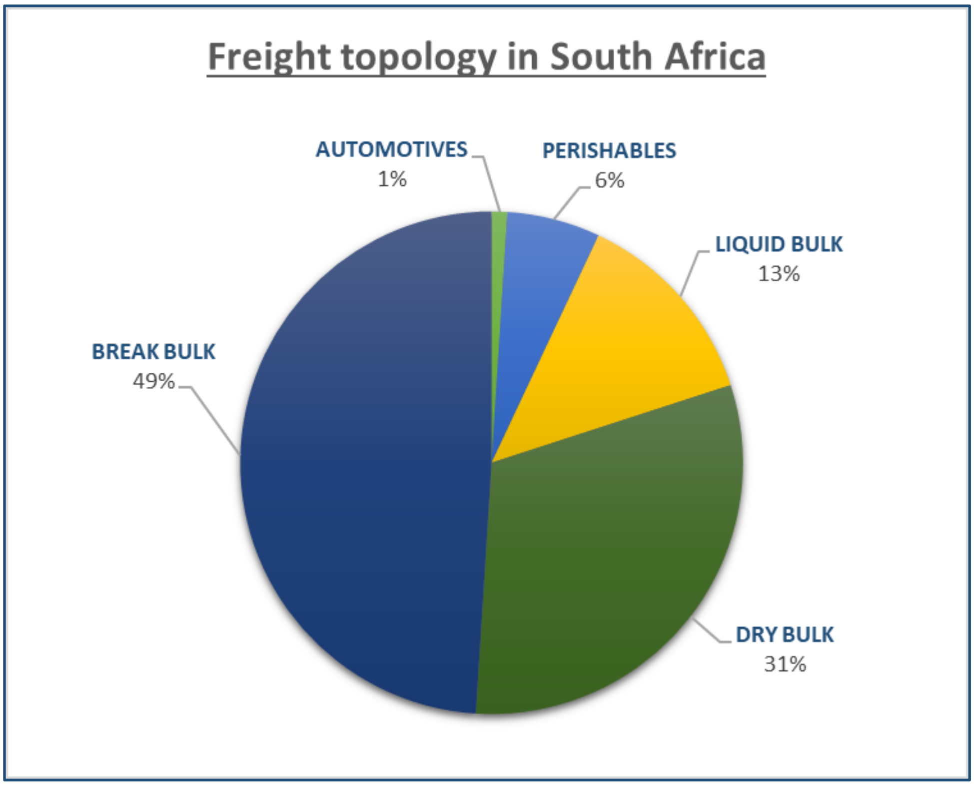


Figure 1.6. *Freight topology in South Africa (after Department of Environmental Affairs, no date).*

1.2.4. Proposed new regulations

On 11 May 2015, the then Minister of Transport, Dipuo Peters, published proposed amendments to the National Road Traffic Regulations, 2000. The proposed amendments were published for public comments in the Government Gazette No. 38772, as required by section 75 (6) of the National Road Traffic Act, 1996. A copy of the Government Notice can be found in Appendix A1.

The proposed regulations to be amended or added can be summarised as follows:

- All drivers that apply to renew a driving license must be re-evaluated, but not by a written test.
- No more than five people (while in employment of the driver) may be transported in the goods compartment of a goods vehicle with a gross vehicle mass (GVM) of less than 3 500 kg.
- No school children or paying passengers may be transported in the goods compartment of a vehicle unless an exemption is issued.
- Speed limits will be reduced to 40 km/h in urban areas, to 80 km/h outside of urban areas (except freeways) and to 100 km/h on freeways passing through residential areas.
- Heavy goods vehicles (HGVs) having a GVM or more than 9 000 kg will be banned from travelling on public roads in urban areas between 06:00 and 09:00 and 17:00 and 20:00.

This study only pertains to the last proposal, concerning the banning of heavy goods vehicles weighing more than 9 000 kg during certain periods. According to the Department of Transport (DoT), the main reason for this proposal was to combat the high number of road deaths related to the involvement of heavy vehicles (Wheels24 Staff, 2015). The implementation of such a ban could, however, have a much greater impact on the transportation network than road safety. Therefore, the focus of this study will not be on the effects that the proposed regulations can have on road safety, but rather on the effects it can have on road traffic and the economy. After careful consideration and review of literature, the author reached the conclusion that the bans would likely have a much bigger impact on traffic than road safety.

It is important to note that, although this study is based on the proposed regulations, it does not always strictly conform to the conditions set out in the regulations. The reason for this is that data sources and the methods used did not always provide adequate information or functionalities to provide for all conditions.

In the regulations, only heavy vehicles with a GVM of 9 000 kg or higher are banned from using public roads in urban areas within the banning periods. However, as discussed in the appropriate chapters, most of the data sources used only made a distinction between light vehicles and heavy vehicles, without specifying the GVM of the vehicles. Furthermore, the modelling software used could not distinctly differentiate between goods vehicles with a GVM higher than 9 000 kg and those with lower GVMs. For these reasons, this study only differentiates between passenger cars and heavy goods vehicles, usually defining a heavy goods vehicle as any goods vehicle with a GVM higher than 3 500 kg. Therefore, the investigation performed looks into the banning of all heavy vehicles, regardless of whether their GVM is higher or lower than 9 000 kg. By applying the restrictions to all HGVs instead of only the heaviest HGVs, the “best-case” scenario is studied. It is argued that, in the case that the removal of all HGVs from the road network would not be beneficial to traffic, it would also not be beneficial to only remove HGVs with GVMs higher than 9 000 kg. However, if it is found that it would indeed be beneficial to ban all HGVs, future research could be performed to only consider the banning of HGVs weighing more than 9 000 kg.

No information is provided on how the DoT plans to implement and enforce the regulations. For this reason, certain assumptions are made in this study relating to the manner in which the regulations could be implemented. The assumptions made are discussed in the relevant chapters.

1.3. Problem statement

South Africa is one of the most congested countries in the world. According to the INRIX Global Traffic Scorecard (Cookson, 2018), the country ranked 8th on the list of the most congested countries in 2017 with drivers spending an average of 36 hours in peak congestion during the year. The same Scorecard identified Cape Town as the most congested city in South Africa, with drivers in this city spending an average of 49 hours in peak congestion. Cape Town ranked 41st out of the 1 360 cities that formed part of the research.

The high levels of congestion in South Africa, especially in the major cities of the country, have much further reaching consequences than merely the time that drivers lose while sitting in traffic. Time lost when stuck in traffic directly translates to a loss in productivity and, therefore, economic losses. In 2014, it was estimated that, as a worst-case scenario, the South African economy could potentially lose over R60 billion per year if it is assumed that all working people in South Africa experience the average congestion in the country (BusinessTech Staff, 2014).

In addition to the high levels of congestion on the country's roads, South Africa faces many challenges with regards to road safety. The number of deaths on South African roads each year is staggering. According to the World Health Organisation (WHO), South Africa ranked as the country with the 42nd highest road death rate in 2013 worldwide (WHO, 2013). Furthermore, it was found that the number of road fatalities in the country has been rising since 2013 with no signs of stopping without intervention. In 2016, an estimated 14 071 people died on South Africa's roads, approximately 9% more than in the previous year (Wheels24 Staff, 2017).

Fatal accidents involving heavy vehicles have received a lot of media attention in recent years, mainly because of the high fatality rates often associated with these types of accidents. The fact that heavy vehicles are inherently large and heavy, means that even though the number of accidents involving these vehicles are low when compared to passenger cars, the fatality rate is often higher. Recent data from the Road Traffic Management Corporation (RTMC) has, however, shown that only approximately 9% of road fatalities are contributed to heavy vehicles (RTMC, 2017). Nevertheless, the extensive media coverage and severity of heavy vehicle accidents have led to a public belief that heavy vehicles significantly decrease road safety on the road network.

As an attempt to reduce the number of fatalities on South Africa's roads, the Minister of Transport proposed new traffic regulations restricting the movements of heavy vehicles in urban areas in 2015. No evidence could, however, be found to show that any research has been performed into the possible effects that these regulations could have in the case that they were implemented. This is worrisome, since these regulations would be implemented on a national scale and could potentially have major impacts on the traffic flow in urban areas, translating to changes in congestion levels and the national economy. Regulations relating to heavy vehicle movements will also, very likely, have a major impact on the operations of the local freight industry. It is crucial to investigate the effects of new regulations before they are implemented, especially if they are to be implemented on a large scale.

By considering the above, the aim of this study is twofold. Firstly, it will investigate whether banning heavy vehicles from urban areas during morning and afternoon banning periods will be beneficial to the traffic flow and economy of the study area. By investigating this, the study will aim to fill the research gap created by the fact that no investigation was performed into the possible effects of the new regulations proposed by the Minister of Transport in 2015.

Secondly, this study aims to investigate the behaviour of freight vehicles in the study area, as this has reportedly never been studied on a detailed level. This information will aid authorities to make important decisions regarding the implementation of policies affecting freight movement.

1.4. Research statement

Restricting heavy goods vehicles from travelling on public roads in the urban areas of Stellenbosch, South Africa between 6 a.m. and 9 a.m., and 5 p.m. and 8 p.m. on weekdays (excluding public holidays) will improve traffic flow in the town and hold significant economic benefits.

1.5. Objectives

The primary objective of this study is:

i. To evaluate what the impact of restricting trucks from travelling in the urban area of Stellenbosch during morning and afternoon banning periods would be on traffic flow and the economy.

The secondary objectives of this study are:

ii. To investigate the current heavy vehicle movement patterns in Stellenbosch.

iii. To create a microscopic traffic model of critical routes in Stellenbosch, with and without the heavy vehicle restrictions in place.

iv. To perform an economic evaluation of the implementation of the heavy vehicle restrictions in Stellenbosch.

1.6. Significance of research

The research contained in this study is significant for several reasons. Firstly, it has been found that not much research has been conducted globally into the effects of banning heavy vehicles in urban areas. Additionally, no proof could be found that research into this field has ever been conducted for the South African environment. The results of this study could, therefore, provide insights into the effects of such bans in South Africa that have not been described before.

In addition to providing theoretical insights into the effects of banning heavy vehicles in urban areas, the significance of this study is also of a practical nature. As discussed in previous sections, restrictions similar to those investigated in this study have been proposed for implementation in South Africa. The results of this study could provide crucial information to the applicable authorities before the restrictions are potentially implemented in the country. By using the results of this study, authorities could make more informed decisions over whether such restrictions would be beneficial to the country, and would enable them to better define the operational requirements for such restrictions to be effective.

Furthermore, this study uses fleet management data in a way that has not frequently been used before, especially not in South Africa. While fleet management data is usually used to analyse and improve the operations of fleets to increase profit for companies, in this study, the author attempts to use this data to gain insight into the movement behaviour of heavy vehicles in a town. This study will, therefore, discuss a new method of analysing and processing raw fleet management data and provide insights into the effectiveness of using this data in the field of traffic engineering.

Finally, this study provides important insights into the movements of heavy vehicles within the town of Stellenbosch that were not previously known. According to the Stellenbosch Municipality, no significant research has ever been performed into the detailed movement patterns of heavy vehicles within the town. Available data on the movement patterns of heavy vehicles merely consider the general movements of heavy vehicles in the vicinity of Stellenbosch and do not specifically consider the movement of heavy vehicles on the roads of the town's road network itself. There is also some practical significance in shedding light on the movements of heavy vehicles within Stellenbosch. The results obtained can be used by local authorities and policy makers to make more informed decisions about policies that involve the movement of heavy vehicles in the town.

1.7. Study area

1.7.1. Selected study area

The general study area selected for this study includes the urban areas of the town of Stellenbosch. Stellenbosch is located in the Stellenbosch Municipality in the Western Cape Province of South Africa, approximately 50 km east of Cape Town. **Figure 1.7** indicates the location of Stellenbosch in the Western Cape. **Figure 1.8** shows the edges of the urban areas in the town as defined by the Stellenbosch Municipality in 2017.

According to the 2011 national census, Stellenbosch Municipality is home to more than 155 733 people of which a large percentage is aged in their early twenties (Statistics South Africa, no date). This can be contributed to the fact that Stellenbosch is the location of the main campus of one of South Africa's leading universities, namely Stellenbosch University. In 2017, 31 639 students were enrolled at the university, of which most attended the main campus (Stellenbosch University, 2017). The high number of students in Stellenbosch leads to some unique traffic characteristics, since many students travel by foot, bicycle or other non-motorised transport (NMT). This leads to a high percentage of vulnerable road users on the town's roads. Because a relatively large percentage of Stellenbosch's population consists of students, the traffic conditions differ significantly between periods when the university is in recess and when it is not.

Stellenbosch is located in the Cape Winelands, the largest winemaking region in South Africa (SA-Venues.com Staff, no date). As such, many wine farms surround the town and the quality of wine made in this region attracts a large number of tourists each year. Stellenbosch is also one of the oldest European settlements in South Africa, attracting even more tourists to the university town for the historical value it holds. In addition, the large number of wine farms generates a significant amount of freight trips.

Although the main focus will lie on the urban area of Stellenbosch, the study area considered differs for the different datasets and analysis methods used throughout the study. Therefore, the specific study area considered will be discussed in each applicable chapter. It must be noted, however, that all study areas considered fall within the town of Stellenbosch or the surrounding area.

Figure 1.7. *Location of Stellenbosch within South Africa (OpenStreetMap, no date).*

1.7.2. Motivation for the choice of town

Stellenbosch was selected as the study area for very specific reasons. The reasons for choosing this town over others are explained in this section.

While conducting the research for this study, the author was a member of the Stellenbosch Smart Mobility Laboratory (SSML). The SSML, opened in 2014, is a research and education lab at Stellenbosch University, focusing on the study of Intelligent Transport Systems (ITS). One of the SSML's missions is to turn Stellenbosch into the first "Smart City" in South Africa, with regards to transportation. By selecting Stellenbosch as the study area of this study, the author supported this mission. Additionally, the results obtained from this study were part of a larger research effort to improve the transportation system in Stellenbosch.

Furthermore, Stellenbosch was selected as the study area because of the available data sources. While conducting the research for this study, the SSML had agreements in place with key data providers that were based in Stellenbosch and could provide data related to the transportation system of the town. Some of the data used in this study was not available for areas outside of Stellenbosch and would, therefore, have limited the scope of the research that was performed.

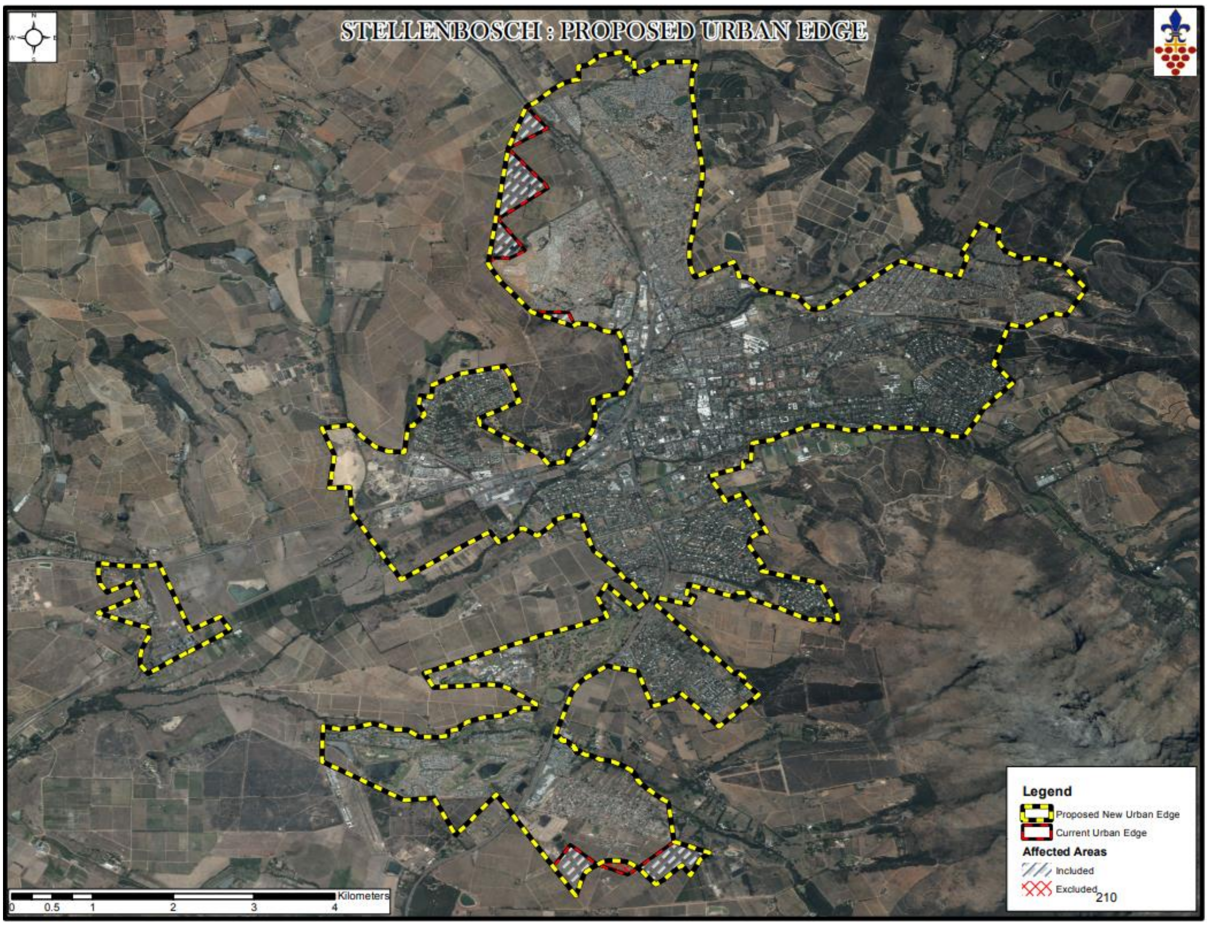


Figure 1.8. *Current and proposed new urban edges of Stellenbosch (Stellenbosch Municipality, 2017a).*

The traffic characteristics of Stellenbosch played a major role in selecting the town as the study area. Stellenbosch is located nearby to South Africa's two largest national routes, the N1 and the N2. This means that the town is easily accessible, and traffic would not be influenced by potential accessibility problems. Additionally, Stellenbosch is relatively isolated from other towns. This helps to contain the study area in the sense that most traffic in the area of the town are deliberately travelling in the area and are usually not traffic spilling back from nearby towns. This ensured that the results obtained for the study area were not significantly influenced by external factors.

The large number of wine farms in the vicinity of Stellenbosch further motivated the choice of the study area. It was believed that, since the farms produced large amounts of wine and other beverages, several freight trips would be generated in the study area. It was the belief of the author that this would ensure that the freight population in the study area would be large enough to provide sufficient datasets to work with.

Finally, Stellenbosch was selected as the study area because of the relatively high levels of congestion on the town's roads. Because the study investigated the effects that heavy vehicle bans would have on traffic flows, a town had to be selected with significant congestion levels in order to provide noticeable results.

1.7.3. Traffic in Stellenbosch

Stellenbosch is fed by the following three major roads:

- The R44 connecting Stellenbosch to Somerset West in the South and providing access to Klapmuts and the N1 in the North.
- The R310 providing access between Stellenbosch and Franschhoek in the East and to Kuils River (via the M12) and the N2 in the West.
- The R304 connecting Stellenbosch to the Northern Suburbs of Cape Town and the N1.

These main routes are indicated in **Figure 1.9** on the next page.

Stellenbosch is located relatively close to two major national highways, the N1 and N2. This means that the town is easily accessible from the surrounding towns. **Figure 1.10** shows the desire lines between the urban area of Stellenbosch and the surrounding towns. The thickness of the arrows indicates the desire of people to travel between two destinations, with thicker lines indicating greater intensity of travel. From **Figure 1.10**, it can be seen that the desire for travel between Stellenbosch and the Franschhoek area is much smaller than on the other major roads feeding Stellenbosch. The desire lines indicate that the most traffic can be expected on the R44 (North and South), the R304 and the R310 (West).

With local traffic growing by an average of 4% per year (Stellenbosch Municipality, 2017b), Stellenbosch experiences major congestion problems during peak travel periods. Traffic growth is even higher when only considering the major roads. It was found that the number of vehicles on these roads increases by up to 6% per annum (Royal Haskoning DHV, 2016). This high growth rate has led to several road sections operating beyond their capacity. The Stellenbosch Status Quo Report of 2017 (Stellenbosch Municipality, 2017b) identifies these road section and they are indicated in **Figure 1.11**. The report also found the intersection between the R304 and the R44 to be heavily congested in the peak periods, causing long queues to form that create problems at upstream intersections.

One of the largest transportation related challenges faced by Stellenbosch is the availability of parking space, especially in the centre of town. This shortage leads to a high level of illegal parking, which in turn contributes to higher congestion levels (Sinclair, Bester and Van Dyk, 2012). In 2010, it was estimated that the number of additional parking spaces required on the university campus alone was between 4 000 and 5 000 (Sinclair, Bester and Van Dyk, 2012). Solving the problem, however, is not as easy as merely constructing more parking lots. Stellenbosch has grown at a significant rate and there is simply not enough open land to provide more parking spaces. A possible solution could be to construct underground parking areas, but this is often a costly exercise. The ideal solution for the parking problem in

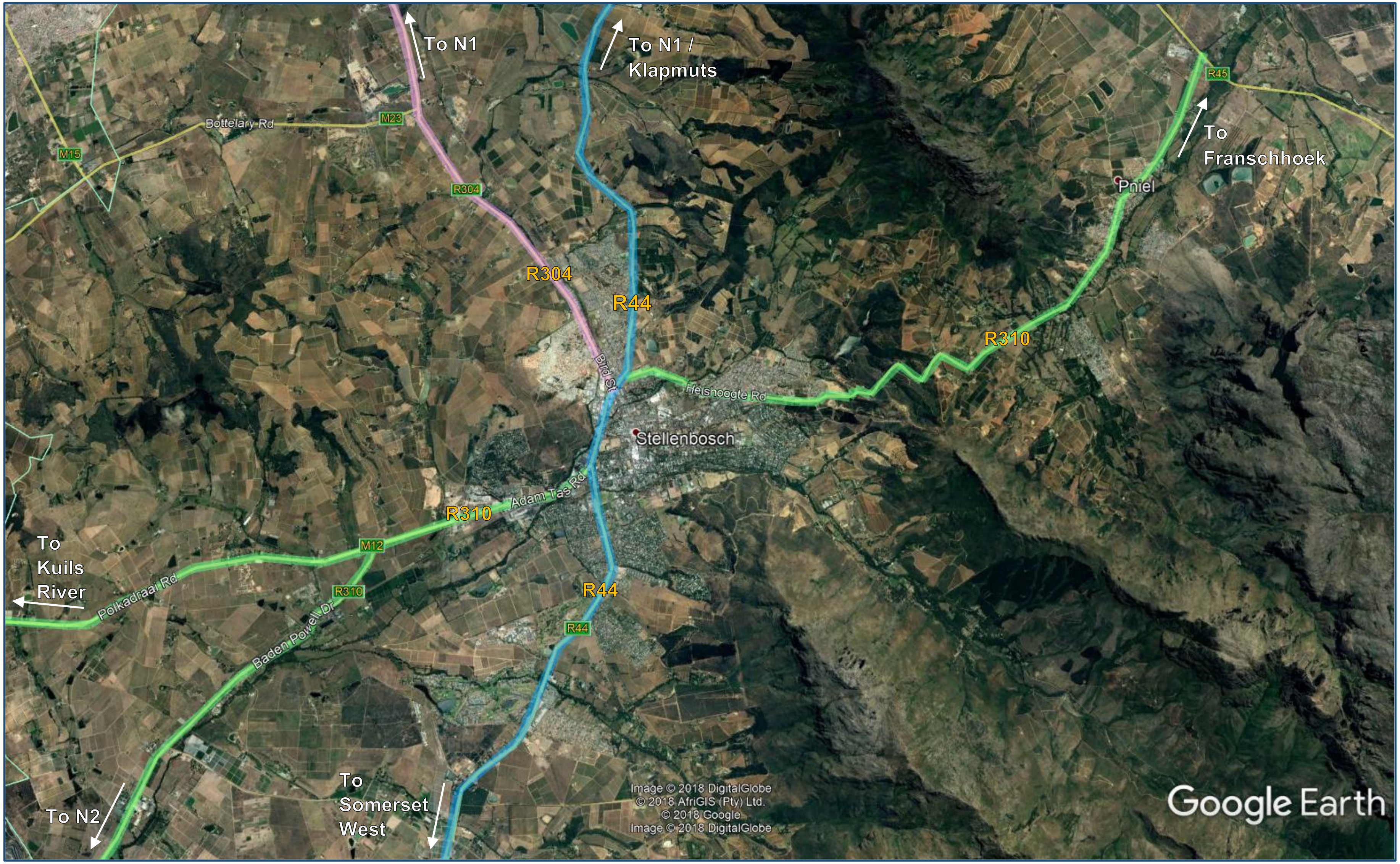


Figure 1.9. *Three major roads feeding Stellenbosch (Google Earth Pro, 2018).*

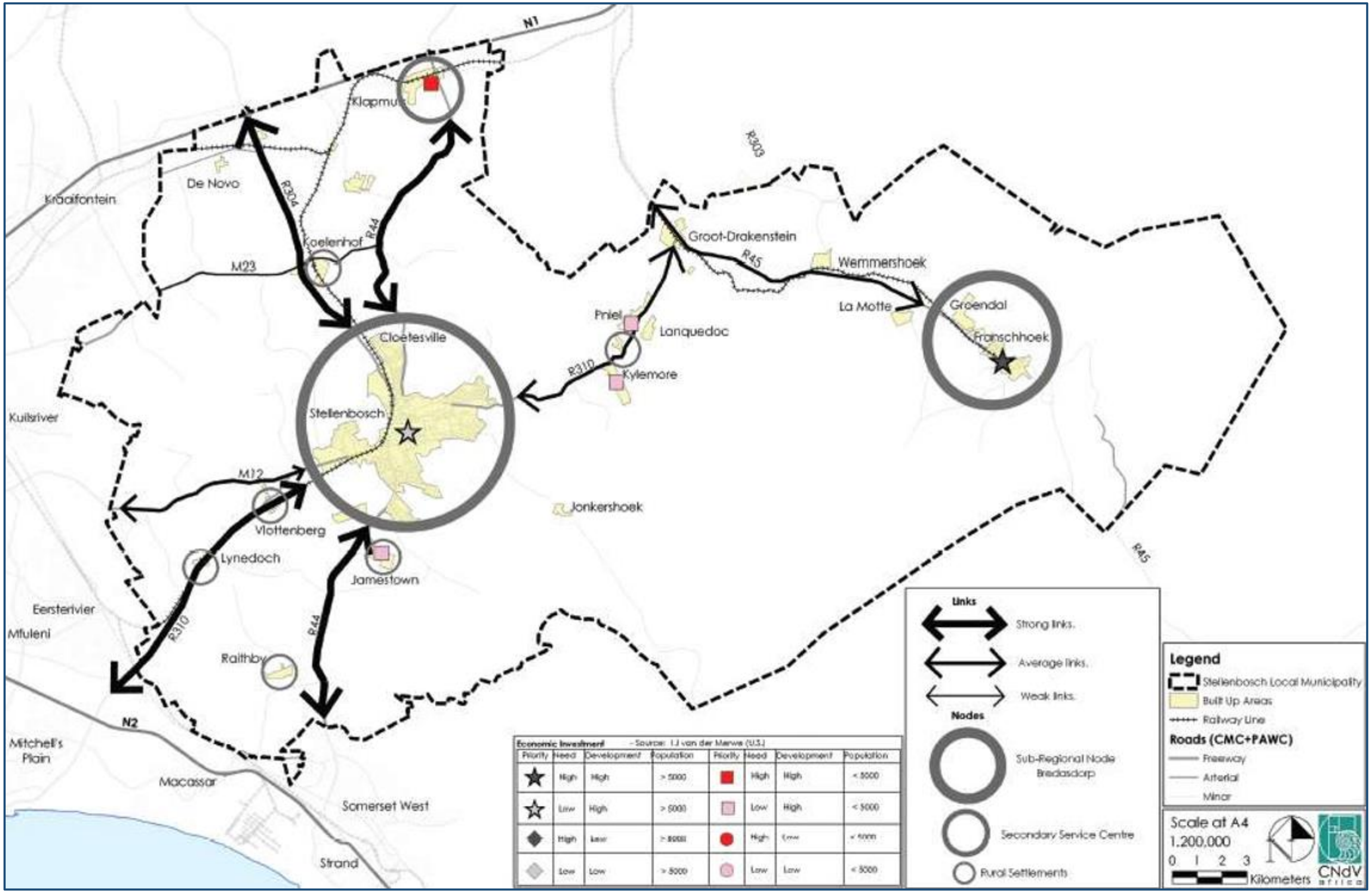


Figure 1.10. *Stellenbosch desire lines (Sustainability Institute, 2012).*

Figure 1.11. *Road sections operating beyond capacity in Stellenbosch (Google Earth Pro, 2018).*

Stellenbosch would be to increase the use of NMT, especially under students. The problem, however, is that poor road safety for these road users deter them from switching from cars to NMT (Sinclair, Bester and Van Dyk, 2012).

1.7.4. Freight in Stellenbosch

The Stellenbosch Municipality experiences a relatively high number of heavy vehicles on its roads. This is partly due to the high number of wine farms in the region that generate many freight trips for deliveries and transportation of wine products. In the municipality, the average heavy vehicle traffic makes up approximately 4% to 5% of the total traffic stream (Stellenbosch Municipality, 2017b). Within the town of Stellenbosch, the heavy vehicle population is estimated to be approximately 1.5% of the total traffic stream (Royal Haskoning DHV, 2016). Additionally, it has been estimated that inbound heavy vehicles make up 1% of the traffic stream during the morning peak period (Royal Haskoning DHV, 2016).

The heavy vehicle movement in Stellenbosch has been found to be mainly local traffic and heavy vehicles passing through the town to neighbouring municipalities (Sinclair, Bester and Van Dyk, 2012). Many heavy vehicles travel through the town to avoid the weighbridges located close to the N1 and N2 (Sinclair, Bester and Van Dyk, 2012), leading to trucks often being overweight. Overloading has become a major problem in Stellenbosch, since overloading laws are not adequately enforced (Royal Haskoning DHV, 2016). Furthermore, it seems that the number of heavy vehicles travelling through the town, without having a trip end in Stellenbosch itself, is increasing (Royal Haskoning DHV, 2016). It has also been estimated that the number of trucks travelling in Stellenbosch would double between 2009 and 2030 (Sinclair, Bester and Van Dyk, 2012). This increase in heavy vehicle traffic is concerning, since this could have many negative effects on the congestion levels and road conditions in the town. As previously mentioned, Stellenbosch is already experiencing major congestion on some of its main roads and such a significant growth rate for heavy vehicle presence cannot be supported.

1.8. Limitations and assumptions

1.8.1. Limitations

The data used within this study was limited to the sources that were available. Agreements between the SSML and industry partners allowed the student access to fleet management data from MiX Telematics (Pty) Ltd. and historical traffic data from TomTom NV. The author was limited to only using these data sources, since no data provision agreements were set up with other similar data providers. This restricted the ability of the author to compare datasets and establish the accuracy of the received data. The data providers used were, however, well known in the industry and it was assumed that the data received would be reliable and sufficient.

Although this study attempted to investigate the effects of the regulations proposed by the Minister of Transport in 2015, it does not precisely conform to the conditions of the proposed regulations. The data and software used during the research process limited the study to investigate the effects of banning all heavy vehicles instead of only considering heavy vehicles with a GVM higher than 9 000 kg, like in the proposed regulations. In most cases, the data or software did not allow for a distinction between heavy vehicles weighing more or less than 9 000 kg. Additionally, although the regulations were proposed to be implemented on a national scale, the scope of this study was limited to investigating the implementation in a single town, namely Stellenbosch. This was due to the time constraints and available data.

The scope of this study does not include the comprehensive design of the operating procedures required for the investigated heavy vehicle restrictions. This includes the practical aspects such as how freight companies will be persuaded to comply with the new regulations, the design of media campaigns to inform the public of the new regulations, how the regulations will be physically implemented, and the responsive behaviour of the freight industry to the regulations. Furthermore, the enforcement measures that would be required for the implementation of the new regulations are not defined.

Finally, the scope of this study does not take into account any traffic management measures implemented in conjunction with the heavy vehicle restrictions investigated. Normal traffic growth is taken into consideration, but any significant changes in traffic conditions after data was collected is ignored.

Additional limitations specifically relating to the data sources, software and methodologies used in this study are discussed in the relevant chapters.

1.8.2. Assumptions

It is assumed that the data sources used for the research contained in this study were accurate and reliable. Although reliability tests are performed where possible, the data providers used were well-known and could be assumed to provide accurate data. Additionally, an assumption is made that the data received from the data providers was an accurate representation of the entire population and that other data sources would have yielded similar results.

Throughout the research process, it was assumed that any mention of a heavy vehicle refers to a HGV with a GVM higher than 3 500 kg, unless specifically stated otherwise. Furthermore, because of limited data and as an attempt to simplify certain processes, it is assumed that all vehicles defined as freight vehicles, were by default classified as HGVs, unless otherwise stated. It was also assumed that the number of heavy vehicles exempted from the restrictions (such as emergency vehicles), would be negligible and were not considered during any part of the research process.

For the purpose of the research performed for this study, an assumption was made that there were no significant changes in conditions within the study area that would render the collected data incorrect or unusable.

Additional assumptions specifically relating to the data sources, software and methodologies used in this study are discussed in the relevant chapters.

1.9. Brief chapter overview

CHAPTER 2: Literature Review

This chapter provides an extensive and detailed review of literature relating to freight and other aspects related to this study. Various topics are discussed, including the complexities of urban freight, the physical and sociological effect of freight vehicles and the details of freight restrictions that have been implemented in different locations across the world. Additionally, background information is provided regarding the penetration rates of fleet management data, the modelling procedure used in PTV Vissim and the cost-benefit analysis procedure.

CHAPTER 3: Proposed New Regulations

A detailed discussion of the new regulations proposed by the DoT in 2015 is provided in this chapter. This includes a detailed review of what the regulations entail, potential issues that could be faced and the potential benefits that the implementation of these restrictions could hold.

CHAPTER 4: Methodology

This chapter provides a brief overview of the methodologies followed during this study. It includes the steps followed and the methods used to achieve the set objectives.

CHAPTER 5: Data Collection

This chapter includes a detailed explanation of the data collected for the research included in this study. The data sources, data content and other important aspects relating to the data sources are discussed.

CHAPTER 6: Fleet Management Data

CHAPTER 6 contains the methodology and results of processing fleet management data to determine the movement behaviour of freight vehicles in Stellenbosch. In addition, the results are compared to floating car data (FCD) to determine its validity.

CHAPTER 7: Vehicle movement surveys

A detailed analysis of vehicle movement surveys (VMSs) performed in Stellenbosch is discussed in this chapter. The results of the VMSs are used to aid in the determination of freight movement in Stellenbosch.

CHAPTER 8: Link Traffic Counts

This chapter provides the methodology and results of the analysis of link traffic counts that were performed in Stellenbosch. The counts are used to determine the penetration rate of the fleet management data used in CHAPTER 6, to calculate heavy vehicle percentages in Stellenbosch and to predict whether latent demand is present in the town.

CHAPTER 9: Microscopic Traffic Modelling

This chapter contains the methodology followed to construct a microscopic traffic model, a discussion of the data used in the model and the results obtained after running the model.

CHAPTER 10: Economic Evaluation

CHAPTER 10 includes the details and results of the economic evaluation that was performed to determine the financial impact of the investigated heavy vehicle restrictions.

CHAPTER 11: Conclusions and Recommendations

The final chapter provides a summary of the findings of the study and discusses the conclusions that could be made. Additionally, recommendations for future research is provided.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter provides an extensive and detailed review of literature relating to topics covered in this study. The examination of existing literature provides crucial background information that provides the basis for any research that will be conducted.

Firstly, the sector of urban freight is discussed in great detail, providing information on the manner in which freight is distributed in urban areas and the factors that need to be taken into account when working in this complex field. Next, the effect of heavy vehicles on the road network and society is examined. Previous studies relating to the determination of these impacts are reviewed. A considerable section of this chapter is dedicated to the discussion of the implementation and results of heavy vehicle restrictions in countries other than South Africa. In addition to this, a section is included that provides a discussion of the compliance issues that are faced when a new traffic law is implemented.

Finally, information is provided on the penetration rates of fleet management data, the theoretical background of PTV Vissim and the cost-benefit analysis used in this study.

2.2. Urban freight

2.2.1. Definition

Global urbanisation has been increasing at a significant pace. In 1950, 50% of the world's population lived in urban areas and by 2007, this number had risen to 72%. Furthermore, it is expected that 85% of the global population will live in urban areas by 2050 (United Nations, 2008). The growth in urbanisation levels significantly increases the amount of domestic and commercial goods that are required within cities and towns, which in turn leads to a higher demand for urban freight transport. A strong correlation has been found between population size increase and the number of freight trips occurring in urban areas (Button and Pearman, 1981). Although the exact relationship between urban growth and freight movement has not been definitively established, the fact that the correlation between the two is positive has been firmly confirmed.

One of the first definitions of urban freight transport was proposed in 1977 as follows (Hicks, 1977):

> *"all journeys into, out of, and within a designated urban area by road vehicles specifically engaged in pick-up or delivery of goods (whether the vehicle be empty or not), with the exception of shopping trips"*

It is important to note that this definition is quite limited and does not take all aspects of urban freight into account. Due to this, many different definitions have been proposed since this first attempt in 1977. The exclusion of shopping trips (usually made by passenger cars) has, however, been a point of agreement amongst most authors who have attempted to define urban freight (Ballantyne, Lindholm and Whiteing, 2013). Contrary to the definition presented above, many have defined urban freight transportation as potentially including road, rail or water transport, but it must be noted that most urban areas rely mainly on road transport (Ballantyne, Lindholm and Whiteing, 2013). Additionally, it is important to note that only light and heavy goods vehicles are usually included in the definition of urban freight transport, excluding all passenger cars. Most definitions also imply that the cargo being transported must be of a large enough quantity in order for the trip to count as an urban freight trip.

2.2.2. Types of urban freight movement

When discussing urban freight, it is important to define the types of freight movements that are included. For the purpose of this study, the categorization of urban freight movements used in The Economics of Urban Freight Transport (1981) is accepted. The categories of freight movements are defined as follows:

1) *Import movements*: The transportation of goods into an urban area, with the urban area being the final destination of the goods.
2) *Export movements*: The transportation of goods out of an urban area to any other destination, with the goods being produced or manufactured in the urban area.
3) *Transient movements*: The transportation of goods through an urban area, but not originating or terminating in that area. It is possible that the goods can stay in the urban area for a period of time, but will eventually be transported elsewhere, either by the same vehicle that delivered it or by another vehicle.
4) *Intra-urban movements*: The local transportation of goods within an urban area, with the trips originating and terminating in the same urban area.

It is important to note that these movement types rarely interact with each other, mostly occurring completely independently (Button and Pearman, 1981). This makes the analysis of urban freight movements a very complex task.

The size of an urban area has a major influence on the types of freight movements that take place in the area. It has been found that the proportion of freight trips that involve intra-urban movements increases significantly as the size and population of an urban area increases (Button and Pearman, 1981). This means that the number of import and export movements becomes proportionately less as the size of the area increases. A study in the USA has shown that the citizens of urban areas become more self-sufficient as the size and population of the area increases, therefore, requiring less goods from other areas (Button and Pearman, 1981). This supports the idea that intra-urban freight movements would increase at a faster pace than import and export movements as an urban area grows.

2.2.3. Characteristics of urban freight

Urban freight transport plays an important role in the economic sustainability and growth of a city or town (Lindholm and Behrends, 2012). It is, however, a very complex system to manage.

On the one hand, it is important to support the urban freight sector to increase the benefits it has for the economy, but on the other hand, an increase in freight movements in an urban area could hold several negative impacts on the people living in the city. These negative impacts include an increase in traffic congestion, higher levels of air pollution and a decrease in road safety (Browne *et al.*, 2012). Specifically, urban deliveries have been found to have a significant contribution to higher congestion levels (Yannis, Golias and Antoniou, 2006). This could be attributed to the fact that the limited space on an urban road network frequently leads to delivery vehicles parking illegally and, by doing so, obstructing the movement of traffic to some degree. A study in 2005 found that delivery trucks in urban areas caused major delays when parked illegally (Han *et al.*, 2005).

Urban freight transport is much more complex to analyse than rural freight transport due to the fact that it is much more evident on urban roads that heavy goods vehicles and passenger cars contend for space (Russo and Comi, 2011). In urban areas, the presence of intersections, narrower roads, a higher number of vehicles and more pedestrians lead to many more conflicts between heavy vehicles and other road users than on rural roads. Therefore, it is extremely important to effectively manage any freight networks that involve urban areas.

The demand for urban freight transport is strongly dependent on the decisions of three major stakeholder groups. These three groups can be defined as follows (Russo and Comi, 2011):

1) *End-consumers*: The people who will finally use the goods being transported.
2) *Logistics and transportation operators*: Includes the shipper of the goods, the freight carrier and the receiver who will sell or provide the goods to the end-consumers.
3) *Public administration*: Officials who regulate freight movements, but are also focussed on improving urban freight to benefit the economy.

Similar to passenger cars, heavy goods vehicles have peak periods during which the most trucks are present on the urban road network. However, it has been found that the distribution of truck presence differs significantly from that of passenger cars. Additionally, the temporal distribution of trucks differs between different urban areas, depending on the land-use in the areas and the policies in place affecting freight movement (Irannezhad, Mohaymany and Mousavi, 2010). Therefore, the heavy vehicle distribution of one urban area cannot be assumed for another bona fide. Even so, a common trend seems to emerge that shows that most urban freight movements occur during the daytime (Button and Pearman, 1981). This observation could be an indication that freight is moved over long distances between different urban areas during the night (rural freight trips) and is delivered or picked up during the daytime. The operating times of goods vehicles in Greater London in 1977 can be seen in **Figure 2.1**. From this figure, it can be seen that goods vehicles in this area mainly operate during the daytime, peaking in the early afternoon. The distribution makes sense when considering the fact that businesses are usually open during these daytime hours.

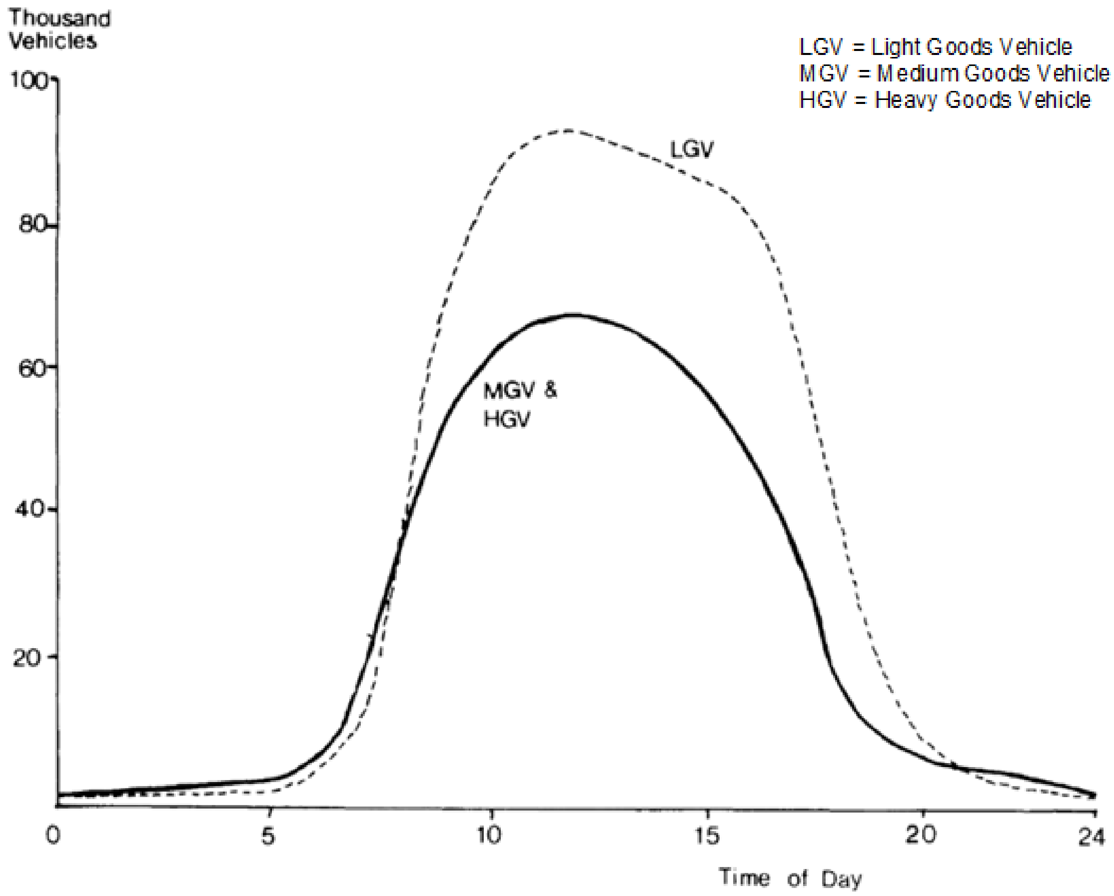


Figure 2.1. *Operating times of goods vehicles in Greater London in 1977 (Button and Pearman, 1981).*

An extensive study was performed into urban freight transport in Great Britain in the 1970s that resulted in some interesting observations (Button and Pearman, 1981). It was found that more light goods vehicles travelled in urban areas than heavy goods vehicles. This could be attributed to the fact that urban road networks are not always designed to accommodate large vehicles and drivers of heavy goods vehicles often choose to avoid these areas (Irannezhad, Mohaymany and Mousavi, 2010). It was noted, however, that heavy goods vehicles could carry significantly larger volumes of goods than smaller vehicles and could be the reason why the absolute number of larger vehicles was smaller (Button and Pearman, 1981).

Another possibility for this observation could be that freight is taken to consolidation centres on the outskirts of urban areas first and then distributed within the urban areas via smaller vehicles. The use of such consolidation centres is discussed in the next section.

It is interesting to note that light goods vehicles in Great Britain followed the same seasonal fluctuations as passenger cars when travelling in urban areas but heavy goods vehicles did not conform to the seasonal fluctuation patterns in any sense (Button and Pearman, 1981). This indicates that light and heavy goods vehicles cannot be lumped into the same group when analysing freight movements.

2.2.4. Urban freight management

Historically, most research into urban freight transport has focused on the impact that urban freight has on freight operators (Lindholm, 2012). The focus on freight operators has allowed for the identification of four main challenges that are faced when having to transport goods in urban areas, listed below (Lindholm, 2012):

- Higher congestion levels increase travel time of freight vehicles;
- Regulations and policies influence operations and limit access to important locations;
- Insufficient parking and unloading areas force drivers to park illegally and
- Problems at the receiver or shipper lead to queuing at pick-up and delivery locations.

In recent years, there has been a shift in focus from the impact that urban freight transport has on freight operators to the impact that it has on the city and its inhabitants. This has been especially true in Europe and the USA, where many initiatives have been investigated that could potentially reduce the negative effects that urban freight transport could hold. Three main methods of managing urban freight transport are used to minimise its negative impacts (Lindholm, 2012):

Restrictions

Restrictions could include restricting access for specific vehicle sizes or types, time restrictions, lane restrictions, delivery time restrictions and road pricing schemes. The use of restrictions in urban areas is extensively discussed in the following sections of this chapter.

Urban consolidation centres (UCCs)

Urban consolidation centres have been a popular attempt to manage the movement of freight vehicles in urban areas. These centres serve as consolidation points where goods delivered from outside the urban area are bundled and transported into the city. It is important to note that the UCCs discussed in this section refer to centres used by different freight carriers and not distribution centres of individual shipping companies.

Large goods vehicles are usually required to deliver goods to UCCs at the outskirts of urban areas after which smaller goods vehicles transport goods from the UCCs to their final destinations inside the urban area. One of these smaller vehicles should deliver goods to more than one destination in a single trip. This process could also work vice versa, with goods being transported to the UCCs by smaller vehicles from the urban area and then transported to other areas via larger goods vehicles. In theory, this measure should decrease the number of freight trips into an urban area by increasing the number of deliveries made by a single vehicle. It also allows intra-urban freight to be transported in smaller goods vehicles, allowing larger goods vehicles to avoid travelling into the area, eliminating some of the issues brought with the presence of large vehicles in these areas (van Rooijen and Quak, 2010).

Many UCC' have been implemented worldwide, with varying levels of success. Over 60 UCCs have been established in Europe, but not all have been successful (Nordtømme, Bjerkan and Sund, 2015). It has been found that these centres usually have very high costs associated with their establishment and operations (van Rooijen and Quak, 2010). Additionally, shippers are often reluctant to make use of UCCs, because it would mean that they would lose control of goods before they were delivered to the end-consumer (Lindholm, 2012). This reluctance could potentially render a UCC unsuccessful. It has been found that significant investment from the government is required for a UCC to be successful (Browne *et al.*, 2005). Furthermore, a study in Oslo, Norway, concluded that financial and stakeholder support are the two main requirements for a UCC to be successful (Nordtømme, Bjerkan and Sund, 2015). It has also been found that UCCs are much more likely to succeed if the urban area that it serves already experiences severe congestion problems and environmental issues (Browne *et al.*, 2005).

In London, a trial was performed for a UCC between 2005 and 2007 that would serve as a consolidation centre for construction materials (Browne *et al.*, 2012). Materials were delivered to the UCC and then distributed to where they were needed on construction sites in the city. During the trial period, there was a 70% to 80% reduction in CO_2 emissions compared to before the trial. There was also a decrease of between 60% and 70% in the number of vehicles delivering materials to construction sites in London (Browne *et al.*, 2012). The trial was a good example that UCCs could work if they are managed well and receive adequate financial and government support.

A more recent example of a successful UCC project can be found in Tokyo, Japan. The project was implemented in 2012 at Tokyo Skytree Town, a new commercial centre in the city. The project involves a joint delivery system (JDS) which entails the use of multiple UCCs. All deliveries that had to be made to Tokyo Skytree Town is first consolidated at one of the three UCCs and then transported by smaller trucks to the centre (Taniguchi, 2014). This project is unique to most of the other UCC case studies discussed in this section, because it receives no subsidies from government agencies (Taniguchi, 2018). It must be noted that the success of such a project with no subsidies relies heavily on the willingness of the developers of the commercial area to pay for the costs associated with constructing and managing the system. In this case, the developers were very interested in investing, because they placed high value in reducing traffic around their area and ensuring excellent delivery and pick-up services for their tenants (Taniguchi, 2014). It was reported that 58% less vehicles were required for delivery and pick-up services at Tokyo Skytree Town due to the implementation of the JDS (Taniguchi, 2018).

Infrastructure improvements

Changing the infrastructure of an urban area is often the most difficult and costly option of managing urban freight movement (Lindholm, 2012). The main reason for this is that infrastructure is usually already constructed and space for additional construction is limited in urban areas. Many authorities, therefore, choose to increase the efficiency of infrastructure use instead of reconstructing it. One of the most popular ways to increase the efficiency of infrastructure is to increase the use of rail as a freight transport mode, decreasing the load on the road network (Lindholm, 2012). It is also a popular measure to improve loading and unloading facilities in urban areas.

2.3. The influence of heavy vehicles

2.3.1. Background

Traffic streams on urban roads consist of various vehicle types and sizes, each vehicle having its own performance characteristics and movement capabilities. Some vehicles are designed to be agile and fast, while others are not designed for manoeuvrability, but rather for carrying capacity. Since different types of vehicles are different in size and performance, it is inevitable that they will influence each other when sharing the same road space. It has been found that the presence of heavy vehicles, even in low volumes, frequently limits other vehicles from performing at optimal levels (Moridpour, Mazloumi and Mesbah, 2014).

Heavy vehicles do not only affect the way in which other vehicles are able to move in the traffic stream, they also have a psychological effect on drivers (Kilcarr, 2011). As discussed later in this section, the effect that heavy vehicles have on drivers' psyche can lead to many problems, one of these potential problems being an increase in the number of accidents. Additionally, heavy vehicles generally cause much more structural damage to the roads that they travel on than the rest of the vehicle population.

2.3.2. Congestion and traffic flow

Because of their inherent properties, heavy vehicles do not have the same acceleration capabilities as passenger cars and commonly occupy much more road space. This frequently leads to the perception that the presence of heavy vehicles on the roads during peak times has a significant impact on the level of congestion. However, some studies have shown that this is not necessarily true. A study performed by the California Department of Transportation found that the effect of heavy vehicles on congestion is only noticeable when the percentage of heavy vehicles on the road is greater than 10% (Grenzeback *et al.*, 1989). This leads to the conclusion that the removal of heavy vehicles from the traffic stream may not have a significant impact if the heavy vehicle presence is low.

Although it is evident that low volumes of heavy vehicles will not have a significant impact on congestion levels, it is important to note that their effect becomes major when a larger number of heavy vehicles is present in a traffic stream. The same study in California (Grenzeback et al., 1989) found that the impact of large vehicles on traffic flow is typically equivalent to the impact of 1.5 to 2 passenger cars on freeways (called passenger car equivalents (PCE)). It must be noted, however, that the impact of heavy vehicles is influenced by several factors. A study in 2004 concluded that the PCEs of heavy vehicles are dependent on both the grade of a road and the number of heavy vehicles present (Al-Kaisy and Jung, 2004). It found that heavy vehicles have higher PCEs when the percentage of HGVs on a flat road is more than 5%. Conversely, in the case that grades are long and steep, the effects of heavy vehicles seem to decrease as the number of heavy vehicles on the road increases. The reason for this phenomenon could be that trucks tend to move close to each other on steep grades and their impacts are consolidated into the impact of a single truck. On flat roads, heavy vehicles usually travel at a larger distance from each other and each vehicle has its own, separate effect on traffic flow.

Other researchers have also proposed PCEs for heavy vehicles. The Highway Capacity Manual (HCM) (TRB, 2016) provides different PCEs for different types of heavy vehicles to account for the differences between the characteristics of these vehicles. The use of these values is, however, limited to application in free-flow conditions only. A study in 2013 concluded that the effect of heavy vehicles in congested conditions is actually much higher than the PCE values proposed by the HCM (Ahmed, Drakopoulos and Ng, 2013). Therefore, the effect of heavy vehicles on congested traffic flow cannot merely be determined by applying the PCEs from the HCM.

Maximum flow rates

Heavy vehicles have a major impact on the maximum flow rate that can be achieved on urban roads. A study that observed the movements of 1.2 million vehicles on urban freeways concluded that the maximum flow that can be achieved on a road starts to decrease when heavy vehicles make up more than 3% of the total traffic stream (Ahmed, Drakopoulos and Ng, 2013). This conclusion is graphically represented in **Figure 2.2**, which shows the relationship between heavy vehicle presence and maximum throughput on an urban freeway as measured by the researchers of the study.

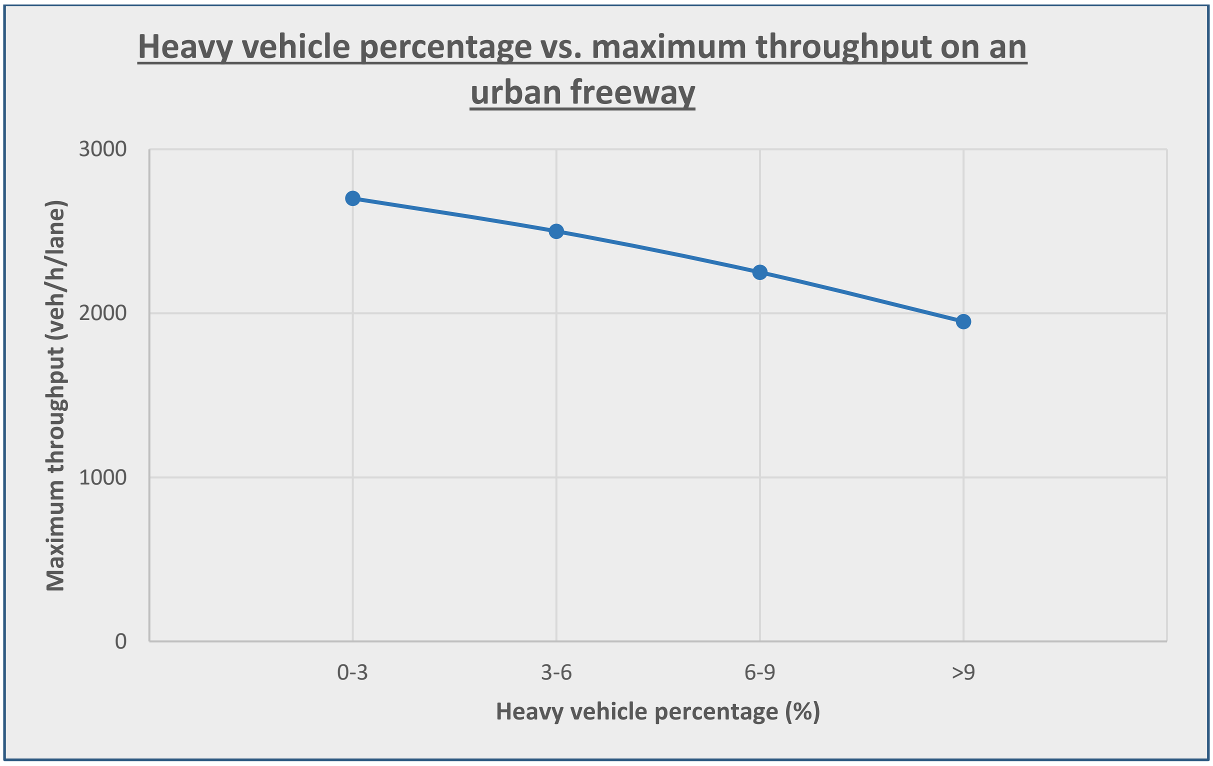


Figure 2.2. *Relationship between heavy vehicle presence and maximum throughput on an urban freeway (after Ahmed, Drakopoulos and Ng, 2013).*

Headways

Several studies have concluded that the average headway on a road increases as the percentage of heavy vehicles on a road increases. It has been found that passenger car drivers are usually more cautious of heavy vehicles and, therefore, increase their headway significantly when travelling behind a truck (Ahmed, Drakopoulos and Ng, 2013; Moridpour, Mazloumi and Mesbah, 2014). As part of their study, Ahmed, Drakopoulos and Ng calculated the 95% confidence interval (CI) headways for passenger cars trailing other passenger cars and passenger cars trailing heavy trucks. The results are shown in **Figure 2.3**. It can be observed that passenger car drivers increase their headways significantly when travelling behind large trucks. Additionally, the same study found that heavy vehicle drivers increase their headways when following passenger cars, possibly due to their limited deceleration capabilities.

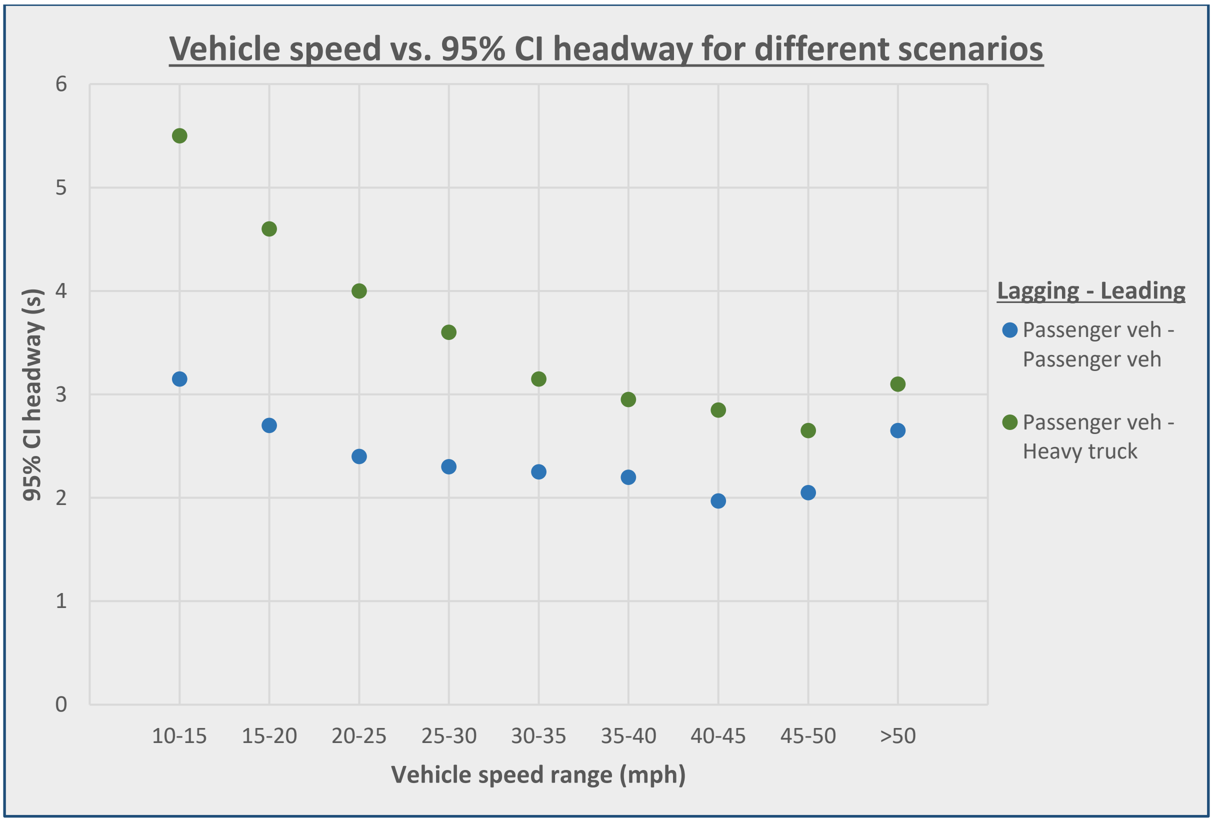


Figure 2.3. *Relationship between vehicle speed and headway for different vehicle combinations (after Ahmed, Drakopoulos and Ng, 2013).*

Average speed

Another characteristic that is influenced by the presence of heavy vehicles on a road is the average speed of the traffic stream. Generally, the average travelling speeds of heavy vehicles are significantly lower than those of passenger cars (Zavoina, Urbanik and Hinshaw, 1991). It is true that this difference in average travelling speeds affects the travelling speed of the entire traffic stream, but there is another reason why heavy vehicles affect the average travelling speed on a network. It has been suggested that passenger car drivers drive slower in the vicinity of heavy vehicles out of fear and caution. Additionally, it has been found that the speeds of passenger cars vary significantly when travelling close to heavy vehicles, possibly due to the fact that it is difficult for heavy vehicles to adjust their speeds at the same tempo as the rest of the traffic stream (Moridpour, Mazloumi and Mesbah, 2014). This could lead to unnecessary braking and accelerating which could lead to the formation of shockwaves, increasing congestion levels on a road network.

Travel times

Heavy vehicles significantly affect the travel times of other vehicles when they are present on a road. **Figure 2.4** shows the link between the percentage of HGVs on a road and average travel times as found in a study in Australia (Moridpour, Mazloumi and Mesbah, 2014). Results shown are for a 15-minute period as measured on a six-lane road. The study found similar results for other periods during the day. It is important to note that Lane 1 was a High Occupancy Vehicle (HOV) lane and therefore, there was a low percentage of heavy vehicles travelling in that lane. Furthermore, the heavy vehicles allowed in the HOV-lane had to have high power-to-weight ratios and could thus maintain relatively high speeds. Thus, the measurements for Lane 1 were frequently found to be outliers in the dataset. It can be concurred from the results that travel time generally increases as the percentage of heavy vehicles on a road increases.

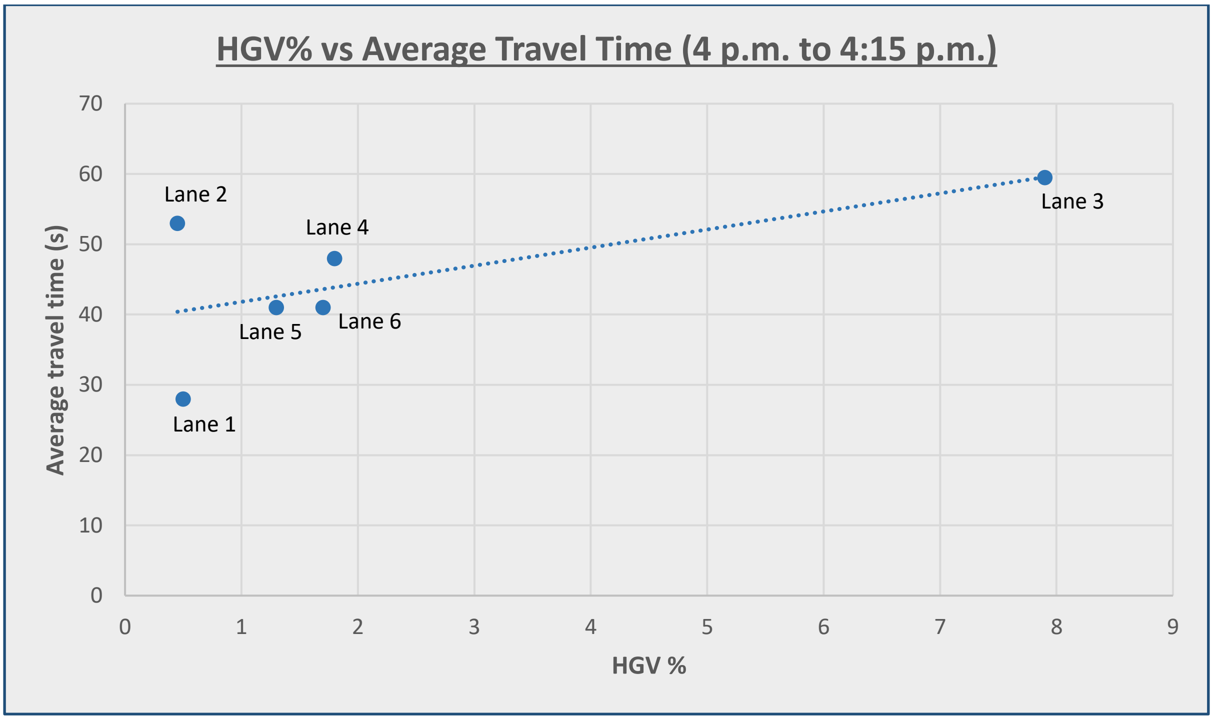


Figure 2.4. *Relationship between heavy vehicle percentage and average travel time (after Moridpour, Mazloumi and Mesbah, 2014).*

2.3.3. Road safety

An important factor to take into account on any road network is road safety. It is always important to consider the effect that a factor will have on the number of road accidents that may occur. It is, however, very difficult to attribute the cause of an accident to a single factor. Traffic accidents are usually caused by a myriad of different factors, rarely occurring due to a single problem. Even so, the types of vehicles present on a road have been found to play a significant role in the number and severity of accidents that occur.

The World Health Organisation (WHO) has stated that traffic accidents are much more likely to result in injuries or fatalities when heavy vehicles are involved than when only passenger cars are involved in the accident (WHO, 2004). Additionally, a study performed on

Interstate 80 (I-80) in California found that the number of accidents on a highway increased as the number of heavy vehicles on the road increased (Moridpour, Mazloumi and Mesbah, 2014). Another study in Spain found that the number of accidents on the country's roads would decrease if the number of heavy vehicles decreased (Ramirez *et al.*, 2009).

Driver psychology

Although a clear link has been found between the number of heavy vehicles present on a road and the number of accidents occurring, it is important to investigate the reasons for these accidents. Several studies in the USA have found that between 71% and 91% of accidents between heavy vehicles and passenger cars were caused by the driver of the passenger car (Jaillet, 2013). This raises a question. Why do passenger car drivers seem to make more mistakes when heavy vehicles are present? The answer lies in the psychology of drivers. A survey performed in the USA found that 38% of surveyed drivers became distressed when having to share a lane with a heavy vehicle (Kilcarr, 2011). This could lead to drivers becoming frantic in their driving behaviour and making decisions that they would not usually make in the absence of heavy vehicles. In order to prove whether or not the presence of heavy vehicles have a notable impact on the psychology of passenger car drivers, a survey was performed in China with 520 passenger car drivers (Kong *et al.*, 2016). The results of the study are shown in **Figure 2.5** to **Figure 2.7**.

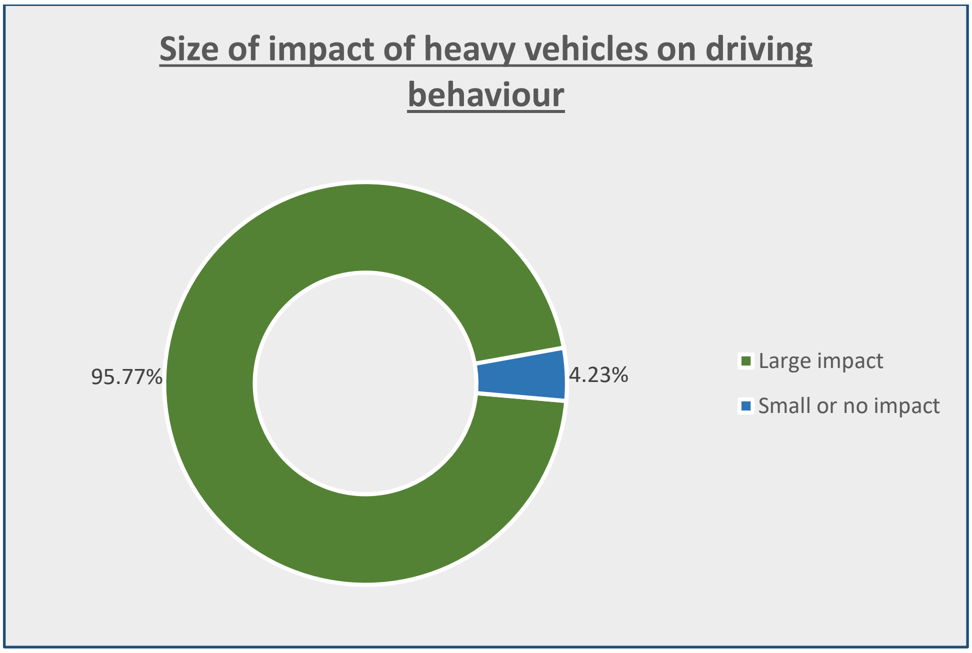


Figure 2.5. *Distribution of survey respondents' answers on the size of the impact that heavy vehicles have on their driving behaviour (after Kong et al., 2016).*

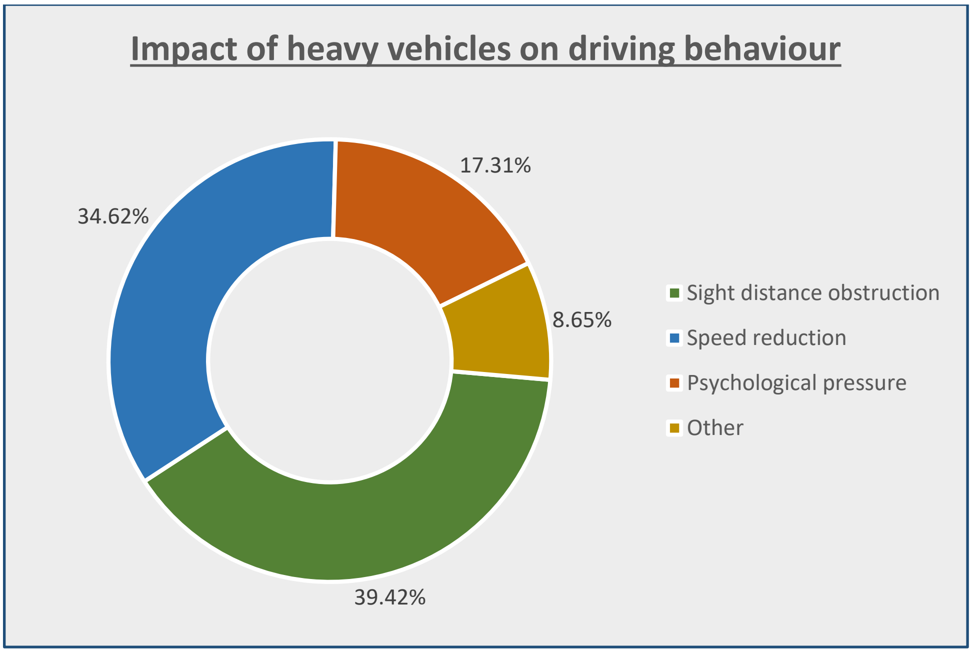


Figure 2.6. *Distribution of survey respondents' answers on the impact that heavy vehicles have on their driving behaviour (after Kong et al., 2016).*

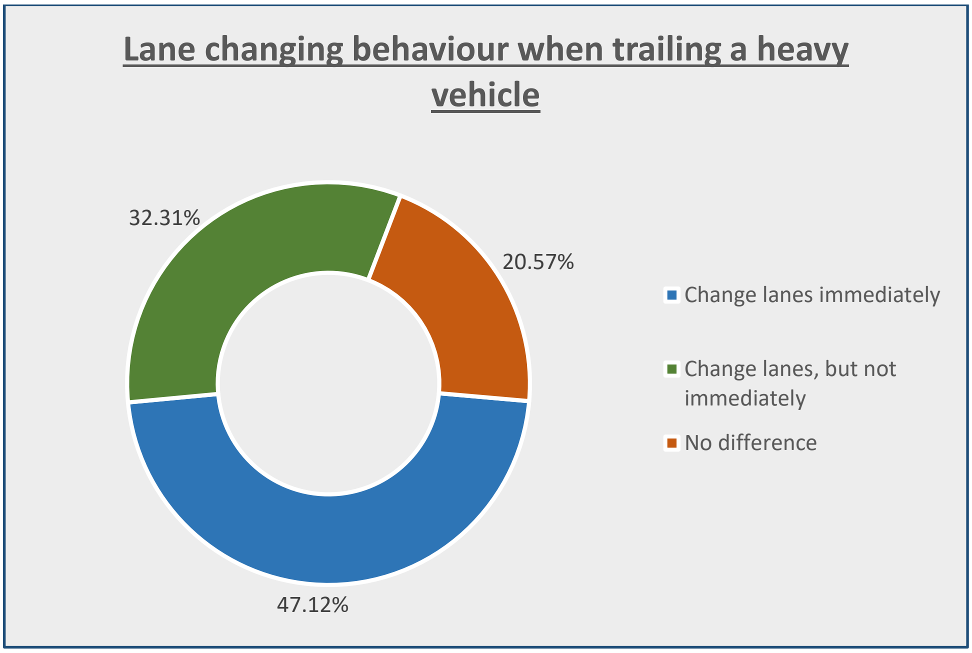


Figure 2.7. *Distribution of survey respondents' answers on lane changing behaviour when trailing a heavy vehicle (after Kong et al., 2016).*

It was found that more than 95% of participants felt that the presence of heavy vehicles impacted their driving behaviour significantly. Furthermore, the study found that approximately 17% of participants felt psychologically pressured when following a truck, while more than a third of participants believed that heavy vehicles forced them to reduce their speeds. Finally, when asked whether they would change lanes to avoid travelling behind a heavy vehicle, almost half of the participants indicated that they would immediately change lanes. The results of the survey are quite concerning. It has been found that the number of lane changes is directly related to the number of accidents that can be expected on a road (Moridpour, Mazloumi and Mesbah, 2014). Furthermore, several studies have found that drivers tend to increase their following distances when travelling behind heavy vehicles or move over to other lanes as soon as possible (Moridpour, Mazloumi and Mesbah, 2014). These changes in driving behaviour could increase the probability of accidents occurring.

Passenger car drivers do not only feel threatened when having to share their own lane with heavy vehicles. The Transportation Research Board (TRB) has found that passenger car drivers drive much closer to the road edge when passing heavy vehicles than when passing other vehicles (Mugarula and Mussa, 2003). This shows that drivers change their behaviour even when heavy vehicles are travelling in adjacent lanes.

Heavy vehicle size

The effect of heavy vehicles on road safety is not limited to changes in the driving behaviour of passenger car drivers. The physical properties of heavy vehicles have also been found to decrease the safety of a roadway. Because of their large size, heavy vehicles severely influence the visibility of the road for other drivers. The survey performed in China (Kong *et al.*, 2016), found that almost 40% of survey participants believed that heavy vehicles caused sight distance obstructions. It has been found that heavy vehicles impede drivers of passenger cars from adequately observing possible dangers, traffic incidents, important message signs and oncoming vehicles that may be ahead (Mannering, Koehne and Araucto, 1993). This may cause drivers to attempt to overtake heavy vehicles when it is not safe to do so. Additionally, the large size of heavy vehicles has an impact on the behaviour of heavy vehicle drivers. The number and size of blind spots greatly increase due to the size of the vehicle, frequently leading to heavy vehicles merging or changing lanes when it is not safe to do so (Mugarula and Mussa, 2003). Heavy vehicles have also been found to increase hazards for other drivers by causing air disturbances and water spray during rainstorms, mainly due to the fact that they have a very large surface area (Mugarula and Mussa, 2003).

Speed differentials

Travelling speeds play a significant role in the number of accidents that occur on a road. The problem, however, is not that heavy vehicles are speeding. They seem to abide by speeding laws on urban roads and often travel much slower than other vehicles on the road. A study in Houston, Texas found that only between 10% and 12% of sampled heavy vehicles broke the speed limit on urban freeways (Stokes and McCasland, 1986). Even when they are travelling at slow speeds, however, it is difficult for heavy vehicles to perform adequate evasive actions in order to avoid accidents. Furthermore, the differences between the travelling speeds of heavy vehicles and passenger cars cause large speed differentials to exist where heavy vehicles are present. It has been proven that traffic accidents are more likely to occur where speed differentials are large. David Solomon performed a study in 1964 with the goal to determine the effect of speed differentials on road safety. He found that there was a much higher probability of being involved in an accident when vehicles travelled more than 10 mph less than the average speed of a traffic stream (Solomon, 1964). He also determined that the accident rate could be predicted for a specific speed deferential. This relationship can be seen in **Figure 2.8**. The relationship, also known as the Solomon curve, has been verified by several studies (Cirillo, 1967; National Highway Traffic Safety Administration, 1991). It is thus clear that slow-moving heavy vehicles that share road space with faster-moving passenger cars pose an immense safety risk.

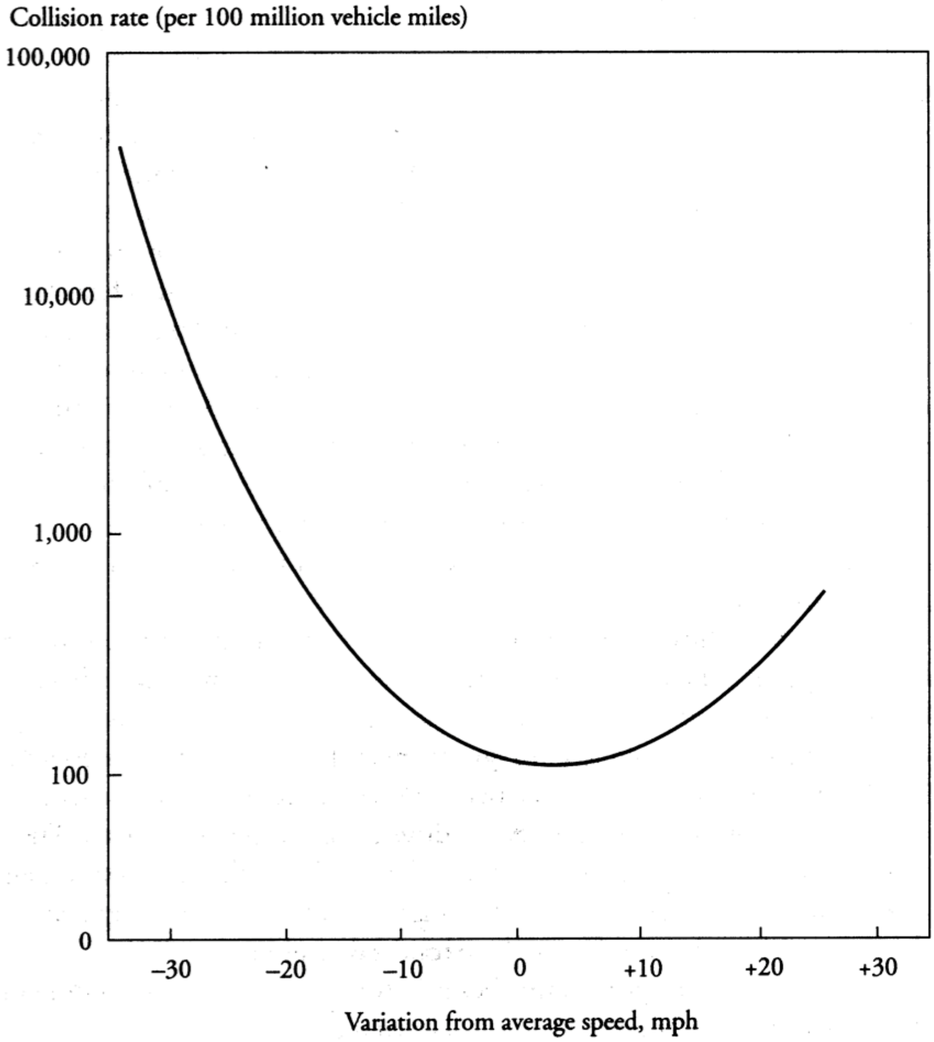


Figure 2.8. *Relationship between accident rate and speed differential (Solomon, 1964).*

<u>*Accident severity*</u>

Although it is clear that heavy vehicles contribute to the number of accidents on a road, they also have an effect on the severity of accidents that occur. Several studies have found that the severity of sustained injuries is increased significantly when a heavy vehicle is involved in a traffic accident (Chang and Mannering, 1999). Additionally, a study in the USA found that the presence of heavy vehicles in a traffic accident increases the dangers posed by factors that do not usually have a large impact on the injuries sustained (Chang and Mannering, 1999). It must, therefore, be noted that, even if an accident could have caused little to no injuries with only passenger cars involved, the same accident could lead to much more serious injuries if a heavy vehicle replaced even just one of the passenger cars.

A study in the USA found that most accidents involving heavy vehicles occur outside of peak times (Grenzeback *et al.*, 1989). Therefore, restricting heavy vehicles from urban roads during peak periods may not be an effective measure to reduce traffic accidents.

2.3.4. Structural damage to roads

Heavy vehicles are, by definition, very heavy. This means that they exert more forces on roads than passenger cars and, therefore, cause more damage to road surfaces (Bai *et al.*, 2009). Studies have found that heavy vehicles cause approximately 500 times the damage that passenger cars cause in South Africa (Department of Environmental Affairs, no date).

Compared to the structural damages that heavy vehicles incur to roads, the impact of passenger cars is negligible. A standard unit used in engineering to measure the damage done to a road is an Equivalent Single Axle Load (ESAL). One ESAL is equal to the damage done by 18 000 pounds on a single axle of a vehicle (Viton, 2012). When comparing the common ESAL values of different vehicles, it can be seen that the damage of passenger cars compared to heavy vehicles is not even mentionable. Some common ESAL values can be found in **Table 2.1**.

Table 2.1. Typical ESAL values for different vehicle types (after Viton, 2012).

Vehicle Type	ESAL Value
Passenger car	0.0008
Urban Transit Bus	0.6806
Single Unit 2-Axle Truck	0.1890
Single Unit 3-Axle Truck	0.1303
Conventional Semi-Trailer 3-Axle Truck	0.8646
Conventional Semi-Trailer 4-Axle Truck	0.6560
Double Trailer 5-Axle Truck	2.3187
Tractor Trailer 5-Axle Truck	0.5317

A study performed in Virginia found that even a small increase in the allowable weight limits of trucks has an enormous impact on the structural damage to roads (Freeman and Clark, 2002). The study, performed in 2002, found that a higher weight limit led to an additional $28 million (almost $40 million in 2018) worth of road damage being done over 12 years.

The design of heavy vehicles has also been found to have an impact on the damage that it causes to a road. In Denmark, it was found that a semi-trailer truck, although it typically weighs much more than a truck with a separate trailer, causes less damage to roads (Hjort, Haraldsson and Jansen, 2008). This was found to be due to the design of the tyres, the axle design and also the dispersion of loads between axles.

In Los Angeles, the impact of removing trucks from the road network has been exhibited in a real-world example. Since Ventura Freeway was opened in 1940, no trucks were allowed to travel on the road due to the fact that the road could not support heavy loads. It was reported in 1992 that the road had never been resurfaced and was still in good condition (Fitzpatrick, Middleton and Jasek, 1992). This is a remarkable lifespan of more than 50 years. It is obvious that roads can last much longer when no truck loads are imposed.

It is easy to see that the presence of heavy vehicles drastically increases the structural damage incurred to roads. But what effect does this have? Mainly, it leads to an increase in maintenance costs. Heavy vehicles decrease the lifespan of the roads they travel on due to more recurrent damage. This in turn, leads to more frequent maintenance being required (Bai *et al.*, 2009). Frequent maintenance does not only have financial implications, it also means that more congestion will be caused by roadworks.

In South Africa, provinces like North West and Mpumalanga are home to many mining activities. This has led to many towns in these provinces reporting extensive road damage in the areas of the mines, mainly due to the fact that a large number of heavy vehicles is required to transport materials to and from these mines. In 2012, the deputy Transport Minister claimed that most of the road damage in North West and Mpumalanga were caused by heavy vehicles, mostly generated from the mines (News24 Staff, 2012).

2.3.5. Other effects

Apart from road congestion, traffic accidents and road damage, heavy vehicles pose several other risks. A study performed in California in 2012 studied the effects of HGVs on residential values of houses located near freeways (Li and Saphores, 2012). The results showed that the value of residences close to freeways decreased significantly when heavy vehicles were present on the roads. It could be argued that living near a freeway would automatically decrease the value of a house, irrespective of the vehicle compositions of the traffic stream. It was found, however, that the value of a house located within 100 m of a freeway, that initially was worth $420 000, decreased by only $24 when the total traffic on the freeway increased by 1%. A house of the same value, located between 100 m and 400 m from the freeway, depreciated in value by more than $2 000 when only truck traffic increased by 1%. It is obvious that an increase in truck traffic has far larger consequences than an increase in total traffic. The main reasons for the decrease in residential values when heavy vehicle numbers increased was identified as noise pollution, air pollution and vibrations caused by the movement of heavy vehicles. Other studies have found similar results (Li and Saphores, 2012).

Noise can never be avoided when dealing with roads, since all vehicles produce some kind of sound when operated. It is, however, true that heavy vehicles produce much more noise than passenger cars on average. This could be due to the fact that passenger cars are frequently designed to be as quiet as possible, while the designers of heavy vehicles typically focus more on capacity requirements.

Several studies have found that heavy vehicles produce more air pollution than passenger cars. **Figure 2.9** shows that heavy vehicles accounted for 23% of transportation-related greenhouse related gas emissions in the USA in 2015 (Richter, 2017). Even though the number of the heavy vehicles was significantly lower than the number of passenger cars, it produced more than half the amount of emissions produced by passenger cars. This air pollution has been proven to contribute to increased health risks to people living close to freeways, including respiratory problems and asthma (Li and Saphores, 2012).

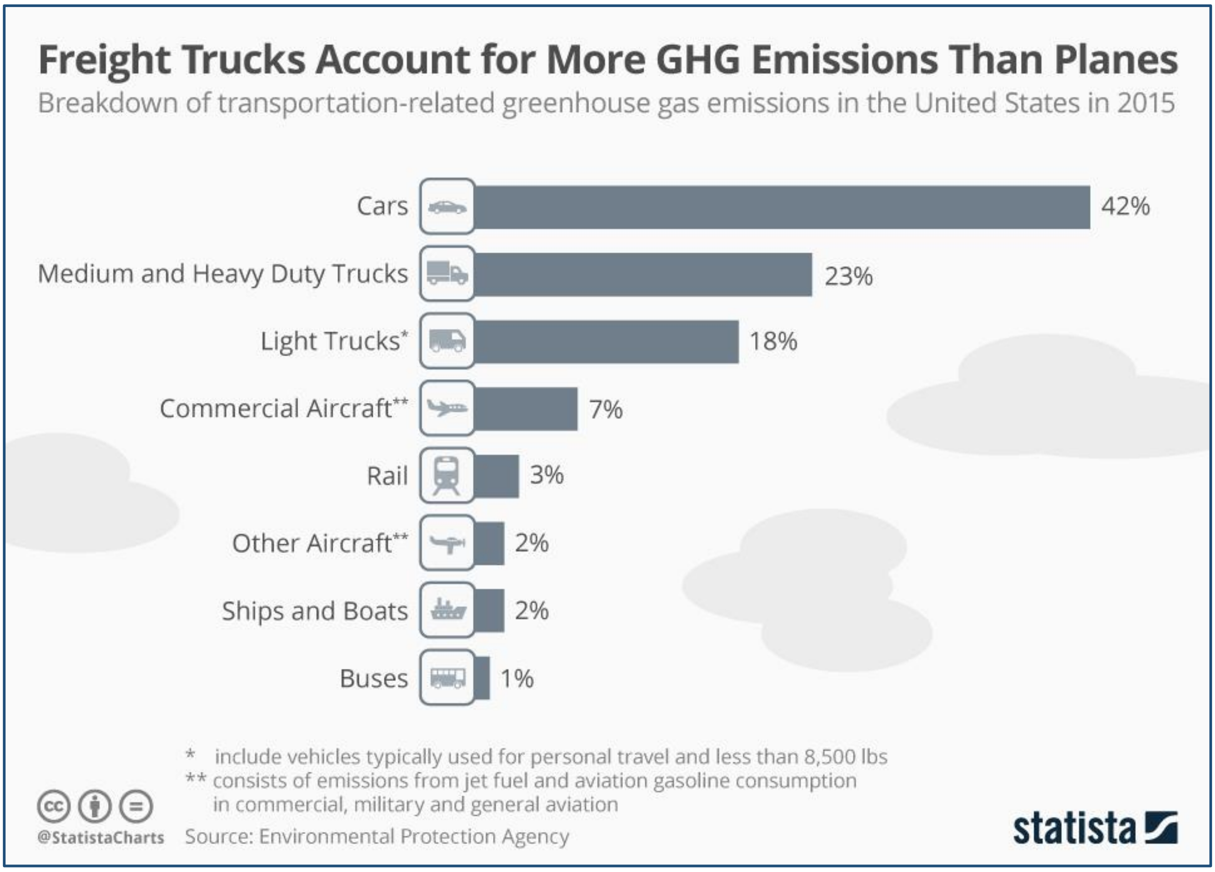


Figure 2.9. *Transportation-related greenhouse gas emissions in the USA in 2015 (Richter, 2017).*

2.4. International operating time restrictions

2.4.1. Background

Several countries have placed restrictions on the times that heavy vehicles may travel on specific roads. These restrictions have been implemented in various forms and have been met with varying degrees of success. Overall, it was found that the level of success of time restrictions was very much dependent on what authorities were trying to achieve by implementing it. It is important to note that the time restrictions discussed in this section are not all peak-period restrictions like the restrictions that this study investigates.

2.4.2. General studies

The effectiveness of restricting heavy vehicles during certain time periods has been studied by several researchers worldwide. Much of the research performed up to date has focused on restricting heavy vehicle movements during peak periods. Proponents of peak period restrictions believe that the absence of heavy vehicles could lead to a significant decrease in congestion levels and travel times for passenger cars. However, those who hold this view frequently fail to consider the latent demand of a road network. By reducing the number of heavy vehicles on a congested road network, the volume that was freed up could potentially be filled by the latent demand of other vehicles. This means that drivers who usually travelled outside of peak times to avoid congestion, could now travel during peak periods due to lower congestion levels and eventually, congestion levels could be high again (Campbell, 1995).

A study performed in the USA (Grenzeback *et al.*, 1989) found that peak-period bans of heavy vehicles on freeways would lead to a slight increase in the average speeds on the freeways, but that this would be short-lived. The researchers suggested that most of the congestion-related benefits of the restrictions would be void within six weeks to six months after implementation. This was attributed to the fact that more drivers who previously travelled outside of peak periods, tended to travel during peak periods after conditions started improving. It is important to note that this would only occur on road networks that were already saturated before restrictions were implemented. The same study estimated that approximately 80% of heavy vehicles would merely use other routes where restrictions are not applicable and only 20% would shift their operation times outside of peak periods. This could pose problems, since congestion on routes not affected by time restrictions could significantly increase. The study finally concluded that area wide truck restrictions would not usually be economically viable and that restrictions should rather be limited to specific roads prone to high congestion or high accident rates.

In 1986, a study was performed in Texas (Stokes and McCasland, 1986) to determine the possible effects of peak-period restrictions on the state's roads. It was found that most accidents involving trucks occurred during off-peak periods and, therefore, peak-period restrictions would have little impact on reducing the number of accidents that occur. Furthermore, the study found that most trucks in Texas already travelled outside of peak periods, thus the impact of banning heavy vehicles during peak periods would be very small in terms of congestion levels. The study finally concluded that time restrictions would not be a viable option for trying to reduce congestion or improve road safety. It also found that such restrictions would be very difficult to implement and enforce.

Another form of time restrictions that has been studied is the requirement that all heavy vehicle deliveries in city centres should take place at night-time. It has been proposed that such restrictions could improve road safety for vulnerable road users like cyclists and pedestrians during the day and that passenger cars would be able to travel at higher speeds. Furthermore, delivery costs would decrease and delivery productivity would increase (Holguín-Veras *et al.*, 2014).

A study in Greece found that the implementation of delivery time restrictions would yield no significant improvements in congestion or air quality (Yannis, Golias and Antoniou, 2006). Although congestion and air pollution levels improved during the hours of restrictions, they were significantly worse outside of these hours. The same study found that the noise of deliveries taking place at night could have a negative impact on people living close to delivery destinations. It was noted, however, that many deliveries, like fresh produce, already took place during the early morning hours, meaning that these people could have already been used to the noise (Yannis, Golias and Antoniou, 2006). The study concluded that the success of any heavy vehicle delivery restrictions depends heavily on gradual implementation, allowing the affected parties to adjust their operations accordingly (Yannis, Golias and Antoniou, 2006).

Two major issues have been identified in terms of the implementation of heavy vehicle restrictions that are based on access according to weight and size. Firstly, it has been found that freight operators commonly modify their fleets to include a higher number of small vehicles that are exempt from the imposed restrictions. This, in turn, leads to an increase in congestion levels (Anderson *et al.*, 2013). Secondly, it is very difficult to enforce these types of restrictions. It is possible that many heavy vehicle drivers are unaware of restrictions when entering unfamiliar urban areas. Interviews with truck drivers in Medan, Indonesia revealed that most of the drivers were unaware of a heavy vehicle ban in the city, two years after it had been implemented (Anderson *et al.*, 2013). Additionally, many additional enforcement officers would be required to enforce access restrictions and they would need to be knowledgeable about the details of the restrictions.

2.4.3. Implementation of operating time restrictions

Restrictions relating to the movement of heavy vehicles during certain periods have been implemented in several cities worldwide, with varying levels of success. What follows is a brief discussion of some of these implementations, including the manner in which they were implemented and the results of the restrictions. **Table 2.2** on page 49 provides a summary of the implementations discussed.

Los Angeles, USA

In the late 1980s, authorities in Los Angeles performed extensive research into possible peak-period bans for heavy vehicles. The research was prompted by the success that was experienced during the 1984 Olympic Games in the city (Reid, 2015). During the event, a voluntary truck ban was instituted on some of the city's most congested freeways during morning and afternoon peak periods. Many truck drivers voluntarily complied with the ban, since a different law banning any deliveries before 7 a.m. in the morning, was lifted during the Games (Quinn, 1987). The restrictions proved extremely effective, with congestion levels on the city's freeways reducing by 60% and truck traffic reducing by 16% during peak periods (Holeywell, 2013).

In 1987, city officials started considering the reimplementation of the heavy vehicle restrictions on a permanent basis. At that moment, Los Angeles was the most congested city in the entire USA (Reinhold, 1988). (It is interesting to note that, at the time of writing, Los Angeles was still the most congested city in the USA and the twelfth most congested city in the world (TomTom, 2016).) It seemed like the reimplementation of the restrictions could make a significant difference in congestion levels during peak periods, since approximately 27% of shipments were received during the morning peak and 58% of shipments were sent out during the afternoon peak (Campbell, 1995). This showed that a considerable number of trucks were present on the city's roads during peak periods. The restrictions considered would remove approximately 70% of the heavy-duty trucks operating in Los Angeles from the roads during peak periods (Reinhold, 1988). Furthermore, it had been estimated that passenger car drivers lost a total of 430 000 hours each day due to congestion on Los Angeles freeways at that time (Campbell, 1995). Therefore, it was crucial to find a way to reduce congestion levels in the city.

Eventually, it was decided to abandon the plans to implement heavy vehicle restrictions in Los Angeles. The main reason for this decision was the fact that California had a law in place which required that officials should provide acceptable alternative routes for heavy vehicles when they were banned from using other roads (Reid, 2015). It was very difficult for authorities to find adequate routes that heavy vehicles could use as an alternative to the roads where they wanted to impose the bans. Two routes were identified, but the public raised numerous complaints over some of the roads that were considered, since the routes passed through small communities (Quinn, 1987). Additionally, it was found that late-night deliveries could cause noise disturbances to residents living in areas close to delivery points (Reinhold, 1988). A study also found that the proposed restrictions could cause significant delays for freight carriers, since they would only be able to make deliveries within small time periods (Campbell, 1995). Considerable opposition from shippers and receivers also contributed to authorities abandoning the proposed restrictions (Holguín-Veras *et al.*, 2006). Furthermore, many stakeholders argued that businesses who opened much earlier or closed much later than usual during the Olympic Games to receive shipments, would not be willing to do so on a permanent basis (Quinn, 1987). Authorities intended to force businesses to stay open for at least four hours at night to receive shipments, but it was found that this could have resulted in significant additional costs for business owners (Reinhold, 1988).

New York City, USA

In New York City (NYC), much research has been performed into the effects of a regulation requiring heavy vehicles to make deliveries during the night between 7 p.m. and 6 a.m. In 2010, it was stated that more than 100 000 deliveries were made in NYC each day (Solomonow and Gastel, 2010). Approximately 80% of the trucks travelling into NYC were found to travel into the city between 6 a.m. and 7 p.m. One study found that such restrictions could potentially reduce congestion and pollution in NYC, but that financial incentives would be crucial to ensure that businesses receiving goods would not be too negatively affected (Holguín-Veras *et al.*, 2006).

In 2010, a four-month pilot project in NYC was implemented in which eight delivery companies voluntarily made deliveries only between 7 p.m. and 6 a.m. (Solomonow and Gastel, 2010). The project revealed that night-time deliveries resulted in better reliability of delivery times, improved travel speeds and more efficient operations overall. Delivery times were found to decrease by 48 minutes on average (Mobility Investment Priorities, no date). Furthermore, GPS tracking showed that a truck that usually travelled at 3 mph during the day on a specific route, travelled at 8 mph at night on the same route (Mobility Investment Priorities, no date). Delivery companies reported savings in fuel costs and drivers claimed that they felt safer and more relaxed while making deliveries. Drivers also received less tickets and fines for illegal parking, since sufficient legal parking for deliveries was available during the night (Solomonow and Gastel, 2010).

Receiving businesses reported that their staff was much more productive because they did not waste time waiting for deliveries during the day (NYC DOT, no date). The project encouraged businesses to provide delivery companies with a key to the delivery location so that businesses would not need their own staff to work during the night to receive deliveries.

All participants, including the delivery companies and the businesses who received shipments, reported savings during the project (Solomonow and Gastel, 2010). The pilot project in NYC showed that collaboration and cooperation between all affected parties would be crucial factor to ensure the success of such a program (Holguín-Veras *et al.*, 2014).

After the success of the pilot project in 2010, the NYC Department of Transportation (DOT) encouraged more businesses and delivery companies to follow suit and only deliver goods between 7 p.m. and 6 a.m. The city proposed that they would assist businesses in the process of moving their deliveries to the night-time, especially in managing noise and providing support for the mitigation of noise complaints. A program to recognise and acknowledge participants in the program was set to be launched in 2017 (Trottenberg, no date). An official regulation was, however, never implemented to force businesses to adhere to these restrictions.

In 2018, a six-month pilot project was implemented in some parts of NYC that imposed similar restrictions on deliveries. The restrictions, which were not voluntary like in 2010, only allowed commercial deliveries to be made between 10 a.m. and 4 p.m. and between 7 p.m. and 7 a.m. (New York Truckstop, 2018). Additionally, the restrictions only allowed deliveries to be made on one side of the road. In order to ensure that the regulations are obeyed, the New York Police Department will add 110 officers for the purpose of enforcing the restrictions (Bisram, 2018). At the time of writing, the results of the pilot project was not yet known.

Mexico City, Mexico

Mexico City was branded as the most polluted city in the world by the UN in 1992 (McGrath, 2017). Even in 2017, the city still struggles with pollution levels far above those recommended by the UN and an almost constant blanket of smog hanging over the city's skyline (Guthrie, 2016). The location and geography of the city plays a large role in the high levels of pollution, but the rising number of vehicles on the city's roads cannot escape blame (Browne, 2016).

In a bid to reduce the air pollution and congestion levels in the city, the capital of Mexico implemented regulations restricting the movement of all heavy vehicles weighing more than 3.5 tons. The ban, implemented in 2008, restricts heavy vehicles from the historical centre of the city between 7.a.m. and 10 p.m. In the same year, Mexico City banned all heavy vehicles weighing more than 3.5 tons or being longer than 7.5 m from the city's main road between 6 a.m. and 11 p.m. (Dablanc and Lozano, 2013). It is important to note that vehicles delivering frozen products, perishable items or constructions materials are exempt from the restrictions (Giuliano *et al.*, 2013).

Although no information could be found on the actual results of the implemented restrictions, some studies have been performed to predict what the results might be.

A study was conducted in 2012 on the impact of freight restrictions in Mexico City, including the restrictions implemented in 2008 (Lyons *et al.*, 2012). The study concluded that the number of heavy vehicles weighing more than 3.5 tons in the city during peak hours was too low to make a difference to congestion and pollution levels by removing them from the city's roads. No research was performed into the effects of the restrictions during off-peak hours. Furthermore, the study found that the restrictions could potentially lead to heavy vehicles using unsuitable and dangerous roads, longer travel paths for heavy vehicles and an increase in logistical and product costs (Lyons *et al.*, 2012).

A study conducted on the effects of banning all heavy vehicles weighing more than 3.5 tons from Mexico City's roads between 7 a.m. and 9 a.m. found that the travel times and emissions of trucks decreased (Lyons *et al.*, 2017). However, it concluded that the benefits to heavy vehicles were cancelled out by other vehicles due to the presence of latent demand. It was determined that the space freed up by the removal of heavy vehicles were immediately filled by other vehicles. Overall, it was concluded that such restrictions would most likely be more harmful than beneficial to the city as a whole (Lyons *et al.*, 2017).

In addition to the heavy vehicle restrictions discussed above, all vehicles on Mexico City's roads, including heavy vehicles, are restricted from using the roads on at least one day in the week. The day on which a vehicle may not be used is dependent on its registration number (Browne, 2016). City officials believed that reducing the number of vehicles on the roads would significantly decrease air pollution in the city. It was even predicted that the restrictions could decrease vehicle emissions by 16% (McGrath, 2017). In 2017, however, it was reported that the restrictions have had no significant effect on pollution levels in the city (McGrath, 2017). This was mainly contributed to the fact that many commuters purchased a second car, actually leading to an increase in the number of vehicles on the city's roads.

Manila, Philippines

In Manila, the lack of an adequate rail network for freight transport led to a large number of heavy vehicles on the city's roads and the roads in the surrounding area (Castro and Kuse, 2005). This resulted in authorities having limited options when trying to reduce the number of heavy vehicles on the city's roads, since the movement of goods was so dependent on these vehicles. The problem of rising congestion levels, however, prompted authorities to implement regulations that restricted the movement of heavy vehicles during certain times of the day in the 1970s.

Time restrictions for heavy vehicles have been in effect in the metro area of Manila since 1978. The restrictions ban all heavy vehicles weighing more than 4.5 tons from using some of the metro's main roads in morning and afternoon peak periods (6 a.m. to 9 a.m. and 5 p.m. to 9 p.m.). Other roads in the metro area are not allowed to be used by heavy vehicles between 6 a.m. and 9 p.m. (Castro and Kuse, 2005). It is important to note, however, that alternate routes are available for heavy vehicles to use within these periods. This is an important provision, since freight carriers will still be able to transport freight between pick-up and delivery points.

Even though the freight industry is still able to operate on alternate routes, there have been some negative effects because of the time restrictions. The National Economic and Development Authority (NEDA) of the Philippines performed a study in 1981 into the effectiveness of the heavy vehicle restrictions in Metro Manila. They found that the economic losses experienced due to the time restrictions up to that date was substantial. Furthermore, it was found that freight trucks only performed at 50% efficiency, where it had been higher before. By 1994, the efficiency of the freight industry had decreased to 33% (Castro and Kuse, 2005).

In 2014, the metro's roads were opened for use by heavy vehicles without any restrictions (Frialde, 2015). The restrictions were reportedly lifted in an attempt to alleviate congestion at the ports in the area. In 2015, however, new restrictions were implemented in Metro Manila. The restrictions banned all heavy vehicles from the metro's roads from 6 a.m. to 10 a.m. and 5 p.m. to 10 p.m. (Delizo, 2016). It is important to note that freight vehicles carrying perishable goods were exempt from the new restrictions. Officials claimed that the congestion levels at ports were again low enough to allow the restrictions to be implemented and, in addition, there was a call from residents in the area for the restrictions to be implemented (Delizo, 2016). Along with the new restrictions, very high fines and strict punishments were implemented for any drivers violating the rules (Frialde, 2015).

The city of Manila itself also implemented its own truck restrictions in 2014. The restrictions banned heavy vehicles weighing more than 4.5 tons from the city's roads between 5 a.m. and 9 p.m. (Sauler, 2014). The restrictions were met with much opposition from neighbouring cities, however. The mayor of one of the cities close to Manila claimed that the restrictions would result in increased congestion and truck traffic in his city and other cities close to Manila (Sauler, 2014).

Seoul, South Korea

In Seoul, all heavy vehicles weighing more than 2.5 tons have been restricted from all inner-city roads during working hours since 1979 (Smith, Michell and Shin, 1986). The main reason for these restrictions was to relieve congestion in the central business area. By implementing these restrictions, officials attempted to force heavy vehicles to make deliveries during the night. The restrictions have, however, led to an increase in the number of small delivery vehicles on the city's roads (Castro and Kuse, 2005). This shift to smaller vehicles was found to potentially worsen congestion in the city (Anderson *et al.*, 2013).

Mumbai, India

Mumbai's economy has experienced extremely high growth rates in recent years. This has led to the city having to struggle with a fast-growing number of vehicles on its roads, contributing to high levels of congestion and a high number of accidents occurring. In an attempt to reduce congestion, the city implemented heavy vehicle restrictions in late 2016 that banned all heavy vehicles from the city's roads during morning and afternoon peak periods (Alok, 2016). The hours of the restrictions are 7 a.m. to 11 a.m. and 5 p.m. to 9 p.m. (DNA Correspondent, 2016b).

It is important to note that Mumbai's restrictions are not applicable to heavy vehicles that deliver perishable goods such as milk and vegetables, government vehicles or buses carrying passengers (DNA Correspondent, 2016b). This means that some important deliveries may still be made within peak hours. This is an important fact to note, since many studies that have found time restrictions to not be economically viable, have focussed on the delivery of goods. If goods that need to be delivered within peak hours are allowed to be delivered, the restriction of other heavy vehicles could prove beneficial to the economy.

Although the main reason for the restrictions was cited as the rising congestion levels, ongoing construction work in the city has also contributed to the decision to ban heavy vehicles during peak periods. Several rail line construction sites in the city cause obstructions to roadways, increasing congestion (DNA Correspondent, 2016b). Furthermore, monsoon season in India brings with it heavy rainfall, frequently causing major road damage (Alok, 2016). The maintenance required to repair this damage also contributes to high congestion levels.

The city of Mumbai has allocated specific sites where heavy vehicles will be able to park and wait during peak periods, reducing the number of trucks having to park next to roadways (DNA Correspondent, 2016b).

Although the restrictions are not as strictly enforced as many other cities', much opposition was received from the trucking industry in Mumbai. The main complaint from the industry was that operating costs and travel times would significantly increase due to restrictions in freight movements (DNA Correspondent, 2016a). Furthermore, it was argued that it could have a severe negative impact on India's economy if other cities in the country were to implement the same restrictions (DNA Correspondent, 2016a). It must be noted that freight transport in India typically takes place over very large distances and therefore, a trip that would usually take only one day, could take several days to complete with peak period restrictions in place. The trucking industry in India placed the blame on the city's lack of adequate infrastructure and claimed that removing trucks from the roads will not significantly improve congestion levels (Alok, 2016).

Stockholm, Sweden

The city of Stockholm seemed to do the opposite of the cities discussed so far in terms of restricting trucks at certain times. Heavy vehicles in Stockholm are banned from making deliveries at night between 10 p.m. and 6 a.m. (KTH The Royal Institute of Technology, 2017). This seems counterintuitive when considering the trend that other cities are following; making freight carriers ship and receive their shipments at night-time in order to reduce the number of vehicles on the road network during the day. Nevertheless, Stockholm has a very good reason for restricting trucks from making deliveries at night. City officials implemented the night-time bans mainly due to complaints from residents that heavy vehicle deliveries created too much noise when taking place at night (Li, 2015). It must be noted that not all heavy vehicles have to adhere to the restrictions. Some trucks have been developed to produce almost no noise and special permits can be granted in Stockholm that allow these vehicles to operate at night (Li, 2015).

The restrictions in Stockholm have created many problems for stakeholders. Freight carriers must frequently send multiple heavy vehicles out at the same time to make deliveries, since they are forced to make many of their deliveries during peak hours (KTH The Royal Institute of Technology, 2017). A single truck cannot make enough round-trips because congestion significantly increases the travel time of each truck during peak hours. This means that many more heavy vehicles are present on Stockholm's roads than would be needed if freight carriers could function at full capacity. A study in 2017 found that the number of freight vehicles on Stockholm's roads could be three times less if trucks were allowed to deliver goods at night

(KTH The Royal Institute of Technology, 2017). The problems caused by the night restrictions in Stockholm has shown that night deliveries could potentially be beneficial.

A study in 2015 found that deliveries outside of peak hours would require up to 21% less travel time than during peak periods in Stockholm (Li, 2015). The same study also found that delivery times during off-peak deliveries would be much more reliable than during peak periods.

London, England

One of the oldest heavy vehicle restrictions exists in the capital city of England. Similar to the restrictions implemented in Stockholm, the restrictions implemented in London ban heavy vehicles during the night, as opposed to the restrictions implemented in many other cities discussed in this section. Under the restrictions, all heavy vehicles weighing more than 18 tons are banned from travelling on several of London's roads during the night and during weekends, with the exception of vehicles that receive prior authorization from the city. The bans are in effect between 9 p.m. and 7 a.m. on weeknights (including Friday nights) and on weekends between 1 p.m. on Saturdays and 7 a.m. on Mondays (London Councils, no date). According to city officials, the restrictions were implemented in 1985 to combat noise generated during the night by heavy vehicles travelling in the city and making deliveries (London Councils, no date).

In 2016, the head of policy for London and the South East of the Freight Transport Association (FTA) claimed that the retractions had led to increased fuel costs for freight carriers because heavy vehicles were forced to take much longer routes than necessary. Additionally, she added that the restrictions had led to an increase in vehicle emissions in the city (Tindall, 2016).

In recent years, freight carriers in the United Kingdom have called for a review of the regulations, since the development of noise-reduction technology has significantly reduced the noise pollution caused by heavy vehicles during the night. In 2017, the regulations were modified after an intensive review process by the London Councils (Pink, 2017). The recommendations included allowing for fleets with adequate "quiet" technology to make deliveries during the night, developing noise standard for the design of vehicles and infrastructure related to freight, reassessing the routes and hours of the restrictions and various other modernisations. The recommendations were approved in June 2017 (Pink, 2017).

Abu Dhabi and Dubai, United Arab Emirates (UAE)

The two biggest cities in the UAE have implemented time restrictions for heavy vehicles for a very unique reason; religion. During the month of Ramadan, a Muslim observance that is approximately one month long, specific rules apply for the movement of heavy vehicles. Muslims, which make up the largest religion in the UAE, fast during Ramadan and this includes not being allowed to eat or drink between dawn and sunset (Ravinsky and Zirulnick, 2013).

During Ramadan in Abu Dhabi, all heavy vehicles, except buses with less than 50 passengers, are banned from using the city's roads in morning and afternoon peak periods. This includes the periods between 8 a.m. and 10 a.m. between and 2 p.m. and 4 p.m. (The National Staff, 2018). In Dubai, heavy vehicles are also banned from using the city's roads in several periods during the day (Roads and Transport Authority, no date). The special restrictions for Ramadan were partly implemented because of the fact that many drivers who have not eaten during the day could experience faintness and low concentration (Wam, 2015). This could in turn lead to an increase in the number of accidents.

Abu Dhabi, however, also implemented permanent heavy vehicle restrictions in late 2016. The new regulations restrict all trucks and large buses from using the city's internal roads during morning rush hour (between 6:30 a.m. and 9 a.m.). The restrictions are enforced very strictly by using surveillance cameras on all roads and punishing offenders with very high fines (Khaleej Times Staff, 2016). Authorities claimed that the restrictions were implemented in an attempt to make the journey to school easier and safer for learners. By removing heavy vehicles, it was believed that road safety would improve significantly. Similar to the proposed restrictions in South Africa, the heavy vehicle restrictions were implemented for the main purpose of improving road safety in the country (Khaleej Times Staff, 2016).

A different heavy vehicle ban was also implemented in 2014 in Abu Dhabi. This ban restricted heavy vehicles weighing more than 2.5 tons from using any of the city's roads when heavy fog was present in an attempt to reduce the number of accidents that occurred in foggy conditions (Wam, 2014). The restrictions required heavy vehicles to wait at the side of the road until the fog had cleared. When considering the fact that visibility was already low, the bans could have posed even more of a safety risk due to many large vehicles standing at the side of roads.

The city of Dubai also implemented heavy vehicle restrictions on a permanent basis. Heavy vehicles that weigh more than 2.5 tons are restricted from using the city's roads during three periods of the day, namely 6:30 a.m. to 8 a.m., 1 p.m. to 3 p.m. and 6:30 p.m. to 8 p.m. (AL SAFA Transport, no date). These restrictions differ slightly from the restrictions that are applicable during the month of Ramadan, when restriction periods are much longer.

No record could be found of the effects that the above-mentioned restrictions had since they were implemented.

Table 2.2. Summary of cities that implemented heavy vehicle operating time restrictions.

City, Country	Year of implementation	Restriction	Purpose of implementation	Results
Los Angeles, USA	1980s	HGVs banned from several freeways during AM and PM peak periods.	To reduce congestion during peak periods. Investigated after success of short-term bans in 1984.	Short-term voluntary ban in 1984 – congestion levels decreased. No official regulations implemented.
New York City, USA	2010	Deliveries only allowed between 7 p.m. and 6 a.m.	To reduce congestion and air pollution.	Pilot project in 2010 – several benefits to delivery companies and receiving businesses. Modified regulations implemented in 2018 – results unknown.
Mexico City, Mexico	2008	HGVs weighing more than 3.5 tons banned between 7 a.m. and 10 p.m.	To reduce congestion and air pollution.	No actual results known. Predicted results – No significant benefits.
Manila, Philippines	1978	HGVs weighing more than 4.5 tons banned between 6 a.m. and 9 a.m., and 5 p.m. and 9 p.m.	To reduce congestion.	Significant economic losses. Loss in freight efficiency.
Seoul, South Korea	1979	HGVs weighing more than 2.5 tons banned during working hours.	To reduce congestion.	Increase in the amount of small delivery vehicles.
Mumbai, India	2016	HGVs banned between 7 a.m. and 11 a.m., and 5 p.m. and 9 p.m.	To reduce congestion	Unknown.
Stockholm, Sweden	Unknown	Deliveries only allowed between 6 a.m. and 10 p.m.	To reduce noise pollution.	Increase in the number of freight vehicles during the day.

London, England	1985	HGVs weighing more than 18 tons banned between 9 p.m. and 7 a.m. on weeknights and 1 p.m. Saturdays to 7 a.m. Mondays.	To reduce noise pollution.	Increased fuel costs for freight carriers and increase in emissions.
Abu Dhabi and Dubai, UAE	Unknown	HGVs banned during peak periods. (Only during Ramadan)	To improve safety.	Unknown.
Abu Dhabi, UAE	2016	HGVs banned between 6:30 a.m. and 9 a.m.	To improve safety.	Unknown.
Abu Dhabi, UAE	2014	HGVs weighing more than 2.5 tons banned during heavy fog.	To improve safety.	Unknown.
Dubai, UAE	Unknown	HGVs weighing more than 2.5 tons banned between 6:30 a.m. and 8 a.m., 1 p.m. and 3 p.m., and 6:30 p.m. and 8 p.m.	Unknown.	Unknown.

2.4.4. Effects of operating time restrictions on the freight industry

Before any heavy vehicle time restrictions are implemented on a road network, it is very important to consider the effects that they will have on freight carriers and the way that they operate.

In the case that freight carriers are not allowed to deliver goods during the day or during peak periods, drivers, warehouse workers and other employees would have to report to work very early or work very late. This would result in more expenses for freight companies, since they would have to pay overtime and hire more employees. Furthermore, a study found that freight carrier operations would be less efficient, since their time windows for travel would be significantly reduced and less deliveries could be completed in allowed delivery periods (Castro and Kuse, 2005). It was also found that time restrictions could increase travel times and fuel costs of delivery vehicles.

To reduce economic losses and logistical complications, freight carriers are expected to change their operation methods.

A study in Mexico in 2017 found that most freight carriers would respond in one of the following ways when faced with time restrictions (Lyons *et al.*, 2017):

- Use many small trucks that do not fall under the restricted vehicle classes instead of a few large trucks;
- Use different routes where restrictions are not implemented;
- Change delivery times to times when heavy vehicles are not restricted or
- Use warehouses to store goods on the border of the restricted areas until heavy vehicles are allowed to make deliveries.

Another study in Manila found similar results (Castro and Kuse, 2005). It must be noted that several studies have found that most freight companies would rather use many small vehicles that are not restricted to travel in order to ensure good customer service (Campbell, 1995). This would most likely lead to higher congestion levels and more emissions than before the restrictions were implemented (Anderson *et al.*, 2013).

2.5. Other international heavy vehicle restrictions

Apart from time restrictions discussed in the previous section, many other kinds of restrictions have been implemented internationally in an attempt to reduce the effect of heavy vehicles on road networks. No single restriction can be classified as the perfect solution, but some restrictions have been found to yield more successful results than others do. It must be noted, however, that the type of restriction that is implemented always depends on the situation and the results that are desired. This section will discuss some common heavy vehicle restrictions implemented worldwide.

2.5.1. Lane restrictions

Lane restrictions have been implemented by several authorities worldwide, with many cities and regions in the USA preferring these kinds of restrictions for heavy vehicles. Lane restrictions can be implemented in various ways:

- Heavy vehicles can be restricted to the use of specific lanes and be completely banned from using others, while passenger cars may travel in any of the lanes;
- Heavy vehicles can be restricted to the use of specific lanes and be completely banned from using others, while passenger cars may only travel in the lanes that are banned for heavy vehicles or
- Heavy vehicles and passenger cars are restricted to use completely separate facilities, without physically being able to cross over to each other's lanes.

It seems like a good idea to restrict heavy vehicles to a specific lane, allowing passenger cars to travel undeterred in another lane at higher speeds. In fact, a poll by the infrastructure consulting firm, HNTB Corp, in 2011 showed that 25% of the participants in the USA felt that lane restrictions for heavy vehicles was the best solution for reducing traffic congestion (Kilcarr, 2011). Several state agencies in the USA have reported that lane restrictions had led to less traffic accidents, higher safety levels in construction zones and better speeds on freeways (Siuhi and Mussa, 2007). Another study in the USA has also found that lane restrictions led to lower congestion levels, smaller headways and less trucks impeding the speeds of passenger cars (Hanscom, 1990). Another study performed in the USA found that lane restrictions are very effective in reducing congestion if it is implemented on a road with more than two lanes (Mugarula and Mussa, 2003).

Even though lane restrictions could reduce congestion, it does not necessarily mean that less heavy vehicles will be present on the roads. A study performed in Texas to evaluate the effects of implementing lane restrictions for heavy vehicles, concluded that the volume percentage of trucks remained constant before and after the implementation of the restrictions (Zavoina, Urbanik and Hinshaw, 1991). Therefore, it can be assumed that lane restrictions do not deter heavy vehicles from using the roads; it merely forces them to travel in specific lanes. The same study found that speed differentials between heavy vehicles and passenger cars seemed to increase after lane restrictions were implemented (Zavoina, Urbanik and Hinshaw, 1991). This could be problematic, since several studies have found that the probability of accidents increase significantly when speed differentials increase in size (Solomon, 1964).

Lane restrictions could also improve road safety. A study in Florida found that the number of lane-change manoeuvres increased by 11% when all lanes were open to trucks, compared to when all trucks were restricted to a single lane (Mugarula and Mussa, 2003). An increase in lane-change manoeuvres has been found to increase the number of accidents on a road (Mugarula and Mussa, 2003). There have, however, been cases where the number of accidents on a road has increased due to lane restrictions. In the 1980s the state of Florida implemented lane restrictions for heavy vehicles on several of its roads. In a study to determine the effects of the restriction, it was found that although accident severity decreased, the number of accidents increased significantly (Fitzpatrick, Middleton and Jasek, 1992). This led to the state scrapping the lane restrictions.

Other concerns have also been raised with the implementation of lane restrictions. One of the most frequently mentioned problems with these restrictions is the fact that roads are usually not designed to carry all heavy loads in a single lane. Restricting all heavy vehicles to a single lane will significantly increase the loads that the pavement experiences and may lead to faster deterioration of that lane (Stokes and McCasland, 1986). This in turn will lead to more maintenance being required and increased costs.

The lane that heavy vehicles are restricted to has an influence on the effectiveness of the restriction. If heavy vehicles are restricted to the outer lane, other vehicles could have difficulty merging to those lanes to take off-ramps. It would also be difficult for vehicles to merge onto a road from an on-ramp. If heavy vehicles are restricted to the inner lane, however, speeds in the outer lanes could increase, making it more dangerous for traffic merging onto the road. The lane that heavy vehicles are restricted to could, therefore, influence the number of accidents that occur on a road.

In the case that heavy vehicles and passenger cars are forced to use completely separate facilities, new benefits and problems arise. Several roads exist in the USA that separates the flow of heavy vehicles from passenger cars by physical barriers. In New Jersey, a metal guardrail separates heavy vehicles and passenger cars. On this road, heavy vehicles are restricted to the outer road, but passenger cars may choose which road to use. It was found that approximately 40% of passenger cars use the outer road (Fitzpatrick, Middleton and Jasek, 1992). This may be because the number of passenger cars are much higher than heavy vehicles and the inner road may have reduced flow if all passenger cars travelled on that road. Separate roads for heavy and light vehicles also exist in California. In this case, a road was reconstructed parallel to the existing roadway. The roads are completely separate from each other and the old road is used as the thoroughfare for heavy vehicles (Fitzpatrick, Middleton and Jasek, 1992).

It has been found that providing separate facilities for heavy and light vehicles usually leads to lower access, but much greater mobility for freight operators. It could be especially beneficial in increasing freight mobility on congested urban roads, but it was found that separate facilities would be difficult to implement in urban areas (Fischer, Ahanotu and Waliszewski, 2003). Furthermore, significant economic benefits will most likely result from such restrictions due to savings in travel time. A study of two different roads that implemented separate facilities for heavy and light vehicles, found that both light and heavy vehicles had savings in travel time when using separate facilities (Fischer, Ahanotu and Waliszewski, 2003).

It must be noted, however, that the use of exclusive facilities for heavy vehicles and passenger cars are only beneficial in the case that truck volumes are very high. Several studies have concluded that the costs to implement such restrictions would far outweigh the possible benefits if truck volumes on a road were low (Lamkin and McCasland, 1986; Fischer, Ahanotu and Waliszewski, 2003). Additionally, the frequency that trucks use the route would also have to be high in order to result in an economic saving (Fischer, Ahanotu and Waliszewski, 2003).

2.5.2. Route restrictions

Authorities commonly implement route restrictions in an attempt to remove heavy vehicles from central urban areas and other roads with high congestion levels. Route restrictions are usually implemented for one of two reasons (Stokes and McCasland, 1986):

- Heavy vehicles should bypass towns and central business districts (CBDs) or
- Heavy vehicles should use roads that are specifically designed for their loads.

Heavy vehicles are frequently perceived as major contributors to congestion and decreased traffic flow in urban areas and business districts. These areas usually have narrow streets, many intersections, small turning radii and few parking places, all posing challenges to the limited manoeuvrability of heavy vehicles (Mobility Investment Priorities, no date). One way to avoid this problem is to restrict heavy vehicles to using only the routes that bypass these areas. By using these alternative routes, heavy vehicles will usually have improved travel times, higher speeds and less conflicts with passenger cars (Stokes and McCasland, 1986). Therefore, route restrictions are often beneficial to both the authorities and heavy vehicle operators. This makes it easier for authorities to implement voluntary bans, since heavy vehicle operators will usually choose the route most beneficial to them. There are, however, cases when heavy vehicles need to travel to the CBD of a town or city to make deliveries or pick up shipments.

Route restrictions are, therefore, often not implemented with the aim of completely banning all heavy vehicles from specific routes, but to make an alternative route so appealing that most drivers of heavy vehicles will choose to use that route. This can often be accomplished by using financial incentives. In this case, heavy vehicles that choose to travel into specific areas or use a specific route that is not designed for carrying heavy loads, must pay high tolls in order to do so (Mobility Investment Priorities, no date). Some of the first tolls, implemented in the 1970s, were calculated according to congestion levels. More recently, though, it is very common for authorities to calculate tolls according to the amount of air pollution a vehicle causes. Alternatively, these operators can apply for permits that grant them access to these areas, but at a cost (Grenzeback *et al.*, 1989). This will allow vehicles that truly need to access areas to do so but will deter other heavy vehicles from using the route unnecessarily.

Important terminals for heavy vehicles include industrial areas, shipping ports and major commercial areas. In order to provide access to these areas for heavy vehicles, dedicated routes are often designed to carry the heavy loads exerted by these vehicles. Heavy vehicles are then restricted to use only these routes, as they will be structurally superior to alternative routes. Although these kinds of routes provide access for heavy vehicles to key areas, there are often very high costs associated with providing the infrastructure required (Stokes and McCasland, 1986). Heavy vehicles are also banned from certain roads due to the structural damage that they cause to pavements. Many roads were simply not designed to carry the large loads that heavy vehicles exert. Banning heavy vehicles from these roads could significantly decrease the maintenance costs required to keep these roads structurally intact.

There are also practical reasons for implementing route restrictions for heavy vehicles. Some freeways in the USA were designed for specific use by passenger cars in the early 1900s (NYC DOT, 2009). Therefore, some elements of the roads are physically too small to support heavy vehicles. For example, some bridges are much too low for heavy vehicles to pass under. This is the case in New York, where several roads are completely banned for use by heavy vehicles (NYC DOT, 2009).

In San Diego, heavy vehicles were banned from a section of Route 163 in an attempt to reduce congestion on the road. The section's location posed unique problems for trying to solve congestion problems in traditional manners. The population of the area heavily protested any construction to add lanes to the road, since this section was located in a very scenic park. This, along with the fact that the road had a relatively high grade and no acceleration or deceleration lanes, prompted authorities to ban trucks from the road section completely (Fitzpatrick, Middleton and Jasek, 1992).

Route restrictions for heavy vehicles have also been implemented to reduce the number and severity of accidents on a specific route. In the 1980s, trucks were diverted to alternative roads in an attempt to prevent heavy vehicles from travelling on a specific freeway in the USA. The diversions followed a very serious accident on the freeway that was believed to be caused by the presence of heavy vehicles (Fitzpatrick, Middleton and Jasek, 1992). It was expected that the removal of trucks from this road could lead to approximately 9% less truck-involved accidents. Route restrictions could, however, merely shift accidents to other roads with no change in the total number of accidents in a region.

2.5.3. Speed restrictions

Three main kinds of speed restrictions can be implemented by authorities:

- Reducing speed limits for heavy vehicles only;
- Reducing speed limits for all vehicles on a road or
- Increasing law enforcement for current speed restrictions.

Since this study concerns heavy vehicles, only speed reductions for heavy vehicles will be considered in this section.

Because of the high mass of heavy vehicles, it is often the view of authorities that roads will be safer in the case that truck speeds are low. Therefore, authorities sometimes implement lower speed restrictions for heavy vehicles than passenger cars.

It has been found that lower speeds could reduce accidents where trucks drive into other vehicles due to limited stopping abilities (Stokes and McCasland, 1986). A study in Texas found that, when trucks were restricted to lower speeds than passenger cars, the number of heavy vehicles colliding with the rear ends of passenger cars decreased significantly (Stokes and McCasland, 1986). Furthermore, heavy vehicles travelling at lower speeds may pose much lower risks to vulnerable road users like pedestrians and cyclists (Davies, 2014). It must be noted, however, that due to the large mass of heavy vehicles, these road users frequently do not survive when involved in an accident with a heavy vehicle, even at low speeds (Davies, 2014).

Speed restrictions do have some disadvantages, however. By only reducing the speeds of heavy vehicles, the speed differentials between heavy and light vehicles will increase significantly. This in turn will most likely lead to a higher number of accidents, since a direct link has been found between the size of speed differentials and the number of accidents that occur (Solomon, 1964). Furthermore, the American National Cooperative Highway Research

Program has found that a vehicle has a much higher probability to be involved in a traffic accident if its speed varies significantly from the average speed of the traffic stream (Davies, 2014). This makes sense in a logical approach. If trucks are forced to travel slower than passenger cars are allowed to, some drivers may become impatient and attempt to overtake trucks when it is not safe to do so. When considering the fact that there are usually much more passenger cars present on a road than heavy vehicles, it can logically be concluded that trucks that are forced to travel slower will have a higher chance of being involved in an accident, since the average speed of the traffic stream will most likely be higher than the speed of the truck.

Additionally, speed restrictions could severely increase the operational costs of freight operators. In Britain, it was found that more than £11 million could be lost per year due to a law forcing trucks to travel 20 mph less than other vehicles (Davies, 2014). This financial loss was mainly attributed to increased travel times due to the lower speeds.

It must also be noted that different speed limits for different vehicle types greatly increase the difficulty for authorities to enforce road laws.

2.5.4. Other measures

Several other heavy vehicle related policies have been implemented worldwide in an attempt to reduce truck-related incidents. Although not as popular or successful as those already discussed, these restrictions can be implemented in conjunction with others to ensure safer and less congested roadways.

Restrictions in shoulder parking

This restriction entails the reduction in heavy vehicles parking on the side of a road. Many truck drivers pull over to the side of the road at night to sleep instead of using designated truck stops. This may be due to a limited number of trucks stops or long distances between these stops. Heavy vehicles parked next to roads pose significant risks to other drivers and may lead to more accidents, especially during the night-time. It has been found that accidents involving trucks parked in shoulders frequently result in fatalities (Fitzpatrick, Middleton and Jasek, 1992).

Increased enforcement of road rules

Increased enforcement of road rules by authorities may ensure that heavy vehicles operate in the safest manner possible. Authorities should ensure that trucks are not overloaded, are in good driving condition and that drivers comply with all licencing requirements. It has been found that drivers that lack proper training and licencing are much more prone to be involved in traffic accidents (Stokes and McCasland, 1986). Speed limits should also be accurately enforced in order to increase the safety of a road for all users.

A common way in which authorities can ensure that heavy vehicles are roadworthy is the use of roadside inspection stations. These stations can be used to assess heavy vehicles and ensure that they comply with all laws. These stations may require large initial investments, but long-term economic benefits could outweigh the initial costs (Fitzpatrick, Middleton and Jasek, 1992). Weigh stations are also implemented to ensure that heavy vehicles are not overloaded and do not cause significant damage to roadways.

Better incident management

Traffic accidents often lead to secondary accidents due to congestion and bottlenecks being caused by the primary accident. The problem with accidents involving heavy vehicles is that these accidents often obstruct more than one lane. Additionally, even larger vehicles are required to tow these heavy vehicles and may contribute to even more congestion. Adequate incident management could reduce the number of secondary accidents by ensuring quick clearing of primary accidents and relieving congestion (Fitzpatrick, Middleton and Jasek, 1992). Incident management also plays another key role when heavy vehicles are involved in accidents. Large trucks frequently carry hazardous materials and when involved in an accident, it is important that other vehicles be diverted away from the accident scene to avoid additional dangerous situations (Fitzpatrick, Middleton and Jasek, 1992).

2.6. Compliance to road rules

A crucial factor to consider when studying any newly proposed law or regulation is whether the public will feel inclined to follow the new rules. Even if non-compliance to a new law is punishable, it can sometimes be the case that the public will still not follow the laws, either due to lenient punishments or poor law enforcement by authorities. According to Malcolm Feeley of New York University, the decision to comply to a law depends on the likelihood and magnitude of the punishments that violators will face (Feeley, 1970). People will first compare the benefits of not complying with a law against the costs of violating it before deciding whether to comply or not. The problem with compliance to laws is well defined in the following paradox, often discussed by law students (Feeley, 1970):

"If a law is not supported by the mores of the community, it is ineffectual; if it is, the law is unnecessary."

When specifically referring to road laws, it has been found that not all road users will comply to the laws, even if all of them agree with the need for the law (Feeley, 1970). This may be because some road users believe their individual actions will not have a significant impact on the entire network. Some road users have also been found to merely seem to agree with a new law because of peer pressure from the rest of the public and then do not comply with the laws if it inconveniences them in any way. Furthermore, it has been proven that many road users will easily violate laws if they gain utility by doing it, for example getting somewhere faster (Bradford *et al.*, 2015). They will, however, be much more inclined to follow road rules if they believe that they will be caught and punished if they violate them (Bradford *et al.*, 2015).

A recent example of new road rules that were not obeyed by many road users is the implementation of e-tolls on freeways in the Gauteng province of South Africa. The decision to impose tolls on several main roads in the province was opposed by most road users and other organisations that would be affected. Tolls are automatically charged to a vehicle owner's account by electronic readers without cash transactions. The opposition resulted in a large number of unpaid accounts, approximately R1 billion in the first six months of implementation in 2013 (Samuels, 2014). In 2017, it was reported that approximately 3 million motorists owed e-tolls out of less than 4 million motorists registered in the province (Ryan, 2017).

The e-tolls saga does not come as much of a shock when considering the compliance rate to road rules by South African road users in general. In many cases, drivers simply do not feel the need to comply with rules or they do not understand them (Moloi, 2016). In 2012, Deputy Director General of the Road Traffic Management Corporation (RTMC) in South Africa, Gilberto Martins, revealed some shocking statistics (Martins, no date). According to him, road users violating one or more road rules precede 90% of all collisions in South Africa. Furthermore, more than 80% of fatal collisions in 2012 were due to human error. For these accidents, the most common causes were identified as drivers travelling at speeds too high for the situation or drivers overtaking when it was not safe to do so. Additionally, 65% of accidents that occurred on weekends involved alcohol abuse. It is obvious that poor compliance to road rules in South Africa has led to some major consequences. Some other figures also revealed by Martins further proved how road users in South Africa do not follow road rules, even if their own safety depended on it. He revealed that only 67% of drivers or front seat passengers buckle their seat belts on long journeys and even less on short trips (Martins, no date). It is clear from the statistics that South Africans do not always follow road rules, not even for their own benefit. This poses the question whether heavy vehicle drivers will obey the newly proposed laws if they are implemented.

The compliance to new road rules have been studied in many other countries outside of South Africa. In New York, a ban of handheld cell phones was implemented for all vehicle drivers in 2001 (McCartt, Braver and Geary, 2003). It was reported in 2003 that the new law was very successful. The use of handheld cell phones by drivers after the implementation of the law was less than half of that measured before the implementation. The success of the new law was mostly contributed to the fact that it was very well publicised before and during the time that it was enforced. Drivers and other members of the public were properly informed of the safety implications of violating the new law (McCartt, Braver and Geary, 2003). This created a form of peer pressure for drivers, since pedestrians and other drivers would help to enforce the cell phone bans. Furthermore, good law enforcement measures also contributed to most drivers complying with the new rules. It is also important to note that drivers did not see the cell phone bans as a major inconvenience, since hands-free devices could easily be used as an alternative. It was found that those who obeyed the law did not lose utility by doing so (McCartt, Braver and Geary, 2003). This is an important factor to consider when assessing the potential effectiveness of a new law.

In Scotland, the compliance rate of road users to traffic laws was found to depend on the perceived effectiveness of law enforcement officers (Bradford *et al.*, 2015). Furthermore, many citizens were found to follow road rules because they felt that it was a moral obligation. They believed that it was morally wrong to break the laws, and therefore decided to obey them. These two main reasons for following traffic laws were also found in a study in 1998 in Israel (Yagil, 1998). This study found that most road users followed traffic laws for either normative or instrumental methods; they followed them due to the fear of being caught and punished or because they felt it was the right thing to do. The study in Israel also found that some road users only followed road rules if they felt it was necessary (Yagil, 1998).

In 1978, authorities in Georgia, USA, implemented a truck ban to avoid truck traffic in central Atlanta. Two years later, a study was performed to investigate compliance with the law. It was found that 5.4% of truck drivers violated the ban (Fitzpatrick, Middleton and Jasek, 1992). This was seen as a relatively low violation rate. A truck ban in Texas also yielded some success in terms of compliance rates (Zavoina, Urbanik and Hinshaw, 1991). Trucks were restricted to a specific lane on a freeway in the state, but no strict enforcement of the new restrictions were implemented. Without the enforcement, compliance rates were found to be between 62% and 76% (Zavoina, Urbanik and Hinshaw, 1991). It must be noted, however, that most trucks tended to travel in the same lane before the new laws were implemented in an attempt to avoid influencing passenger cars. Furthermore, the trucks did not completely lose their ability to travel on these roads, as a total ban would cause. These factors contributed to the fact that compliance rates were relatively high without enforcement. Another study of lane restrictions for heavy vehicles in the USA found that compliance by truck drivers was generally good, but decreased when truck volumes were high on a road (Hanscom, 1990). This could be due to a large number of heavy vehicles being forced to travel in the same lane and influencing each other.

Adequate law enforcement plays a key role in the compliance to road rules by road users. A study on traffic law compliance, performed in 2015, found that drivers' compliance to road rules is not necessarily dependent on the severity of punishments for violations, but rather the probability of being caught. This effectively means that merely raising traffic fines will not have a significant impact on the compliance rates with traffic laws. An increase in the chances of being caught violating a law, however, may deter a large number of road users from breaking the rules. Research has found that compliance rates with traffic laws are directly linked to the number of law enforcement officers present (Stokes and McCasland, 1986). This poses a problem in South Africa, since there are only approximately 17 000 traffic officers in the country (Martins, no date). With so few traffic officers to attend to all the roads in South Africa, it may be very difficult to ensure that heavy vehicle drivers comply with the newly proposed regulations in the case that it is implemented.

There is, however, a fine balance between enforcing a law and making road users comfortable to follow the laws. It was found that a key factor to road users complying with traffic laws is that they need to trust law enforcement officers (Bradford *et al.*, 2015). If they trust law enforcement officers to enforce the law and apply punishments when other drivers offend, they will be more inclined to follow the rules themselves.

It is obvious that coercion is a very important instrument to ensure compliance to traffic laws. In the case that a new law is implemented, it must be ensured that enough law enforcement personnel are available and that they will be effective in enforcing the laws.

2.7. Penetration rates for fleet management data

Penetration rates indicate the percentage of the entire population that a dataset represents. It is very important to consider penetration rates when assuming that a sample dataset is representative of an entire population, as this could be an invalid assumption if the penetration rates are too low. Therefore, to ensure that results are accurate and representative, a dataset must adhere to minimum penetration rates.

As mentioned previously in this document, fleet management data has not often been used in the way it has been in this research, namely for analysing the movement patterns of vehicles within urban areas. Therefore, literature could not be found regarding the penetration rates that would be suitable for this use of fleet management data.

Extensive research has, however, been performed into the penetration rates required for probe data, also known as floating car data (FCD), to be accurate. Although the fleet management data used in this research cannot be defined as FCD, it is similar in the way that both data sources provide vehicle speeds that were recorded at specific locations at a specific time. For this reason and the lack of other appropriate methods, it was decided that the suitable penetration rates for FCD would be assumed to be applicable to the fleet management data used in this study.

Research has shown that accurate results can be obtained when the penetration rates of FCD are at least 3% for freeways and 5% for surface streets (Ferman, Blumenfeld and Dai, 2005). Additionally, a study in California found that a penetration rate of 4% is sufficient for accurate prediction of travel times on highways (Sanwal and Walrand, 1995). A different study concluded that a penetration rate of 2% - 3% is adequate for travel speed estimations (Herrera *et al.*, 2010).

2.8. PTV Vissim

2.8.1. Introduction

PTV Vissim (hereafter referred to as Vissim), is part of the PTV Vision suite of products. Vissim can be used for the simulation of microscopic or mesoscopic simulations to investigate a myriad of different scenarios. The software is used in this study to construct a microscopic traffic model to simulate the effects that the proposed heavy vehicle bans would have on the road network of Stellenbosch.

This section aims to provide the theoretical background required to understand the workings of the software and the models on which the simulations are based. More information on Vissim itself is provided in **CHAPTER 9:**.

2.8.2. Traffic flow operations

Microscopic traffic flow in Vissim is based on the interaction between a traffic flow model and signal control operations. Detector readings and signal statuses are exchanged between these two elements and result in traffic being simulated in a realistic manner. **Figure 2.10** shows the simulation process in Vissim.

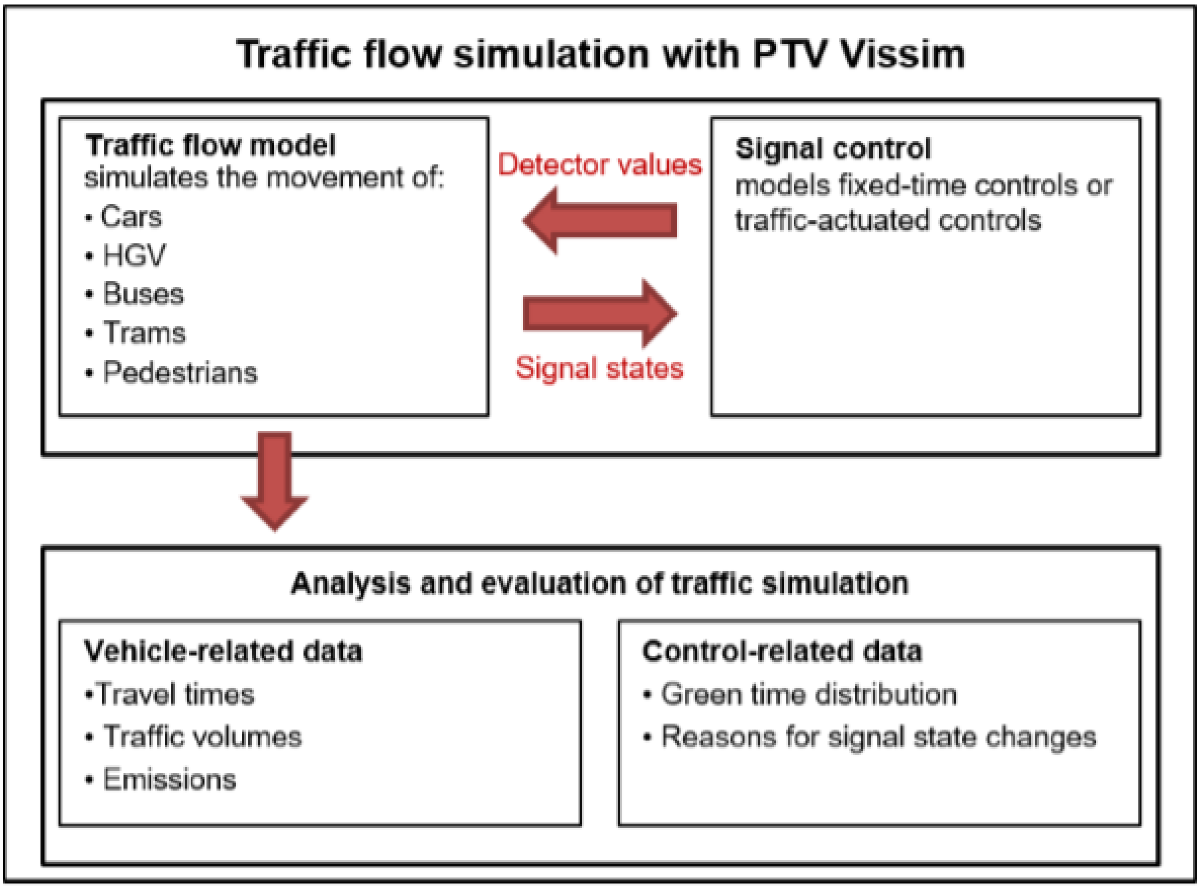


Figure 2.10. *Simulation process in PTV Vissim (PTV GROUP, 2016).*

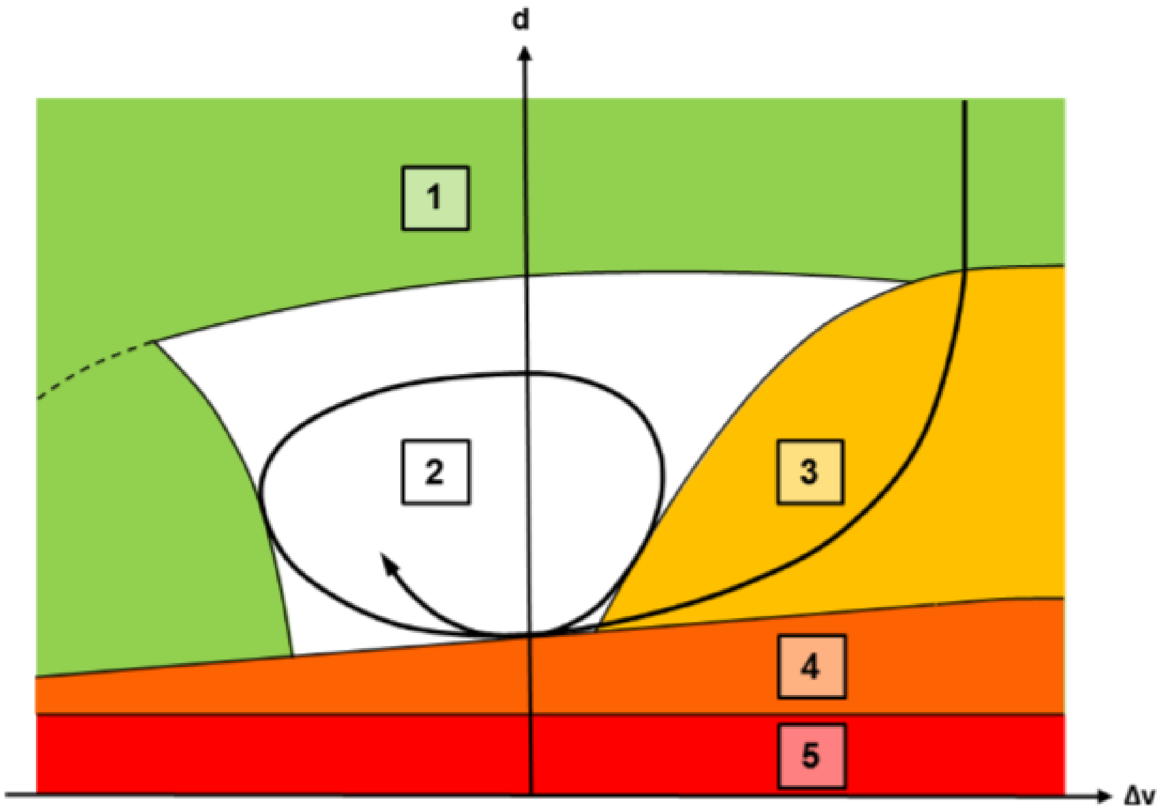
<u>Traffic flow model</u>

The traffic flow model used in Vissim is composed of three components: a car-following model, a lane-changing model and a lateral movement model.

1. Car-following model

Professor Rainer Wiedemann developed the Wiedemann car-following model at the Karlsruhe Institute of Technology (KIT) in 1974 and 1999 (PTV GROUP, 2016). Although the model was developed several years ago, it has constantly been calibrated by KIT to ensure that the changing characteristics of vehicles and drivers are taken into account. The Wiedemann model is used in Vissim to describe the movement of vehicles within a single lane. This model provides for variation in travel speeds and randomness in driver decisions.

The Wiedemann model is based on the assumption that a driver, when approaching a slower moving vehicle, will decrease their vehicle's speed to a speed lower than that of the slower moving vehicle. This is because it will not be clear to the driver at which speed the slower moving vehicle is travelling simply by approaching it. After the initial deceleration, the driver will again accelerate until they need to decelerate again. The driver of the fast-moving vehicle will continue this cycle of accelerating and decelerating until it can reach a free flow state at the desired safety distance. It must be noted that the safety distance and speed at this distance will not be perfectly constant, but will vary by small amounts due to imperfect throttle control. The Wiedemann car-following model provides for stochastic driver behaviour in terms of the speed and safety distance at which vehicles travel. Additionally, each driver will have a unique psychophysical perception threshold i.e. their abilities to estimate distances and speeds and their willingness to take risks. Figure 2.11 shows a graphical representation of car-following behaviour according to the Wiedemann model.



Legend

Axes: **d**: Distance, **Δv**: Change in speed	**3**: Approaching state
1: "Free flow" state	**4**: Braking state
2: Following state	**5**: Collision state

Figure 2.11. *Car-following behaviour according to the Wiedemann model (PTV GROUP, 2016).*

In Vissim, the modeller can define the number of vehicles ahead that a driver will take into account when making decisions. The default used by the software is four vehicles. Although the car-following model is applicable to the movement of vehicles in a single lane, the Wiedemann model also takes into account vehicles in the two adjacent lanes when vehicles travel on multilane roads.

2. Lane-changing model

In Vissim, two different lane-changing movements exist: free lane changing and necessary lane changing. Free lane changes are used for overtaking manoeuvres, while necessary lane changing occurs when vehicles need to move to a specific lane in order to follow their route. For both types of lane changes, vehicles are only allowed to perform the manoeuvre if there is an adequate gap. This gap will depend on the speed of the lane-changing vehicle and the speed of any vehicle that is approaching in the lane that is being switched to.

In addition to an adequate gap being available, free lane changes depend on the minimum allowable safety distance between the lane-changing vehicle and an approaching vehicle in the new lane. The lane change will not be performed if the distance between these vehicles is too small.

For necessary lane changes, the aggressiveness of drivers varies. As a vehicle approaches the decision making point, the driver will become more aggressive if he needs to change to a different lane. This can lead to some vehicles making lane changes even if it will cause approaching vehicles to decelerate. For this type of lane change, drivers are cooperative and allow other vehicles to change lanes.

3. Lateral movement model

The lateral movement of a vehicle within a lane has an impact on overtaking and the possibility of vehicles travelling next to each other in a single lane. One example of this is where cyclists share the road with cars and the two travel next to each other in one lane. Vissim allows the user to specify the lateral position in a lane where vehicles will travel, as well as whether overtaking in the same lane is permitted. The definition of lateral movement parameters is particularly important where the movement of vehicles is not necessarily lane-based and vehicles do not always follow lane markings.

Signal control operations

Signal control in Vissim can be set up as either fixed-time operation or actuated control operation and can be defined with static or dynamic data. For the setup of signal controllers, several external programs like VAP, VSPLUS and SCOOT can be used. Alternatively, fixed-time signal plans can be set up in Vissim itself by utilising the add-in, Vissig.

Driver behaviour at signalised intersections is determined according to the Wiedemann model. This includes the manner in which drivers respond to yellow signals, the response time of drivers when the signal changes, and the headway that drivers allow at these intersections.

One of two models can be selected to define the behaviour of drivers when approaching a yellow signal. A continuous check model allows drivers to make a decision whether to stop or go with each time step. For this model, drivers assume that the light will be yellow for the next two seconds. If the vehicle cannot travel past the stop line at its current speed within the two seconds, it will brake and come to a stop. It will continue driving through the intersection if its maximum deceleration capacity, without exceeding a deceleration of 4.6 m/s^2, will not allow it to stop behind the stop line within two seconds. If a dilemma zone exists where a driver can either stop or go, a normally distributed random variable is used to determine whether a vehicle will stop or go.

If a continuous model is not selected, a single decision model is used. With this model, drivers make a single decision over whether to stop or go when approaching a yellow signal. The probability that a vehicle at the intersection will stop at a yellow light is calculated with a logistic regression function. This function is dependent on the speed that the vehicle is travelling at and the distance that it is from the stop line. It is important to note that this model only allows a single decision to be made without a chance for the driver to change his mind.

It is realistic to assume that some drivers will not obey the signal shown at a signalised intersection. For this reason, Vissim assigns a randomly generated compliance number to each vehicle travelling through an intersection. The user assigns a compliance rate to each intersection, derived from local data. If the number generated for a vehicle is above the compliance rate of the intersection it is approaching, it will not obey the signal displayed.

2.8.3. Vehicle characteristics

In Vissim, traffic is simulated by a combination of drivers and vehicles. Random drivers (with a specific driving behaviour) are assigned to random vehicles (with specific vehicle characteristics). Each type of vehicle has specific characteristics determining the way in which the vehicle moves within the road network.

The following categories of “vehicles” can be modelled in VISSIM:

- Passenger car;
- HGV;
- Bus;
- Tram;
- Pedestrian and
- Bicycle.

Within each category, a user can specify specific vehicle types, for example small minibuses and large articulated buses within the bus category. Each vehicle type and category has specific characteristics defining the physical properties and movement capabilities of the vehicle. Default vehicle types are defined in Vissim but the user can also define the characteristics of specific vehicles. Distributions are used for vehicle occupancies, acceleration capabilities and deceleration capabilities. Weight and power distributions are also defined for HGVs, since these properties have a large impact on the movements of these vehicles. The user defines the vehicle composition of a modelled traffic stream when defining vehicle inputs.

2.8.4. Acceleration and deceleration behaviour

Because Vissim provides for stochastic modelling, fixed values cannot be assumed for the acceleration and deceleration capabilities of driver-vehicle units. Distributions are used for these values, with the function of a distribution depending on the behaviour of a specific driver and the engine of the vehicle that he is travelling in.

Vissim uses one of four functions to determine the acceleration or deceleration of a unit. All four functions are dependent on the speed that a unit is travelling at. The first function is the maximum acceleration function. This distribution function contains the maximum possible acceleration that can be achieved by a unit, largely depending on the gradient that is being travelled on. This function is used when vehicles need to maintain a specific speed on a slope. When the maximum acceleration function is not required, a function of desired acceleration speed is used.

The same functions are used for the deceleration of a vehicle. Maximum deceleration functions are, once again, mainly dependent on the gradient of a road. Desired deceleration functions are used for vehicles approaching a stop line, vehicles approaching other vehicles from behind, when the desired speed of a driver changes or when a driver is cooperating with other vehicles to allow them to enter the traffic stream.

Vissim provides default acceleration and deceleration distribution functions for some typical vehicle types. Each vehicle type can be assigned a unique acceleration and deceleration function to account for the differences in vehicle characteristics. These default functions have been developed and updated from several different research sources to represent the acceleration and deceleration capabilities of each vehicle type. It is important to note that the functions have been developed according to Western European data and should be adapted to local conditions where possible and necessary. In the case that default functions are not accepted, users can define their own functions according to local data.

2.8.5. Conflict areas

Wherever conflicts between vehicles exist in a model, the right-of-way needs to be established. In Vissim, this can be done by defining conflict areas. Conflict areas exist where network links cross, merge or branch and can be set up to either provide right-of-way to one of the links or can be set up to allow equal right-of-way to vehicles travelling on both links (usually in the case of two branching links).

At any conflict area where one traffic stream needs to yield to another, the yielding vehicle will consider the main traffic stream and attempt to accelerate for a few seconds to clear the conflict area without causing a hindrance to the main traffic stream. A yielding vehicle will consider its safety distance and speed when approaching a conflict area. If it can travel through a conflict area without disturbing the major traffic stream, it will continue to travel. If it cannot clear the conflict area in time, it will stop in front of the conflict area and wait until an adequate gap is available.

It must be noted that some drivers do not clear the conflict area in time due to misjudging the situation. In this case, vehicles from the main traffic stream will allow the vehicle to clear before travelling through the conflict area.

For conflict areas that include crossing movements, the user can define that vehicles in the major traffic stream should keep the conflict area clear when queuing occurs. This will allow crossing vehicles from the minor stream to cross while vehicles in the major stream are queueing. Yielding vehicles will always attempt to leave conflict areas as soon as possible, even if it moves into a different conflict area for which an adequate gap is not provided.

2.9. Cost-benefit analyses

2.9.1. Background

The availability of an engineering project does not necessarily mean that it would be beneficial to implement it. The economic impact that a project will have on all stakeholders must be studied and justified in order to determine whether it will be economically feasible. However, it is difficult to define when a transportation project will be economically feasible, especially when it benefits some, but is disadvantageous to others. The quantification of benefits and costs is even harder to achieve when it is not done in monetary terms, but rather in terms of travel time or travel speeds.

The Kaldor-Hicks principle (developed in the 1930s by Kaldor and Hicks), dictates that a project can be deemed economically feasible as long as the total benefits outweigh the total costs (AASHTO, 2010). The principle does acknowledge that some stakeholders might lose out in terms of economic impact, but it proposes that the stakeholders that are benefitted by the project will compensate for the losers. This principle has, over time, evolved into a concept that is today known as the field of *cost-benefit analysis* (CBA).

It must be noted here that economic analyses for transportation projects are frequently not as straight forward as the Kaldor-Hicks principle makes it seem. In these projects, there are often costs and benefits that are very difficult to quantify in monetary terms and, therefore, are difficult to include in an economic analysis. In these cases, significant research has to be performed or existing models need to be used to estimate the economic values of these factors.

In this section, the relevant theoretical background of a CBA will be discussed to provide the understanding needed when it comes to the CBA performed for this study.

2.9.2. Defining the base case and project alternatives

A CBA is always comparative in nature, because a possible project must be compared to the status quo in order to confirm whether it would be economically feasible to implement any changes. More than one alternative to the status quo can be investigated in a CBA, but at the least, the current scenario and one alternative scenario must be included.

The first step of any CBA is defining the status quo scenario (known as the *base case*) and all considered projects (known as the *project alternatives*) in great detail. This step is crucial to ensure the success of the CBA, as it defines the scope of the analysis and vagueness could lead to major oversights.

If the date of analysis is a future date, the base case can be defined as it would be in the future, including any changes that will occur to the base case, but only if these changes will take place irrelevant of whether the project alternatives are implemented or not.

If more than one project alternative are considered, it must be determined whether project alternatives are mutually exclusive or not. If projects are not mutually exclusive, the analyst must determine the combination of projects that would yield the most benefits within the budget available.

2.9.3. Period of analysis

For the base case and all project alternatives considered, the conditions must be projected as far into the future as the project is expected to have an effect. This period will depend greatly on the type of projects considered. In transportation projects, the initial capital expenditure is often very large and takes several years to reach a break-even point. Therefore, the period of analysis should include the construction and implementation of the project and all subsequent years that the project is expected to yield costs or benefits.

Great caution must be taken when selecting the period of analysis, however. Although it is ideal to include the entire period during which the project will have an effect, problems arise when this period becomes too long. Especially in the field of transportation, the long-term future is uncertain and very difficult to accurately predict. This means that many assumptions need to be made and this amount of uncertainty my eventually lead to results that are not reliable and will essentially be irrelevant. It is recommended that the period of analysis for transportation projects should not exceed 40 years. The analyst should instead select a reasonable period to analyse and then predict the value of the remaining project life after the period of analysis has elapsed.

2.9.4. Costs and benefits

All monetary parameters considered in a CBA can be defined as either a cost or a benefit. Benefits are any changes yielding from the implementation of a project that result in an increase in well-being of persons or a decrease in the use of resources. A cost is defined as any capital expenditures, labour or other resources that would be required to construct, implement and maintain a project.

It is important to note that some costs and benefits are not easily measured in monetary terms. For the purpose of including these values in a CBA, relevant models must be used to monetise them.

Several different costs and benefits can arise from transportation projects, depending on the type and scope of the project investigated. Benefits and costs can be investigated on different levels, be it for the entire network, agent-based or for a specific road user type. It is important to ensure that costs and benefits are measured on the same level in order to compare these values.

2.9.5. Analysis measures

Many different measures can be used in a CBA to define which project would be the most beneficial. Two of the most commonly used measures will be discussed in this section.

Net present value (NPV)

NPV involves the subtraction of all costs incurred during the lifetime of a project from all benefits. This method is used when project alternatives are mutually exclusive. It is important to note that all costs and benefits must be discounted to the year of analysis. If the NPV value of an alternative is larger than zero, it means that the project will be beneficial. The NPV of the all project alternatives must be compared and usually the scenario with the largest NPV is selected for implementation. It must be noted, however, that policies, budget availability and public input could lead to a project with a lower NPV could be selected. The equation below (AASHTO, 2010) shows how the NPV is calculated:

$$NPV = \sum_{t=0}^{L} \left(\frac{B_t - C_t}{(1+r)^t} \right) \qquad \text{(Equation 2.1)}$$

With:

B_t = nominal value of benefits in year t;

C_t = nominal value of costs in year t;

L = lifetime of project in years and

r = nominal discount rate.

Benefit-cost ratio (BCR)

The BCR of a project indicates the relative magnitude of the total benefits of a project when compared to the total costs. Similar to the NPV, all costs and benefits need to be discounted to the year of analysis. This method is typically used when budget constraints play a large role in the selection of which project(s) should be implemented and when project alternatives are not mutually exclusive. If the BCR is found to be larger than one, the project is deemed beneficial. In most cases, the project (or group of projects) with the highest multiple of BCR values is selected for implementation. The equation below provides the method of calculating the BCR of a project:

$$BCR = \sum_{t=0}^{L} \frac{B_t}{(1+r)^t} \Bigg/ \sum_{t=0}^{L} \frac{C_t}{(1+r)^t} \qquad \text{(Equation 2.2)}$$

With:

B_t = nominal value of benefits in year t;

C_t = nominal value of costs in year t;

L = lifetime of project in years and

r = nominal discount rate.

2.10. Conclusion

This chapter provided a detailed review of relevant literature relating to this study. It was found that several similar restrictions to the ones investigated in this study have been implemented across the world with varying levels of success. It was also found that other restrictions on heavy vehicles have been implemented and studied. Overall, it seemed that no single heavy vehicle restriction has been identified as a perfect solution. The theoretical background of some of the methods used in this document was also investigated and discussed.

CHAPTER 3: PROPOSED NEW REGULATIONS

3.1. Background

In an attempt to reduce the number of road accident fatalities on South Africa's roads involving heavy vehicles, the then Minister of Transport, Dipuo Peters, proposed new traffic regulations in 2015 that would restrict the movement of heavy vehicles on South Africa's public roads (Wheels24 Staff, 2015). These regulations were part of several changes to the National Road Traffic Regulations, 2000 proposed by the minister. This study, however, will only consider the regulations pertaining to the movement of heavy vehicles in urban areas. The official Government Notice containing the proposed regulations, as published in the Government Gazette of 11 May 2015, can be found in **Appendix A1**. The first part of the proposed regulations reads as follows:

"No person shall operate on the public road in an urban area a goods vehicle the gross vehicle mass of which exceeds 9 000 kilograms between the hours of 06h00 to 09h00 and 17h00 to 20h00 Monday to Friday except weekends and public holidays."

The proposed regulations essentially impose a ban on all heavy vehicles that have a gross vehicle mass (GVM) higher than 9 000 kg between 6 a.m. and 9 a.m. and between 5 p.m. and 8 p.m. It is important to note that the ban is only applicable to public roads in urban areas and only on weekdays that are not public holidays. Additionally, no bans are implied for vehicles that have a GVM lower than 9 000 kg.

The second part of the proposed regulations provide more clarity on exceptions to the rule above:

"The provisions of subregulation (1) shall not apply in case of emergencies, to the driver of a fire -fighting vehicle, a fire-fighting response vehicle, an emergency medical response vehicle, a rescue vehicle or an ambulance, who drives such vehicle in the performance of his or her duties, a traffic officer or a person appointed in terms of the South African Police Service Act, 1995 (Act No.68 of 1995), who drives a vehicle in the carrying out of his or her duties, any person driving a vehicle while responding to a disaster as contemplated in the Disaster Management Act, 2002 (Act No. 57 of 2002) or a person who drives a vehicle while it is used in connection with the construction or maintenance of a public road or the rendering of an essential public service."

The second part of the regulations is crucial to include, as it provides for emergency situations where large vehicles will be required to travel in urban areas during the proposed banning periods. However, it is important to note that these vehicles will only be allowed to travel in urban areas in cases of emergencies and in cases where it is necessary to do so for the driver to carry out his duties. Additionally, the second part of the regulations state that only vehicles related to the construction or maintenance of public roads or the provision of essential public services are included in the list of exceptions. This part of the regulations leads to some ambiguity, since it is not always easy to exactly define what an essential public service would be, as discussed in the next section.

3.2. Definitions

The proposed regulations contain many terms that define the scope under which the bans will be implemented. In this section, some of the most important concepts are defined and discussed.

3.2.1. Public road in an urban area

The National Road Traffic Act of 1996 defines a public road as follows:

"public road" means any road, street or thoroughfare or any other place (whether a thoroughfare or not) which is commonly used by the public or any section thereof or to which the public or any section thereof has a right of access, and includes

(a) the verge of any such road, street or thoroughfare-,

(b) any bridge, ferry or drift traversed by any such road, street or thoroughfare; and

(c) any other work or object forming part of or connected with or belonging to such road, street or thoroughfare.

An urban area is defined by the same act as follows:

"urban area" means that portion of the area of jurisdiction of a local authority which has by actual survey been subdivided into erven or is surrounded by surveyed erven, and includes the public roads abutting thereon.

3.2.2. Gross vehicle mass of higher than 9 000 kg

The GVM of a vehicle is the most that the vehicle can weigh when loaded to the maximum. The GVM is specified by the vehicle manufacturer and should never be exceeded. By studying commonly used guidelines and regulations in South Africa, it was found that 9 000 kg is not commonly used as a limit for a truck category. In most cases, the lower bounds of heavy vehicle categories are 3 500 kg and 16 000 kg. This could make the enforcement of the new regulations a difficult task, as enforcement officers may not be familiar with this classification measure. It is also important to note that the regulations would apply to all vehicles with a GVM higher than 9 000 kg, regardless of what the actual loaded weight of the vehicle is.

3.2.3. Emergencies

The word “emergencies” is not very precise and open for interpretation. The Cambridge Dictionary defines an emergency as:

"Something dangerous or serious, such as an accident, that happens suddenly or unexpectedly and needs fast action in order to avoid harmful results."

For the case of this study, this definition of an emergency is accepted. It is assumed that an emergency is any event for which one or more of the emergency vehicles listed in the regulations are required to provide assistance in the line of duty.

3.2.4. Essential public service

The definition of an essential public service may pose to be the most ambiguous of all the terms used in the proposed regulations. No definition of this term is provided in the National Road Traffic Act of 1996, but a definition of essential services is given in the Labour Relations Act of 1995 as follows:

(a) a service the interruption of which endangers the life, personal safety or health of the whole or any part of the population;

(b) the Parliamentary service;

(c) the South African Police Services;

This definition provides some clarity on what an essential public service entails, but it still allows for some interpretation, since it is possible to argue that the interruption of various different services could endanger the life, safety or health of a person.

3.3. Public response

Many stakeholders have responded to the proposed regulations, with arguments being made for and against the implementation of the restrictions. It seems that most responses that support the bans come from public citizens and road users. It has been suggested that this group is often in favour of truck bans because they believe that heavy vehicles occupy too much space and move too slowly on the road network. On the other side of the debate, a large part of the freight industry seems to oppose the implementation of such bans.

The Johannesburg Chamber of Commerce and Industry (JCCI) stated that consumers will ultimately be the losers if the proposed regulations are implemented (fin24 Staff, 2015). They argued that the implementation of such regulations would lead to significant economic losses because of inefficient freight transport. Furthermore, they claimed that the additional infrastructure required for the implementation of the regulations would be much too expensive to make the regulations feasible.

JB Cronjé, a research from Trade Law Centre (tralac), commented that freight companies would experience significant losses if they were restricted to travelling during certain periods of the day, since maximum profitability is reached when trucks can make as many trips as possible (Cronjé, 2015). He also mentioned that such a strategy would require very good law enforcement to work. Additionally, he noted problems with the intention of the regulations to decrease the number of road deaths in South Africa. He found that most accidents on the country's roads in 2010 occurred over weekends and during the hours of darkness (Cronjé, 2015). He argued that the removal of trucks from urban areas during the proposed periods would, therefore, not have a significant impact on road safety.

Other key stakeholders have raised similar concerns to those discussed above, including the South African Road and Freight Association (RFA), who believes that trucks are unfairly blamed for many deadly accidents in South Africa (News24 Staff, 2015). The RFA also questioned whether enough research has been conducted into the possible effects of such regulations before they were proposed. Similarly, Arrive Alive responded to the proposed regulations by stating that, even though they understood the reasoning behind the proposal, proper research would have to be conducted into the effect they would have if they were implemented (News24 Staff, 2015).

3.4. Implementation

The manner in which the proposed regulations will be implemented and enforced is not discussed in the Government Notice. The logistics behind implementation, however, are important to discuss in order to consider whether it is viable and possible to implement and enforce the proposed bans.

The first question that arises, is whether there will be adequate facilities outside of urban areas for heavy vehicles to park during banning periods. Depending on the number of trucks that usually travels through the urban area during these periods, large rest areas may have to be constructed close to towns. This may lead to large initial capital costs. Additionally, the location of the rest areas will have an influence on the ability of truck drivers to exit urban areas before the banning periods start. This may lead to the need for a grace period that truck drivers can use to exit urban areas. This in turn, however, provides some challenges since the size of the urban area would have to play a role in the length of the grace period. Furthermore, it is important that adequate signs should be provided to indicate to truck drivers when they enter and exit urban areas.

Many logistical challenges also present themselves in the enforcement of the regulations. How would officers enforce the regulations? Since the regulations are based on GVM, the officer would need to know what the GVM of a truck is. This could possible require that check points would have to be constructed. Additionally, what would the enforcement method be and, if the regulations were not followed, who would be penalised? As an example of how difficult it is to enforce truck bans, consider a section of the M13 in Durban where trucks were banned in one direction between 06:00 and 09:00 and in both directions between 16:00 and 18:30. Researchers from The Mercury visited the road during the morning peak hour and found that twenty trucks travelled in the banned direction in a single hour (All4women Staff, 2014). It is obvious that strict and serious enforcement methods must be used in order to adequately enforce a nationwide ban.

Another logistical issue to consider is the response from the freight industry. It is possible that freight companies would simply convert their fleets to include many more small trucks that could travel through urban areas during the banning periods. This could lead to a higher number of vehicles on the road and could ultimately eliminate any benefits obtained from banning larger trucks. A freight company in South Africa, Container Domestic Cargo, responded to the proposed regulations by stating that they would have to increase the number of vehicles in their fleet by 35% (Lewis, 2015). The JCCI also confirmed that freight companies will be forced to increase their fleet sizes to prevent significant losses (fin24 Staff, 2015). Additionally, freight companies may decide to use alternative routes that do not pass through urban areas. This could lead to very high truck volumes on roads that were not designed to carry such loads.

Although the proposed regulations provide for emergency vehicles, it does not consider heavy vehicles that provide services within urban areas or local heavy vehicle trips. These vehicles could include large tow trucks, large delivery vehicles, construction vehicles that do not provide essential public services, waste collection vehicles, cranes and concrete mixer trucks. In the case that they are restricted from entering urban areas in the proposed banning periods, they would not be able to provide services. This may in turn lead to significant economic losses for the country.

3.5. Progress of implementation

At the time of writing, the proposed regulations had not been implemented, although it had already been proposed in 2015. According to the Automobile Association, many laws that are proposed in South Africa are either never implemented or are implemented under different conditions (Automobile Association, 2017). The reasons for this vary, with some proposed laws being rejected due to overwhelming negative feedback. The amount of negative feedback from the trucking industry could be a cause for the delay in implementing the proposed regulations. Additionally, the fact that the logistics behind the implementation of the regulations have not been fully discussed could further delay their implementation.

3.6. Potential problems

Possible issues with the implementation of the proposed regulations are:

- Freight companies could increase their number of small trucks and avoid using large trucks, leading to many more small trucks on the country's roads.
- Additional infrastructure, in the form of rest areas or weigh bridges, may have to be constructed.
- Trucks that provide services such as large tow trucks, large delivery vehicles, construction vehicles that do not provide essential public services, waste collection vehicles, cranes and concrete mixer trucks would not always be able to provide the services they are needed for.
- Some ambiguities exist over which services would permit a construction or maintenance vehicle to enter an urban area.
- Adequate enforcement measures would have to be implemented to ensure that the rules are followed.

3.7. Potential benefits

Possible benefits of the implementation of the new regulations include:

- Improved road safety in urban areas.
- Improved congestion levels on public roads in urban areas.
- More efficient movement of freight.
- Long-term economic savings due to a decrease in travel times and road deaths.

3.8. Conclusion

This chapter provided a detailed discussion on the new regulations regarding the movement of heavy vehicles in South Africa's urban areas. It was found that several factors relating to the proposed regulations have not been fully examined and that some ambiguities exist when considering the implementation of the bans.

Furthermore, it was found that the proposal of these new regulations generated opinions both for and against their implementation. In general, the general public seemed to be in favour of the implementation of these regulations, while the freight industry raised concerns over economic losses to the industry and the country.

The regulations had not been implemented at the time of writing and it was found that this could be due to negative public feedback or the fact that the proposed regulations have not been investigated in adequate detail to allow for implementation.

CHAPTER 4: METHODOLOGY

4.1. Introduction

This chapter provides a general overview of the methodology followed in this study. It is important to note that this chapter is not an in-depth discussion, but merely provides the outline of the research design employed. More details on the methodology of each analysis method is provided in the relevant chapters.

4.2. Research design

4.2.1. Data collection methods

Several data collection methods were used to acquire the data required for this study. Because the number of datasets that had to be acquired is substantial, the detailed discussion of the data collection process is not included in this chapter, but is provided in a chapter of its own (**CHAPTER 5:**). **Table 4.1** indicates the data collected and the source of each dataset. The data used in this study is exempt from ethics clearance. Data that was provided through collaboration with an organisation or company is not linked to individuals, any personal accounts or personal information and access to the data was granted by an authorised representative of the organisation or company.

Table 4.1. Data sources used in the study.

Dataset	Data source
Fleet management data	MiX Telematics
Vehicle movement survey data	Kantey & Templer (Consultants for Draft CITP, Stellenbosch Local Municipality)
Floating car data (FCD)	TomTom
Link traffic counts	Collected in field
Traffic volumes	Stellenbosch Local Municipality Collected in field
Signal plans	Stellenbosch Municipality Collected in field

4.2.2. Data analysis methods

Several different methods of analysis were used to reach the objectives of this study. What follows is a brief description of each analysis method.

Fleet management data analysis

Fleet management data was used in this thesis to provide an understanding of the heavy vehicle movement behaviour in Stellenbosch. The data was analysed by using Visual Basic for Applications (VBA). This programming tool allows the user to write code that performs different functions within Microsoft Excel. VBA was used to perform various analyses with the fleet management data, allowing for the determination of the temporal and spatial distribution patterns of heavy vehicles in Stellenbosch to be established.

Vehicle movement surveys

Vehicle movement survey data was analysed to contribute to the understanding of heavy vehicle movements in Stellenbosch. This data was used to identify vehicles only for purposes of identifying general movement patterns on main routes through Stellenbosch. The number plates were not linked to any database that could identify the owner or driver of the vehicle. Additionally, vehicles were not traced to explicit origins and destinations. The dataset was analysed with the use of Microsoft Excel.

Microscopic traffic modelling

A microscopic traffic model was constructed in order to investigate the effects that the proposed regulations would have on traffic in Stellenbosch in the case that they are implemented. This was done with the use of PTV Vissim, a microscopic simulation software of the PTV Vision group. This software allowed for the simulation of different traffic scenarios and could provide information on the traffic conditions that prevailed in each scenario.

Economic evaluation

An economic evaluation was performed to investigate the economic effects of the proposed heavy vehicle bans. This evaluation included the calculation of value of time costs, vehicle operating costs, emission costs and finally the Net Present Value of different scenarios.

4.2.3. Summary

Figure 4.1 on the next page provides a graphical representation of the research design that was followed in this study.

4.3. Conclusion

This chapter provided an overview of the methodology followed in this thesis. The discussion in this chapter was not very detailed, as the applicable information regarding each analysis method can be found in the relevant chapters. The next chapter provides a detailed discussion on the data collection process used.

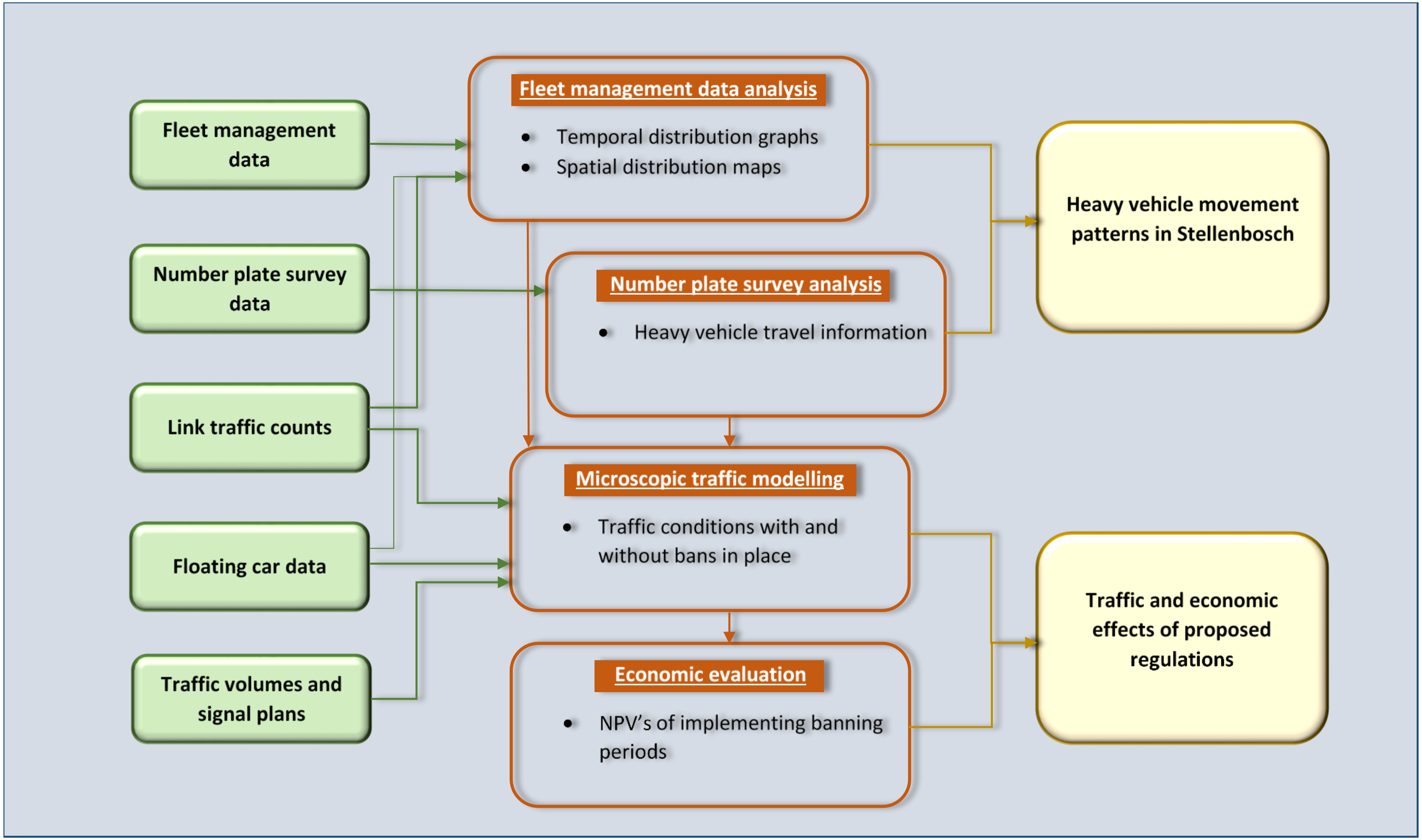


Figure 4.1. *Research design used in the study.*

CHAPTER 5: DATA COLLECTION

5.1. Introduction

The research contained in this document required several datasets from various sources. For this reason, it is essential to provide an explanation of the data obtained and the origin of these databases. This chapter aims to provide this information and, in addition, provide details on the aspects that had to be considered when working with this data.

5.2. Fleet management data

5.2.1. Background

Fleet management data plays an important role in the maintenance and operational planning of commercial vehicle fleets. The collection and processing of this data is frequently outsourced to private companies specialising in fleet management services, since it is often a costly and labour-intensive process for companies to manage themselves. By using fleet management services, companies can improve the performance of fleets, ensure that drivers and vehicles comply with all applicable laws, ensure that safety requirements are met and provide managers with insights into the areas where fleet operations can be improved.

Although fleet management data is usually used by companies to improve and manage their own fleet operations, it can also be used for other applications. In this study, fleet management data is used to analyse the movements of heavy vehicles in Stellenbosch.

5.2.2. MiX Telematics Ltd.

Mix Telematics Ltd. is one of the leading fleet management companies in the world, providing fleet management and mobile asset management services to over 120 countries. The company's headquarters were established in South Africa in 1996, where the company is listed on the Johannesburg Stock Exchange (JSE). Although MiX Telematics was only founded in South Africa in 1996, the company's international affiliation dates back to 1985, with offices located in the United States of America, the United Kingdom, Brazil, Uganda, Australia, and the United Arab Emirates (MiX Telematics, 2017).

MiX Telematics provides commercial fleet management services that include vehicle tracking, the provision of required hardware and software, stolen vehicle recovery and many other products and services that customers can use to improve fleet performance and efficiency. Customers have access to an online platform from which fleet specific reports and databases can be generated.

As a company that is devoted to the development of research into the improvement of fleet management data, MiX Telematics formed a partnership with the Stellenbosch Smart Mobility Lab (SSML). As part of this partnership, the author was provided with live tracking data of all trucks that were tracked by MiX Telematics within the town of Stellenbosch and the surrounding area. This data included the tracking information of all vehicles that were present in the area, irrespective of who the owner of a vehicle was. It is important to note that vehicles were identified with a unique number and no other identification of the vehicles, driver, owner or freight company was included in the dataset received. The format and content of this data are discussed in the following subsections.

5.2.3. Files received

On average, one data file was uploaded to the online database every 15 seconds. Each uploaded file contained all data points generated in the five minutes leading up to the file being uploaded. It is important to note that a data point could not be uploaded more than once. Therefore, if a data point was already included in the previous file, it was not included again in the next uploaded file. This uploading process allowed for all data points generated in a day to be included in the database, even if a device was delayed in sending a data point to the system. It was assumed that data points would not be delayed by more than five minutes.

5.2.4. Data format and content

Between 5 000 and 6 000 files were downloaded for each day that was analysed. Each line in a file represented a single data point or, in other words, a single tracked location. The following table contains a description of each parameter contained in the data.

Table 5.1. Parameters of fleet management data points.

Parameter	Description
Address	A unique identification number linked to the tracking device of a specific vehicle.
Latitude	The latitude of the device in decimal format.
Longitude	The longitude of the device in decimal format.
HDOP	Horizontal dilution of precision of the coordinate point.
Heading	The heading of the vehicle in decimal degrees, clockwise from North.
Speed	Speed of the vehicle in km/h.
Time	The date and time that the data point is recorded. The time is recorded in Greenwich Mean Time (GMT) in the following format: “yyyy-mm-dd’T’hh:mm:ss”.

Below is a sample of three data points as it was present in one of the data files:

```
1.2719.9775,-33.70919,18.97597,1,0,0,2017-10-30T23:58:52
1.226.22,-34.07939,18.84775,0,334,16,2017-10-30T23:59:03
1.226.9,-34.08644,18.85336,0,130,28,2017-10-30T23:59:10
```

5.2.5. Minimum sample size

Whenever sample data is used as a representation of an entire population, it must be ensured that enough data points are included in the sample set to accurately represent the distribution of the population. The minimum required sample sizes for the fleet management data received by MiX Telematics were calculated with the use of **Equation 5.1** (Transportation Pooled Fund Program, 2009).

$$n_{min} = \left(\frac{z_{\alpha/2} \times \frac{\sigma}{\mu}}{\theta}\right)^2 \qquad \text{(Equation 5.1)}$$

With:

n_{min} = minimum required sample size;

$z_{\alpha/2}$ = critical normal deviate for a specific confidence interval;

σ = standard deviation;

μ = average and

θ = allowable error (in %).

Because each data point in the database contained several attributes, the minimum sample sizes were calculated for the recorded speeds, as this information was numerical and easier to use for these kinds of calculations. A maximum confidence interval of 99% and a recommended margin of error of 5% were used. It must be noted that the average speed and standard deviation of the entire population was unknown. However, it is recommended that the average and standard deviation of a sample could be used as approximations of the population's average and standard deviation in this case (Rumsey, 2016). The only requirement for this is that the sample should be sufficiently large. The sample sizes for the fleet management data were deemed large enough to accept this simplification.

Table 5.2 contains the standard deviation, average speed, required sample size and observed sample size for each of the eight days analysed. The samples considered were the daily datasets after all data refinement was completed and all zero-speed entries were removed (discussed in **CHAPTER 6:**).

Table 5.2. Minimum sample sizes required for fleet management data.

Day	σ (km/h)	μ (km/h)	n_{min}	$n_{observed}$
1. Sunday, 22 Oct	29.08	37.80	1 576	3 588
2. Tuesday, 24 Oct	24.05	25.43	2 382	11 408
3. Wednesday, 25 Oct	25.78	27.38	2 361	10 463
4. Thursday, 26 Oct	25.81	26.69	2 490	10 583
5. Sunday, 29 Oct	27.38	31.87	1 966	5 164
6. Tuesday, 31 Oct	25.89	26.49	2 543	11 932
7. Wednesday, 1 Nov	25.70	25.65	2 673	9 916
8. Thursday, 2 Nov	24.27	24.47	2 619	11 608

As can be observed from the table, the sample size of each day was significantly larger than the required sample sizes. Therefore, the datasets were deemed to be accurate representations of the population data.

5.3. Vehicle movement surveys

5.3.1. Background

Vehicle movement surveys (VMSs) were conducted on 13 and 20 June 2018 (two consecutive Wednesdays) between 3 p.m. and 6 p.m. at several points in the vicinity of Stellenbosch. The vehicle movement surveys were specifically conducted to track the movement of freight vehicles. This data was provided by Kantey & Templer, who collected it for Stellenbosch Local Municipality as part of the preparation for the Comprehensive Integrated Transport Plan (CITP).

5.3.2. Data received

The VMS data received from Kantey & Templer included the times that freight vehicles with specific number plates passed one of the locations included in the VMS. For each of the locations, a list of number plates and the corresponding timestamp was provided. The number plates were not related to the personal information of drivers or vehicle owners, and were only used to identify vehicle movement patterns on the main routes in Stellenbosch.

5.4. Floating Car Data (FCD)

5.4.1. Background

Traditional methods of collecting traffic data, such as vehicle speeds and travel times, usually require intensive field work which involves the expenditure of a significant amount of time and money. Additionally, roadside hardware must often be installed to collect the data. FCD allows for the circumvention of these traditional methods by collecting data through probe devices. These devices could include GPS navigation systems and cell phones. Contrary to traditional data collection methods, probe devices move freely with vehicles and are, therefore, not bound to a stationary location. This allows for a greater data collection area.

5.4.2. Objectives

FCD is used for the following purposes in this research:

- For the validation of the findings of fleet management data analyses;
- For the prediction of latent demand;
- For the determination of speed distribution profiles in Stellenbosch and
- For the validation of the outputs of the microsimulation model.

5.4.3. Data received

The FCD used in this research was provided by TomTom NV, one of the world’s leading providers of navigation and telematics technologies. Through a partnership between TomTom and the SSML, the author was able to access data from an online portal, known as TomTom Traffic Stats.

Data can be acquired from the TomTom Traffic Stats portal on a route or an area basis. For either case, the user specifies the route or area for which data is required and the type of vehicles that should be included in the probe database. Additionally, the user must define the dates and time periods over which data should be aggregated. Travel time and speed data is then generated for the set of parameters.

Table 5.3 provides details on the different datasets obtained from TomTom and the purpose for which each was used.

Table 5.3. FCD datasets obtained from TomTom.

Dataset	Dates included	Vehicles included	Purpose
1 (Area)	24 October 2017 25 October 2017 26 October 2017 31 October 2017 1 November 2017 2 November 2017	Fleet	Determine temporal distribution and most used routes of heavy vehicles. (**Section 6.12**)
2 (Route)	Weekdays of February and March of 2013 and 2018.	All vehicles	Predict the presence of latent demand. (**Section 8.6**)
3 (Route)	Weekdays between 7 May and 8 June 2018.	Fleet, Passenger cars	Determine speed profiles of different vehicle classes. (**Section 9.7.5**)
4 (Route)	Weekdays of August, September and October of 2018.	All vehicles	Validation of the microscopic modelling results. (**Section 9.9**)

5.5. Link traffic counts

5.5.1. Background

Traffic counts on specific links in Stellenbosch were required for several of the analyses performed in this study. However, no traffic volumes were available at the time of performing the analyses. Therefore, traffic counts were conducted at three locations in Stellenbosch during morning and afternoon peak periods. The author and several students from the SSML manually counted all vehicles travelling in both directions of travel at the three locations for seven hours a day, on three weekdays in April 2018, with care to exclude any periods affected by holidays. Counts were conducted with the use of an electronic counting application loaded onto the counters' smart phones. The number of passenger cars, heavy goods vehicles, and buses were recorded for each fifteen-minute period. All goods vehicles with a GVM of 3.5 tons or higher were classified as heavy goods vehicles.

5.5.2. Objectives

The results obtained from the traffic counts were used to serve the following three objectives:

- To determine the share of the total heavy vehicle population that is represented by the fleet management data provided by MiX Telematics.
- To determine the proportion of the traffic stream on three major routes into and out of Stellenbosch that are heavy vehicles.
- To estimate the presence of latent demand on the major routes to and from Stellenbosch.

5.5.3. Times

Traffic counts were conducted on the following three weekdays for seven hours a day:

- Tuesday, 17 April 2018;
- Wednesday, 18 April 2018 and
- Thursday, 19 April 2018.

The results of the analysis of the fleet management data provided by MiX Telematics were consulted to select the appropriate periods during which to conduct the traffic counts. The temporal graphs created during this analysis indicated the peak periods of heavy vehicles in the Stellenbosch area on weekdays. Counting periods were selected to include these peak periods as much as possible, as well as the most likely peak hours of the general traffic stream on the selected routes. For the purpose of estimating the presence of latent demand on the routes, periods were selected to be of considerable length to enable the observance of peak spreading if it were to occur. The afternoon period was selected to be longer than the morning period, because the peak hour for heavy vehicles and the general traffic stream was estimated to be further apart in the afternoon than in the morning. For the above reasons, the counting periods were selected as follows:

- **Morning counting period (three hours):** 6:30 a.m. to 9:30 a.m.
- **Afternoon counting period (four hours):** 2 p.m. to 6 p.m.

5.5.4. Locations

Traffic counts were conducted at the three locations shown in **Figure 5.1**. It is important to note that counts were performed on one day at each location. The date on which counts were performed at each location is also indicated on the figure.

The locations where the traffic counts were performed were selected for very specific reasons. All locations were selected to include the major routes into and out of Stellenbosch used by heavy vehicles, indicated by the results of the fleet management data analysis. Furthermore, count locations were selected at a large enough distance from the central town area in order to prevent congestion and intersection control devices from influencing the results. It was, however, important to select the locations close enough to the town to ensure that there was a high probability that Stellenbosch was included on the travel path of the counted vehicles.

Figure 5.1. *Locations and dates of traffic counts (Google Earth Pro, 2018).*

The three locations selected for the traffic counts are discussed below.

Location 1 (R304)

Location 1 was located next to the R304 just before the road intersects with Bottelary Road, when travelling from Stellenbosch. At this location, the road had one lane in each direction of travel. The specific location was selected to be adequately far enough from the town of Stellenbosch. Additionally, it had to be located away from the signalised intersection between the R304 and Bottelary Road, to prevent the influence of queueing. Location 1 could not be located more northwards than the selected location, since many vehicles travelling on Bottelary Road travelled to and from Stellenbosch. These vehicles had to be included in the traffic counts. Furthermore, the selected location was found to provide an adequate view of the traffic stream in both directions. Additionally, the counts had to be performed on the southern side of the access road to the Caltex fuel station situated next to the R304 in order to avoid the influence of vehicles turning off to the fuel station and joining the traffic stream again after a period of time.

Location 2 (R310)

Location 2 was located next to the R310 between Stellenbosch and Kuils-River, before the signalised intersection of Baden Powell Drive and Polkadraai Road. The road had two lanes in each direction of travel at this location. Similar to Location 1, Location 2 had to be located an adequate distance from the signalised intersection to prevent the influence of queueing. It was a challenge to select this location at a large distance from the centre of town, since both Baden Powell Drive and Polkadraai Road both carried traffic travelling to and from Stellenbosch. Therefore, the location had to be located on the eastern side of the intersection of these two roads to include all traffic merging from the roads onto the R310. Location 2 provided a clear and unobstructed view to counters.

Location 3 (R44)

Location 3 was located next to the R44 between Stellenbosch and Somerset-West, just after the signalised intersection of the R44 and Annandale Road. The road had two lanes in each direction of travel. Like the other two locations, the location had to be selected at an adequate distance from the intersection to prevent the influence of queueing. Location 3 was located at a significant distance from the centre of Stellenbosch, preventing congestion in town from influencing the results. Additionally, the selected location provided a sufficient view of the traffic stream to counters.

5.5.5. Method

The traffic counts discussed in this section were collected by manual counting. Automatic counting could not be performed due to a lack of required technology and devices at the time of counting. In addition, the duration of counting periods was short enough to allow for accurate manual counts to be performed.

When counted, vehicles were classified as either passenger cars, heavy vehicles or busses. Motorcycles, bicycles, pedestrians, tractors and all other vehicles that could not be classified as belonging to one of the three categories were ignored. Heavy vehicles were defined as goods vehicles having a Gross Vehicle Mass (GVM) of larger than 3 500 kg. Because the GVM of a vehicle was not always easy to identify, counters had to use their discretion when classifying a counted vehicle. **Figure 5.2** on the next page was used to inform counters of how to classify the vehicles while counting.

5.6. Data required for microscopic model

5.6.1. Background

In order to create and run a microscopic model, several input parameters are required. This data is usually acquired from the relevant authorities but if all data is not available, it must be collected before the model can be completed. This section discusses the origin of two main datasets required as input when using Vissim. The source of other required input parameters are discussed in **CHAPTER 9:**.

5.6.2. Traffic signal plans

For realistic simulation of traffic flow at signalised intersections, the actual implemented signal plans for each intersection must be modelled. The model that is included in this research contains 19 signalised intersections. The signal plans of 18 of the intersections were received from Stellenbosch Municipality. These plans identified the signal phases, the green, yellow and all red times of each phase, the phasing sequence, and the method of operation of each intersection. It is important to note that the signal plans had to contain data for both the morning and afternoon peak periods, as both these periods would be modelled.

No signal plan was available for one of the traffic signals in the model, namely the intersection of the R310 and Oude Libertas Road. This signal was timed by the author during the morning peak period and afternoon peak period of 25 October 2018 to estimate the maximum green time, as this signal was believed to be vehicle actuated or semi-actuated. By measuring the maximum green times, the signal could be approximated as a fixed-time signal for the purposes of the model. The green times for the morning peak and afternoon peak were assumed to be applicable to the entire morning and afternoon modelled periods respectively.

5.6.3. Traffic volumes

Traffic volumes are required for a Vissim model for two reasons. Firstly, the vehicle inputs of all incoming links of the network are calculated from these volumes. This includes the total volume of vehicles entering the traffic stream as well as the vehicle composition of each incoming traffic stream. Secondly, traffic volumes were required to determine the routing decisions at all intersections for both passenger cars and heavy vehicles.

Several data sources were used to obtain the necessary traffic volumes for the model. What follows is a brief description of each data source and the manner in which the data from each source was modified (if applicable) to be used in the model. Traffic volumes were required for 15-minute intervals between 6 a.m. and 9 a.m., and 5 p.m. and 8 p.m. **Figure 5.3** indicates the data source used for each location in the network where inputs were required.

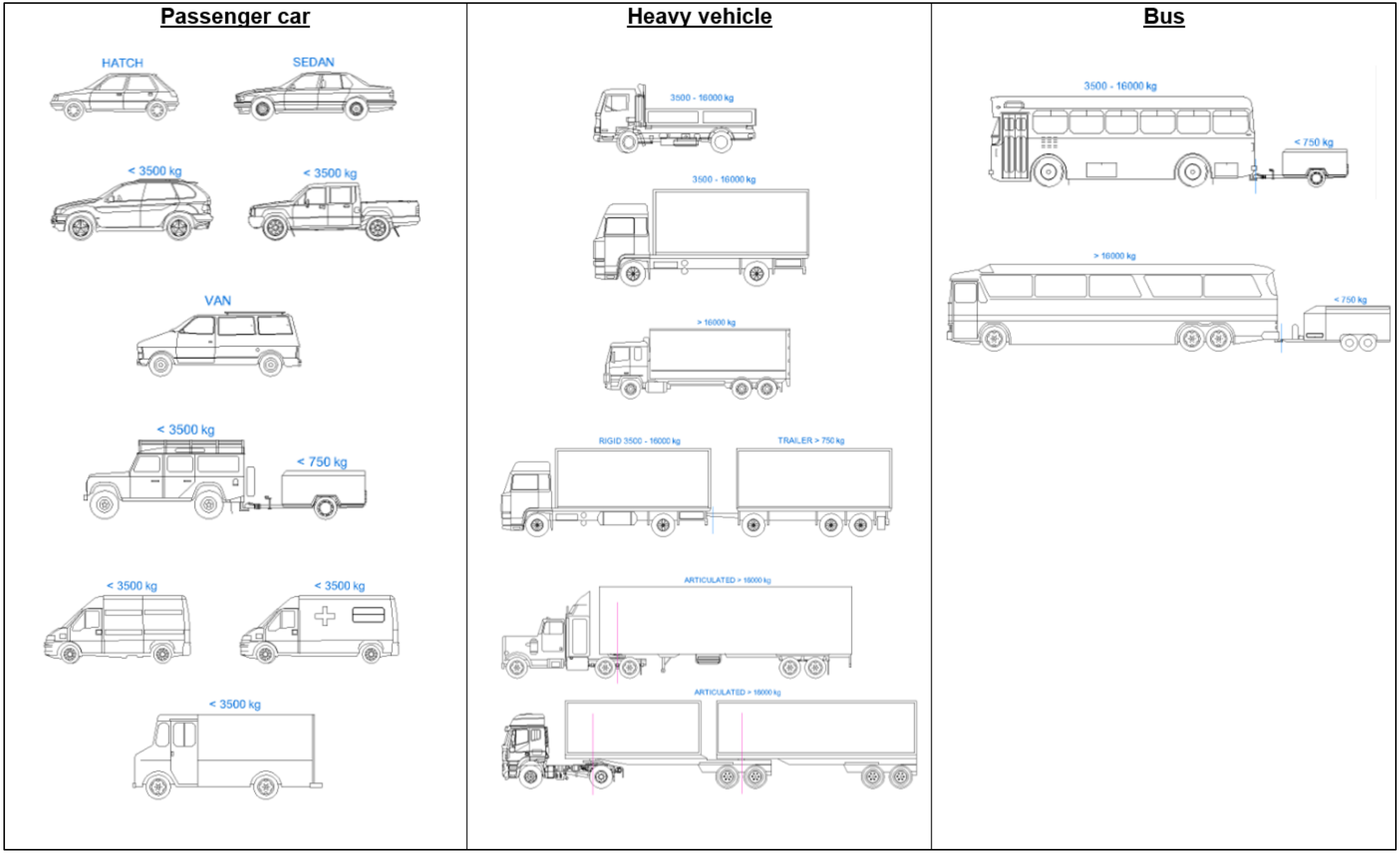


Figure 5.2. *Diagram used to help counters with vehicle classification (Drive It, 2018).*

Figure 5.3. *Volume data sources of modelled intersections (Google Earth Pro, 2018).*

1. Nick Venter Traffic Surveying

Nick Venter Traffic Surveying was appointed by the SSML to conduct traffic counts at several intersections in Stellenbosch. Counts were conducted on 26 September 2018 and 10 October 2018 and included both modelling periods. The dates were selected to exclude public holidays, school holidays and university recess or examination periods. The volumes were determined separately for passenger cars, minibus taxis, buses and heavy vehicles.

2. Manual intersection counts

The author conducted intersection counts at ten intersections between 25 September 2018 and 11 October 2018. Counts were only conducted on weekdays that did not fall within public holidays, school holidays or university recess or examination periods. It must be noted that protest action took place during two morning counts on Bird Street between 8:30 a.m. and 9 a.m. It was believed that traffic flow was significantly impacted by this because the road was completely blocked by protesters. For this reason, additional counts were performed between 8 a.m. and 9 a.m. on different days to determine accurate volumes. Passenger cars and heavy vehicles were counted separately.

3. Manual link counts

As discussed in **Section 5.5**, link volume counts were conducted in April 2018. These counts were also used as input for the model.

4. Municipality volumes

Stellenbosch Municipality provided the results of traffic counts that were performed at several intersections in Stellenbosch on 22 February 2018. It must be noted that the volumes provided by Stellenbosch Municipality were only available until 6 p.m. Volumes between 6 p.m. and 8 p.m. were estimated by using the volume distributions of nearby, similar intersections.

5. Calculated volumes

Even though several sources of traffic volumes were available, the volumes at all intersections included in the model were not obtained, mainly due to the fact that the model contained such a large number of intersections. These unknown volumes could, however, be estimated. Traffic flows at adjacent intersections and volume ratios of different movements at similar, nearby intersections were used to calculate unknown volumes.

5.7. Conclusion

The nature of the research contained in this document is very data intensive and, therefore, requires many different sources of data. This chapter discussed all datasets obtained for this research and the purpose for which it was required. Additionally, the origin of each dataset was discussed in detail and any limitations were explained.

CHAPTER 6: FLEET MANAGEMENT DATA ANALYSIS

6.1. Background

The Cambridge Dictionary defines fleet management as follows:

"the job or activity of taking care of a company's cars, trucks, planes, etc."

Although this definition is very wide, one thing that is certain is that fleet management has to do with the vehicles owned by a *company*. Companies use fleet management systems to obtain information relating to the movements of their vehicle fleets for commercial purposes. These fleets could include any type of vehicle, including cars, heavy vehicles, trains, ships or even airplanes. The information provided by fleet management systems can be used for vehicle maintenance planning, transportation logistics, determining driver behaviour, fuel management or for vehicle telematics (tracking). It is important to note that each vehicle management system is unique and the functionality of each system depends on the final goal that a company wants to achieve by using the system.

Fleet management can be performed by companies themselves or can be outsourced to fleet management specialists. Either way, fleet management data is traditionally only used by the *companies themselves* to improve their operations, efficiency and profitability. Great value could, however, be found in third parties analysing this data for application in the engineering field. The information provided by fleet management systems could shed light on the routes that heavy vehicles follow, the fluctuations of heavy vehicle presence on road networks, and many other revealing properties of heavy vehicle movements. Furthermore, fleet management systems could potentially provide authorities with information that would be otherwise very difficult or expensive to collect and could assist in the decision-making process when managing local transportation policies. Even so, the use of fleet management data by third parties is rare. In this study, the author attempts to use fleet management data in a way that it has not been used in many other cases, by attempting to establish the movement behaviour of heavy vehicles in Stellenbosch. It was found that no significant research had previously been performed into the detailed movement patterns of heavy vehicles in Stellenbosch.

This chapter discusses the analysis of the fleet management data used in this study. The results of the analysis, as well as a discussion regarding the conclusions made, are provided.

6.2. Objectives

The objectives of using fleet management data in this study are:

- To determine the most popular routes used by heavy vehicles in Stellenbosch;
- To determine the fluctuation pattern of heavy vehicle presence in Stellenbosch during a day;
- To compare the movement patterns of heavy vehicles in Stellenbosch on weekdays and weekends and
- To define areas in Stellenbosch where possible problems regarding heavy vehicle presence could arise.

6.3. Semester exchange at North Carolina State University

The fleet management data used in this study contained large amounts of information. In order to adequately analyse this data, the skills and knowledge required to work with Big Data Systems had to be acquired. For this, the author attended North Carolina State University (NC State) in the USA during the second semester of 2017 as part of a semester exchange program. NC State was specifically selected as the exchange university because of the fact that this university could provide the knowledge and skills required to work with Big Data.

During the semester abroad, the author worked under Prof. Nagui Rouphail at the Institute for Transportation Research and Education (ITRE) at NC State. ITRE has extensive experience in working with Big Data in the transportation field and was able to provide the necessary tools and advice for the processing and analysis of the fleet management data received from MiX Telematics.

6.4. Software used

The following software was used to process and analyse the fleet management data obtained from MiX Telematics:

- Microsoft Excel 2016
- Microsoft Visual Basic for Applications 7.1 (VBA)

6.5. Assumptions and limitations

6.5.1. Assumptions

The following assumptions were made for the analysis of the fleet management data:

1) It was assumed that all tracked vehicles that were included in the dataset were heavy vehicles with a Gross Vehicle Mass (GVM) higher than 3 500 kg. The weights of the tracked vehicles were unknown, but since the majority of vehicles tracked by MiX Telematics were freight vehicles, this assumption was believed to be reasonable.
2) It was assumed that a recorded coordinate point was accurate enough if the Horizontal Dilution of Precision (HDOP) was larger than three.

3) It was assumed that a tracked vehicle would have a negligible impact on the results of the analysis if it was only present in the study area for five minutes or less.

6.5.2. Limitations

The process of analysing the fleet management data was subject to the following limitations:

1) The information provided by MiX Telematics was limited due to privacy issues and the fact that the desired data was not always able to be recorded by the devices used. This means that the following information about the tracked vehicles could not be obtained:
    - Weight and size of the vehicle;
    - Type of vehicle;
    - Purpose and use of the vehicle;
    - Industry that the vehicle served and
    - Owner of the vehicle.
2) Since the fleet management data only provided tracking data within a delimited area, the origins and destinations of many of the tracked vehicles could not be determined if it fell outside of the study area.
3) On average, vehicle speeds were only recorded every 15 seconds. This meant that the variation of speeds of a vehicle along a route could not be accurately determined. This was accepted since it was inherent to the fleet management system used and could not be changed. It was believed that the available speeds could still provide adequate data to achieve the final objectives of the study.
4) There was not clarity over the conditions under which speeds of 0 km/h were recorded. The data providers stated that a zero-speed could have been recorded under a variety of conditions, including when a vehicle was stopped at a traffic control device, when a vehicle was making a delivery or when a vehicle was stuck in traffic. It was even found that some vehicles could record zero-speeds when it was parked and switched off. This ambiguity led to the exclusion of any data point with a recorded speed of 0 km/h.
5) Some data was lost during the process of downloading datasets from the data server. Because of this, one of the analysed days (Wednesday, 1 November 2017) did not have a complete dataset. Approximately one hour of data was missing, but it was found that this did not significantly influence the results or conclusions made.

6.6. Study area

The study area for the analysis of the fleet management data is shown in **Figure 6.1**.

The study area includes a square area, 10 km wide on each side, around the centre of Stellenbosch. This area was selected to include the entire urban area of Stellenbosch and significant sections of the main routes feeding the town. Care was taken to ensure that the study area did not include roads that did not feed Stellenbosch or could be influenced by the presence of other towns. It was found that the selected study area was big enough to provide the information required to reach the objectives of the analysis, without being significantly influenced by external influences.

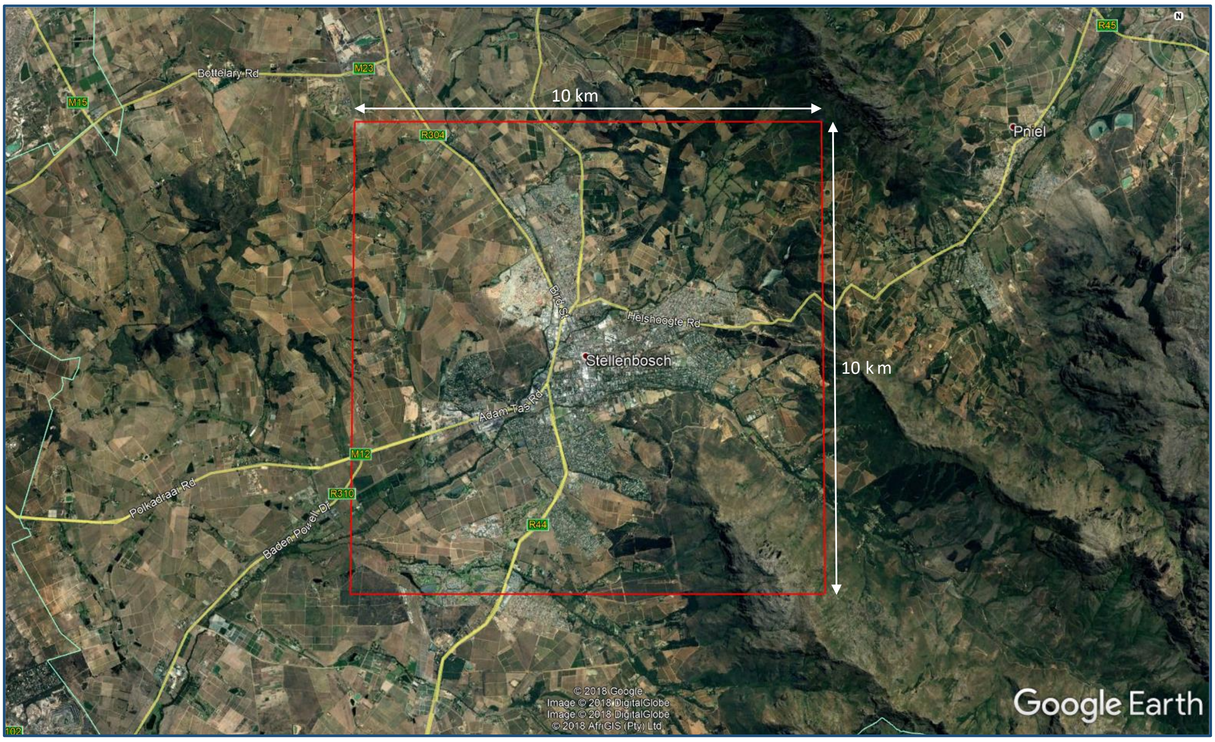


Figure 6.1. *Study area for analysis of fleet management data (Google Earth Pro, 2018).*

6.7. Analysis period

The following eight days were selected as the analysis period for this study:

- 22 October 2017 (Sunday)
- 24 October 2017 (Tuesday)
- 25 October 2017 (Wednesday)
- 26 October 2017 (Thursday)
- 29 October 2017 (Sunday)
- 31 October 2017 (Tuesday)
- 1 November 2017 (Wednesday)
- 2 November 2017 (Thursday)

The analysis period was selected to exclude any public holiday, school holiday or the recess periods of Stellenbosch University. Although the dates fell within the examination period of Stellenbosch University, it was assumed that the potential changes in student driver behaviour during examinations would not have a significant impact on the rest of the traffic stream, including the movement of heavy vehicles.

Additionally, the dates selected included at least one day that fell within the weekend (Sunday). This allowed the author to analyse the differences in heavy vehicle movements between weekends and weekdays. The other days in the dataset (Tuesday to Thursday) were assumed to be days that would display average weekly truck behaviour, without being influenced by the effects of weekends. It is common for Mondays and Fridays to be excluded from traffic engineering studies since traffic volumes on these days are not always consistent and may be influenced by their proximity to weekends. Especially in urban areas, Fridays tend to have higher traffic volumes than other days in the week.

6.8. Data consolidation

On average, a data file was uploaded to the online database every 15 seconds. This large number of individually generated files led to a considerable amount of difficulty in analysing the data. Therefore, all files for each day had to be combined into a single Excel file. A macro was written in VBA to perform this task and, ultimately, 44 967 data files were condensed to eight.

6.9. Data analysis

After the fleet management data was consolidated into eight individual datasets, it was analysed by using VBA coding within Microsoft Excel (hereafter referred to as Excel).

The VBA coding platform was used to write macros (sections of code that automate tasks and calculations in Excel) that were implemented within the Excel files to perform the analyses. Although VBA is not as powerful as some other analysis software, it was decided that VBA would be sufficient for the amount of processing that would be required in this study. The format of the datasets was also much more compatible for use within VBA. Using other software could have required additional formatting of the data before analysis could take place, leading to a more time-consuming process. This section provides a brief overview of the different processes used to analyse the data.

6.9.1. Data refinement

Removal of coordinates that are out of range

The data provided by MiX Telematics was not limited to the study area; it included data points that were recorded in Stellenbosch and a large area surrounding the town. For this reason, the data had to be filtered to remove the entries that fell outside of the defined study area. A macro was written in VBA to identify and delete all entries that did not fall within the study area by examining the coordinates of a data point.

Removal of entries with low precision

The GPS coordinates of each point in the dataset were associated with a Horizontal Dilution of Precision (HDOP). The HDOP of a GPS point is a measure of the accuracy of the recorded horizontal position of the point. A higher HDOP value indicates lower accuracy, while a lower HDOP value indicates the opposite. The HDOP of a recorded data point is dependent on the relative configuration of the tracking satellites with regards to the receiver recording the coordinates. When the satellites are very close to each other, the precision of the horizontal position of the recorded coordinates will be low and this will yield a high HDOP value. When the satellites are more spread out, however, the precision will be higher and the HDOP value will be low. **Figure 6.2** and **Figure 6.3** provide a graphical representation of this concept.

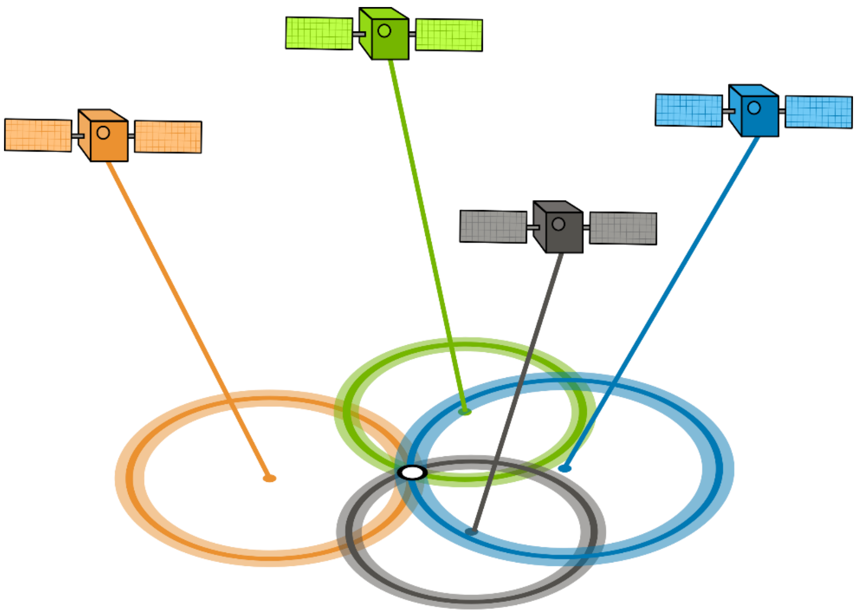


Figure 6.2. *Satellite configuration yielding a low HDOP (GIS Geography, 2018).*

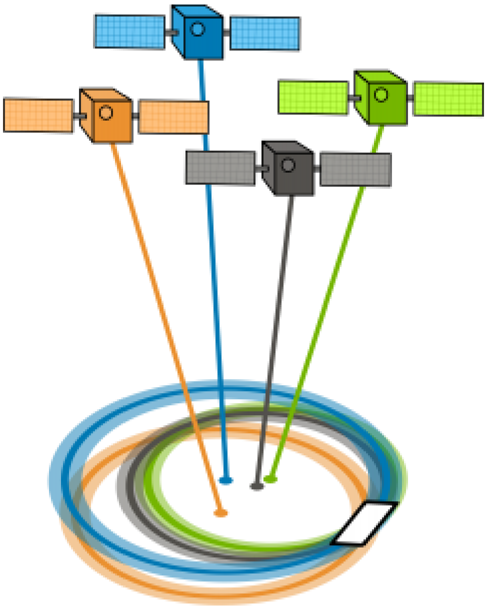


Figure 6.3. *Satellite configuration yielding a high HDOP (GIS Geography, 2018).*

There is no fixed limit to what the maximum value of the HDOP should be, but an HDOP value of equal or less than one is always the most preferred. However, removing all data points that have an HDOP value greater than one may prove to remove a considerable portion of a dataset. Therefore, the acceptable maximum HDOP value of a set of GPS points is determined on a case-by-case basis, depending on what the information will be used for. For the purposes of the data analyses performed in this study, it was decided that a maximum HDOP value of three would be permitted. An HDOP value of three generally indicates that a recorded GPS point is accurate enough for most scientific applications.

A macro was written that, when executed, counted and displayed all entries in a dataset with an HDOP value larger than three in a text box. The user could then be aware of how high the identified HDOP values were, giving an indication of the precision of the dataset. Another macro was written to remove all entries with an HDOP value larger than three.

Removal of trucks with a presence of less than five minutes

While analysing the data, it was noted that some heavy vehicle addresses only appeared in the datasets with very few entries. This could have been because heavy vehicles were travelling on a path that briefly passed through the edge of the study area and never actually travelled to the town. The data from these vehicles was assumed to be irrelevant, since their movements would not occur in Stellenbosch and would have a negligible impact on the movement of other vehicles. Additionally, it was theorised that the GPS receivers of some heavy vehicles may have lost signal while the vehicle travelled within the study area and, therefore, only logged a few coordinate points. This could lead to inaccurate results, since it would seem like these vehicles simply jumped from one position to another, not following a specific route.

A minimum presence of five minutes was selected for all heavy vehicles to be included in a dataset. Five minutes was selected because of the size of the study area. By taking into consideration the speed limits on the major roads feeding Stellenbosch, it could be deduced that a heavy vehicle would most likely be travelling to the town when present in the area for longer than five minutes. Additionally, it was noted that local heavy vehicle movements that were both generated and terminated within Stellenbosch would most likely last longer than five minutes because of the locations of likely origins and destinations within the town.

A macro was written in VBA to delete all vehicles from the database that were not present for at least five minutes.

6.9.2. Temporal distribution of entries

The temporal distributions of logged data points were determined with the used of pivot tables and pivot charts. The first set illustrated the number of data entries recorded in each hour when considering the entire database, while the second showed the temporal distribution of all entries with speeds not equal to zero. From these graphs and tables, it could be determined during which times of the day most of the tracked vehicles travelled within the study area.

6.9.3. Temporal distribution of trucks

The temporal distribution of data entries could not give a precise indication of the actual heavy vehicle presence during each hour, since all vehicles did not generate the same number of data points. Therefore, the temporal distribution of heavy vehicles needed to be determined. This could not be done with pivot tables and charts. A macro was written in VBA to count the number of trucks present in each hour and display this data in a graph. It is important to note that a truck address was only counted once per hour, instead of counting one entry for each time that a data point was logged.

6.9.4. Spatial distribution maps

Spatial distribution maps were created with the use of an online mapping tool called HamsterMap. A map was created for the proposed morning banning period (6 a.m. to 9 a.m.), the afternoon banning period (5 p.m. to 8 p.m.) and for the entire day (24 hours).

In order to use the mapping tool, the datasets had to be formatted to conform to the conventions of the tool. The following information had to be provided:

- Latitude (in decimals);
- Longitude (in decimals);
- Marker (defines the shape of a data point on the map) and
- Colour (defines the colour of a data point on the map).

Excel was used to generate this information for each data point in a dataset. Additionally, all entries with speeds equal to 0 km/h were removed from the datasets.

The colour of each data point was dependent on the speed recorded for that entry. This allowed for a form of a heat map to be created, indicating where heavy vehicles travelled slower. **Table 6.1** indicates the speed ranges that were used to define the colour of a data point on the maps.

Table 6.1. Speed ranges for colour of data points plotted on maps.

Speed range (km/h)	Colour
< 24	Red
25 - 44	Orange
45 - 64	Yellow
65+	Green

6.9.5. Speed reasonability test

While analysing the fleet management data, it was deemed necessary to build in some form of a reasonability test in order to determine whether the data made sense. For this, it was decided to plot all speeds recorded during each of the eight days in the study. To do this, a pivot table was created to count the number of entries that was recorded at a specific speed. The data was then used to plot a speed distribution graph for each day.

6.10. Results

This section provides a discussion of the results of the analysis process described before. It is important to note that only the results for Thursday, 2 November 2017 are shown in many of the subsections. It was found that the results for the analysed weekdays were very similar and, therefore, not all results were included in this section. The results of all eight days can, however, be found in **Appendix A2**. The results for 2 November were merely included in this section for illustrative purposes where required. This allows the reader to better understand the discussions regarding certain results. Where the differences between weekday and weekends are discussed in this section, the results of Sunday 29 October 2017 are included, again for illustrative purposes. The result for the two Sundays analysed were also found to be similar.

6.10.1. Data consolidation

Figure 6.4 provides a visual representation of the number of data points recorded on each of the eight days after it was consolidated into eight files. It can clearly be observed that the number of data points recorded on Sundays was significantly lower than those recorded on weekdays. This figure also indicates that Tuesdays, Wednesdays and Thursdays were similar in regards to the number of data points recorded. Additionally, more data points were recorded during the second week. It seems that the second Wednesday does not conform to the pattern followed by the other days, but as explained before, there was approximately one hour of missing data points for this day.

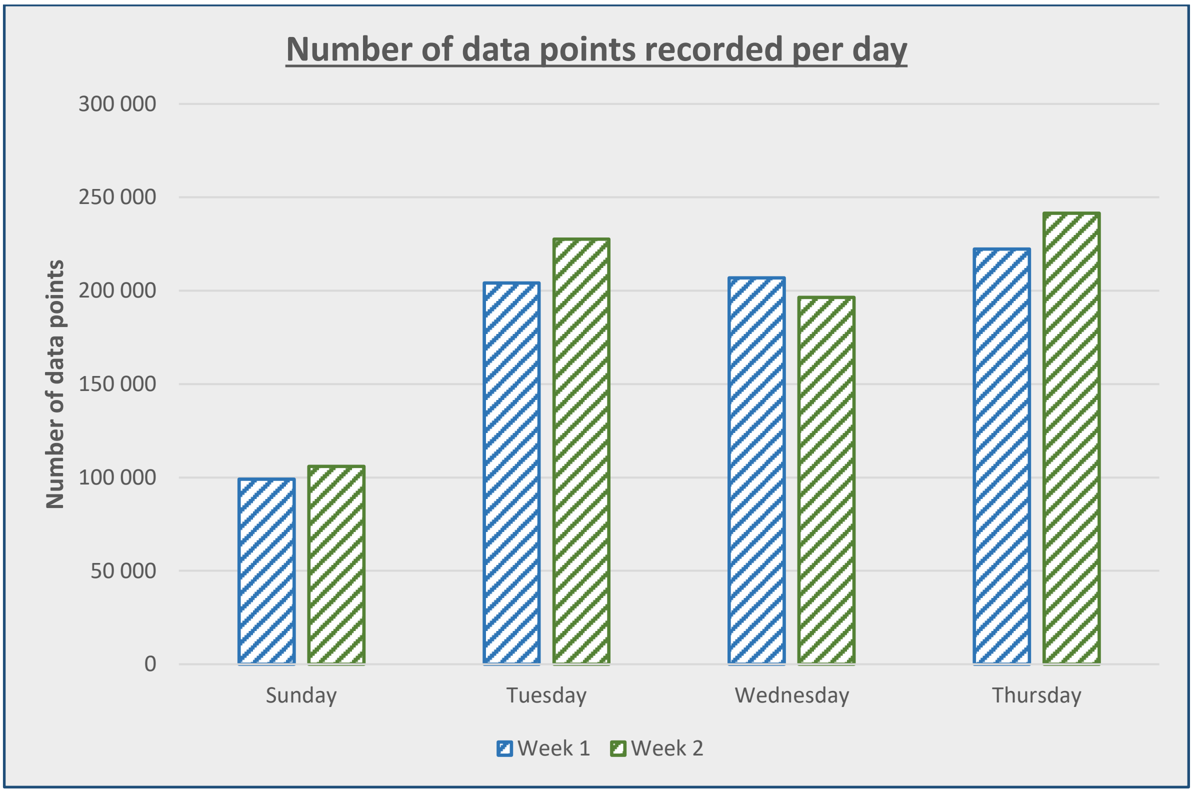


Figure 6.4. *Number of data points recorded during each day of the analysis.*

6.10.2. Data refinement

The database of each weekday contained approximately 200 000 data points and the database of each Sunday contained approximately 100 000. After all refinement processes were complete, approximately 10% of the original datasets remained, making the analysis process much easier.

Removal of coordinates that are out of range

Table 6.2 contains a summary of the results of removing all data points that did not fall within the study area.

Table 6.2. Results of removing all data points outside of study area.

Day	Percentage of data points outside of study area
1. Sunday, 22 Oct	92.80%
2. Tuesday, 24 Oct	88.75%
3. Wednesday, 25 Oct	89.29%
4. Thursday, 26 Oct	89.76%
5. Sunday, 29 Oct	91.27%
6. Tuesday, 31 Oct	88.41%
7. Wednesday, 1 Nov	88.78%
8. Thursday, 2 Nov	89.84%

It can be seen that approximately 90% of each day's database fell outside of the defined study area. This made sense, since the area covered by the fleet management system provided by MiX Telematics was significantly larger than the study area used in this study.

Removal of entries with low precision

Table 6.3 indicates the percentage of files that were removed due to having HDOP values higher than three.

Table 6.3. Results of removing all data points with low accuracy.

Day	Percentage of data points with high HDOP value
1. Sunday, 22 Oct	0.34%
2. Tuesday, 24 Oct	0.50%
3. Wednesday, 25 Oct	0.34%
4. Thursday, 26 Oct	0.43%
5. Sunday, 29 Oct	0.27%
6. Tuesday, 31 Oct	0.82%
7. Wednesday, 1 Nov	0.39%
8. Thursday, 2 Nov	0.33%

Less than one percent of each day's dataset was found to be inaccurate. From this, it could be deduced that the data received from MiX Telematics could be deemed trustworthy.

Removal of trucks with a presence of less than five minutes

Table 6.4 contains the number of vehicles removed each day, as well as the number of vehicles left. Additionally, the final number of data points for each day after the data refinement process is indicated.

Table 6.4. Results of removal of trucks with low presence.

Day	Number of trucks removed	Number of trucks left in database	Number of data points left in database
1. Sunday, 22 Oct	52	59	6 887
2. Tuesday, 24 Oct	62	260	22 542
3. Wednesday, 25 Oct	65	253	21 750
4. Thursday, 26 Oct	44	264	22 429
5. Sunday, 29 Oct	63	64	8 971
6. Tuesday, 31 Oct	73	289	25 776
7. Wednesday, 1 Nov	67	267	21 595
8. Thursday, 2 Nov	66	292	24 156

An average of 62 vehicles were removed from each dataset, with approximately 60 vehicles remaining on Sundays and between 250 and 300 vehicles remaining on weekdays. It is interesting to note that, although there were much less vehicles tracked on Sundays, the number of vehicles that were present for less than five minutes were similar on weekdays and Sundays.

6.10.3. Temporal distribution graphs

Three temporal distribution graphs were created for each day that was analysed. The first two graphs show the number of data points recorded during each hour of a day, with the second of these graphs only showing data points that had non-zero speeds. It was found that these two graphs had similar distributions and, therefore, only the second graph for Thursday, 2 November 2017 (the distribution of non-zero speed entries) is shown in figure **Figure 6.5**.

When studying the figure, it is clear that most data points were recorded during the day, with significantly less entries being recorded during the night. This conclusion corresponds to what was found in literature, namely that freight movement in urban areas are most likely to occur during the day. During the period analysed, sunrise and sunset occurred at approximately 5:45 a.m. and 7:15 p.m. respectively. It can be observed that freight trips were significantly less before and after these times.

The third temporal distribution graph that was created for each day was the distribution of heavy vehicle presence throughout the day. **Figure 6.6** shows the temporal distribution of the number of heavy vehicles recorded in the study area during each hour of Thursday, 2 November 2017. The distribution graphs of all other days can be found in **Appendix A2**. Although not immediately clear when scrutinizing **Figure 6.5** and **Figure 6.6,** the two graphs do not represent the same thing. **Figure 6.5** shows the distribution of all tracked data points, irrespective of whether it came from the same truck or not, while **Figure 6.6** shows the distribution of discrete trucks in the study area. It is important to note that the proposed bans are only applicable to weekdays. Therefore, any conclusions regarding the proposed banning periods are only discussed for the weekdays analysed.

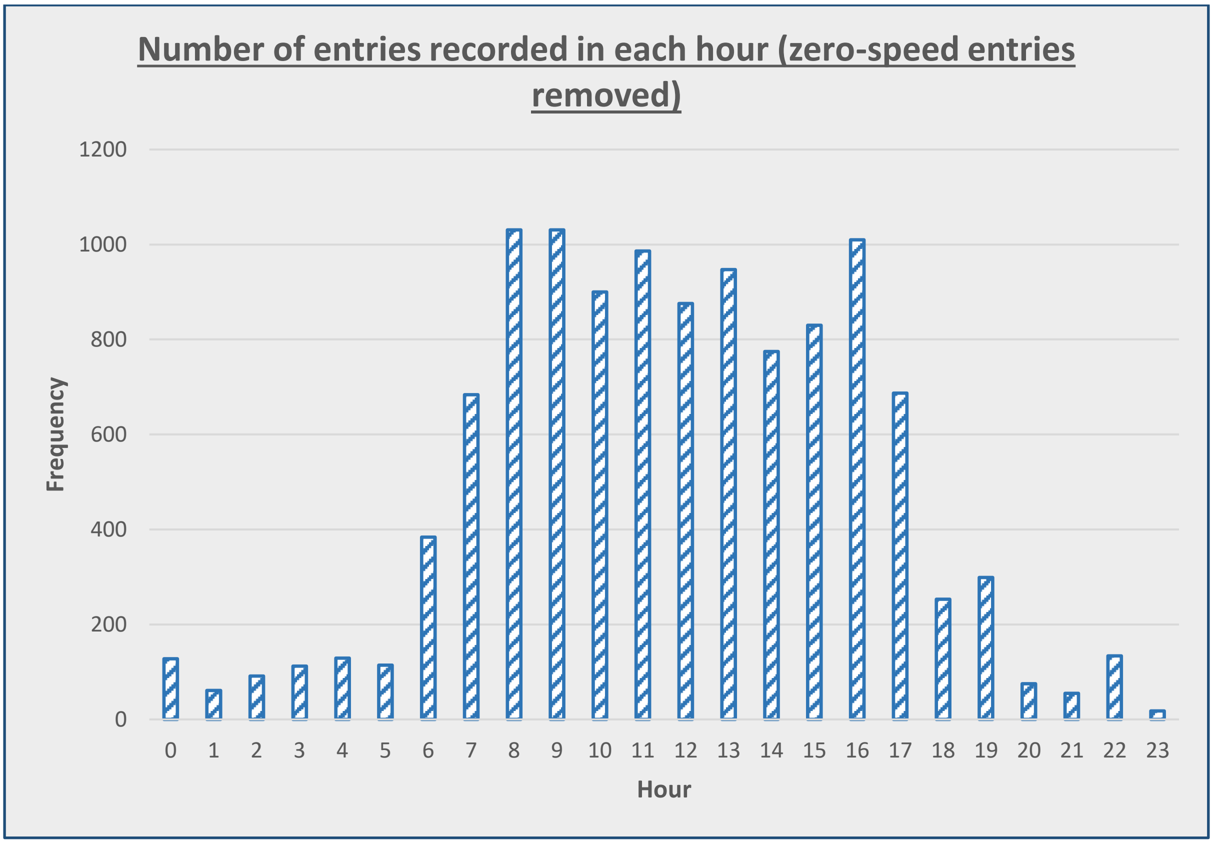


Figure 6.5. *Number of non-zero speed entries recorded in each hour on Thursday, 2 November 2017.*

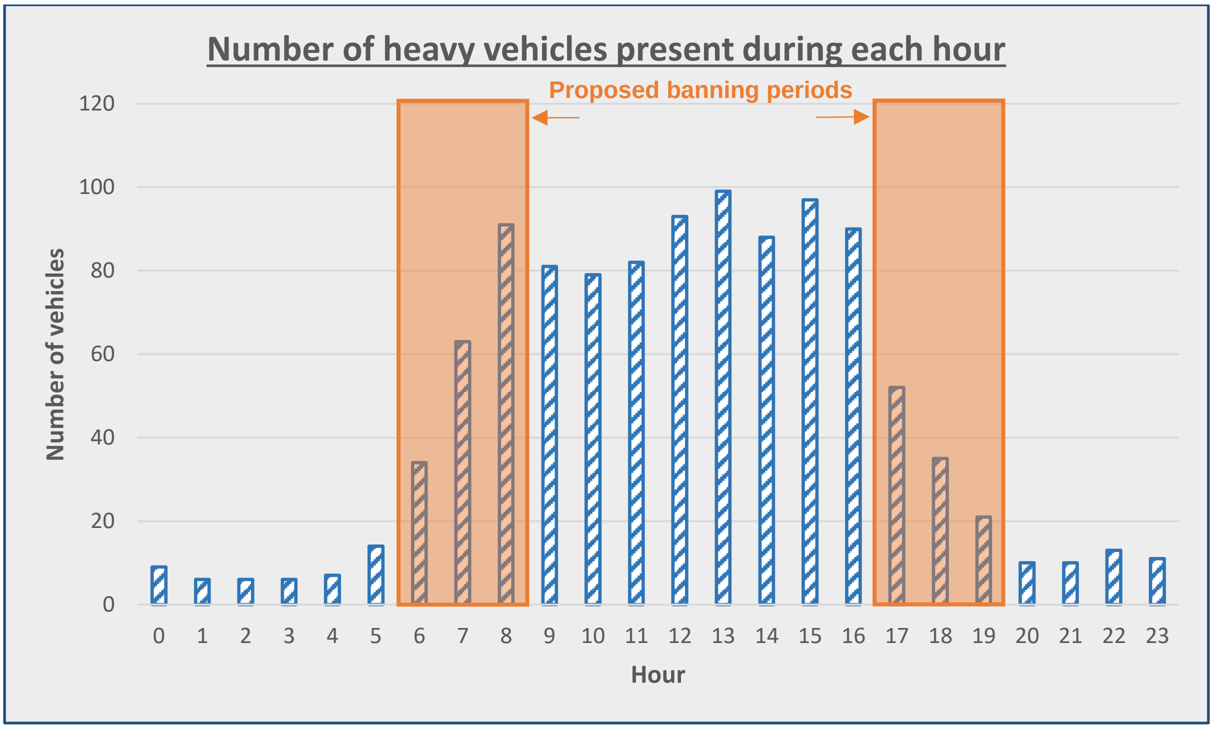


Figure 6.6. *Number of heavy vehicles present in study area during each hour of Thursday, 2 November 2017.*

The distribution of heavy vehicle presence in the study area was found to be similar to the distribution of recorded data points. This made sense, since the number of data points was found to be directly proportional to the number of heavy vehicles present on the study area.

Although it was very clear that the majority of heavy vehicles travelled in the study area between 6 a.m. and 8 p.m., significant morning and afternoon peaks did not seem to exist as it usually does for passenger cars. Although small peaks could be identified, the volumes during the peak hours did not significantly differ from the volumes during other hours. It seems that heavy vehicle presence was fairly constant during the daytime, not varying much throughout the day.

By studying **Figure 6.6**, it can clearly be seen that the proposed banning periods did not include the hours during which most heavy vehicles were present in the study area. During the morning banning period, the number of heavy vehicles were increasing, while during the afternoon banning period, the number of heavy vehicles were found to decrease. Between these periods, the number of heavy vehicles in the study area was constant. Because of the distribution of heavy vehicle presence in the study area, it is most likely that the proposed bans would increase the number of heavy vehicles between 9 a.m. and 5 p.m., instead of increasing the number of heavy vehicles during the night-time. This could lead to problems in the middle of the day, since heavy vehicles would make up a higher proportion of the traffic stream than before. As found during the literature review, higher heavy vehicle percentages could potentially lead to many problems, like an increase in accidents, higher congestion levels and more air pollution.

Although peak periods were not very *significant* in the distribution of heavy vehicle presence in the study area, morning and afternoon peak hours could still be identified. These can be found in **Table 6.5**. For all weekdays, it was found that the afternoon peak hours did not fall within the proposed afternoon banning period; the peak hours were generally found to occur in the early afternoon. This raises the question of whether the proposed ban in the afternoon would have a significant impact, since most of the tracked vehicles travelled outside of the proposed period.

The morning peak hour of heavy vehicles fell within the proposed morning banning period in most cases. It has to be noted, however, that the number of trucks was low in the beginning of the proposed banning period (at 6 a.m.) and increased during the period. This indicates that most trucks entered the traffic stream during the proposed morning banning period. Because the road network is usually congested during this period, it can be deduced that these heavy vehicles most likely need to reach their destinations at specific times in the morning. It would be illogical to travel in congested conditions if this was not the case. This means that the banning periods would have a significant impact on the operations of these vehicles.

Overall, it was determined that the banning periods were not ideal if the goal is to remove as many heavy vehicles from the road network as possible. The low number of heavy vehicles present during the banning periods may lead to the regulations not yielding any significant results.

Table 6.5. Morning and afternoon peak periods of heavy vehicles.

Day	Morning peak hour	Afternoon peak hour	Proposed banning periods
1. Tuesday, 24 Oct	None	13:00-14:00	06:00 to 09:00 and 17:00 to 20:00
2. Wednesday, 25 Oct	09:00-10:00	12:00-13:00	
3. Thursday, 26 Oct	11:00-12:00	None	
4. Tuesday, 31 Oct	08:00-09:00	15:00-16:00	
5. Wednesday, 1 Nov	08:00-09:00	15:00-16:00	
6. Thursday, 2 Nov	08:00-09:00	13:00-14:00	

The distribution of heavy vehicles in the study area was found to differ between weekdays and Sundays. **Figure 6.7** shows the distribution of heavy vehicles on both Thursday, 2 November 2017 and Sunday, 29 October 2017. Contrary to what occurred on weekdays, the number of heavy vehicles present in the study area during the day did not differ significantly from the number of vehicles present during the night on Sundays.

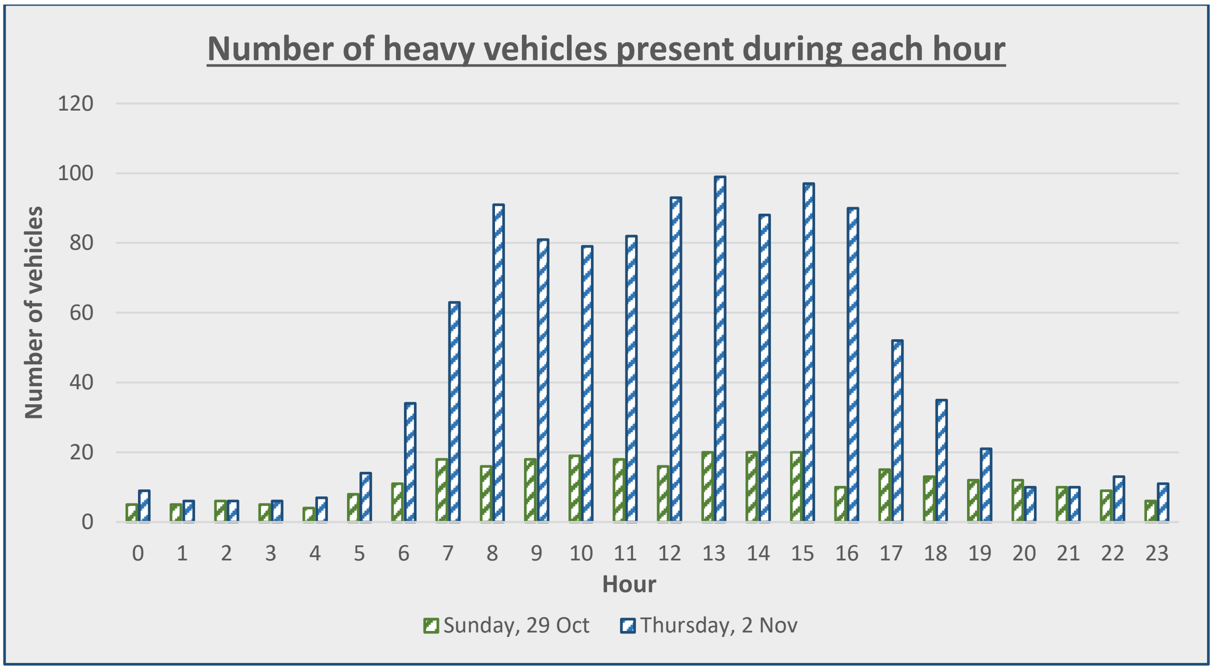


***Figure 6.7.** Comparison of heavy vehicle presence on Thursday, 2 November and Sunday, 29 October 2017.*

Upon closer examination, it was noted that the actual number of vehicles present during the night did not significantly differ between Sundays and weekdays. From this observation, it can be deduced that, during the night, approximately the same number of trucks travelled within the study area, regardless of the day. This was an interesting conclusion to make, since it indicated that the day of the week did not influence the movement of night-time trucks, but indeed the movement of trucks travelling during the day.

6.10.4. Spatial distribution maps

By creating temporal distribution graphs, an idea could be formed of *when* most heavy vehicles travelled in the study area, but it was also necessary to know *where* the vehicles were travelling. For this reason, spatial distribution maps were created.

For each of the eight days in the study period, three spatial distribution maps were created. One map was created for all data points that were generated during the proposed morning banning period (6 a.m. to 9 a.m.), one for data points created during the proposed afternoon banning period (5 p.m. to 8 p.m.) and a third map for all data points created during the entire day. It is important to note that only data points with non-zero speeds were included on the maps.

Even though the investigated bans are only applicable to weekdays, maps were also created for the two Sundays in the study in order to analyse whether there was a significant difference between the movement patterns of trucks on weekdays and weekends.

Figure 6.8 indicates the spatial distribution of heavy vehicles for the 24 hours of Thursday, 2 November 2017. From this, the most popular roads used by heavy vehicles in the study area were identified. This is indicated in **Figure 6.9**. Once again, the results for all weekdays were found to be similar and, therefore, all weekdays are included when referring to “weekdays” in this section. Interesting observations made about the spatial distribution maps are listed below:

- Sundays were much less populated with heavy vehicles in comparison to weekdays. This correlates with the results of the temporal distribution graphs.
- More entries were recorded in the investigated morning banning period than the afternoon banning period for all days. This correlates with the results of the temporal distribution graphs.
- Heavy vehicles travelled into the centre of town more frequently during the investigated morning banning period than the afternoon period. It seems that most heavy vehicles that were recorded during the afternoon period wanted to travel through Stellenbosch and did not have a trip end located in the centre of town.
- The routes that were most frequently used by heavy vehicles in the study area gave an indication that most vehicles travelled through Stellenbosch and did not stop in town.
- The speed distribution between the morning and afternoon banning periods did not differ significantly from each other. During both periods, slow speeds were recorded in the centre of Stellenbosch, while speeds on the main roads feeding the town were relatively high.
- Congestion only seemed to be a problem in the centre of town. Most recorded speeds on the main roads outside of the centre of Stellenbosch were relatively high. This could be an indication that congestion only affects the movements of heavy vehicles inside town.

- Some heavy vehicles seemed to travel on roads that were not designed to be a main thoroughfare through Stellenbosch in order to avoid congestion on the main roads. This was most evident on Bird Street, Dorp Street and Merriman Road. It also seemed that trucks used George Blake Street in Plankenbrug to circumvent the congestion on the main roads.
- The number of trucks travelling to/from Franschhoek via the R310 was much lower than the number of trucks travelling on the other main roads feeding Stellenbosch.
- Four major areas were identified where trucks seemed to cluster away from main routes (presumably indicating a destination).
  1. The first area was at the shopping centres in Stellenbosch. It makes sense that trucks would stop here to make deliveries to the stores.
  2. The second area where many trucks seemed to stop was the Devon Valley Industrial area, where industrial buildings of several companies are located. It makes sense that trucks would travel to this area for delivery and collection purposes.
  3. Some clustering was also evident at two of the largest wineries in the town extent: Distell Libertas and Bergkelder. This clustering was attributed to deliveries and collections.
  4. The fourth and most noticeable location where many trucks stopped in Stellenbosch was south of Kayamandi, in Plankenburg. Plankenburg is an industrial area in Stellenbosch, so it would make sense that many heavy vehicles would have to stop in this area. Upon closer inspection and investigation, it was discovered that this area is also a popular rest stop where many heavy vehicles park before embarking on new trips. Because there is a large open area at this location and there are no other adequate rest stops in Stellenbosch, drivers frequently park their vehicles here.

The three locations where clustering occurred is shown in **Figure 6.8**. It is important to note that clustering of trucks at the first three locations only occurred on weekdays, while trucks seemed to stop in Kayamandi on both weekdays and weekends. When considering the fact that the trucks stopping here were most likely partaking in long-distance trips (local trips would not have to stop here to rest before making another trip), this finding made sense. Previous results indicated that approximately the same number of night-time trips occurred during the week and the weekend. When assuming that night-time trips are most likely part of long-distance trips, it would be expected for clustering at the rest area to be present on weekdays and weekends.

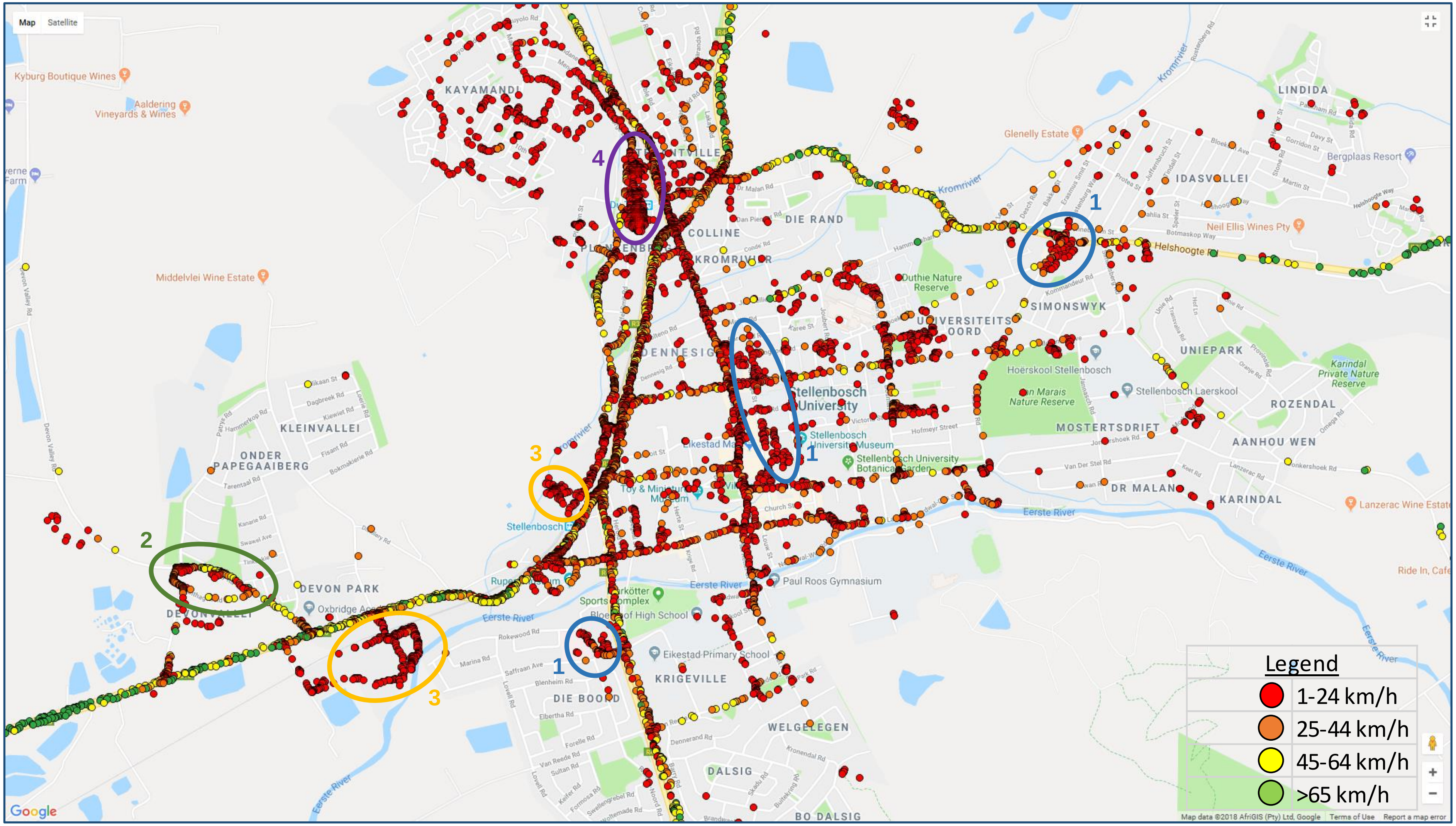


Figure 6.8. *Spatial distribution map of heavy vehicles during 24 hours on Thursday, 2 November 2017 (HamsterMap, no date).*

Figure 6.9. *Most popular routes used by heavy vehicles in the study area (Google Earth Pro, 2018).*

6.10.5. Speed reasonability tests

In an attempt to determine whether the data received from MiX Telematics was logical and reasonable, a frequency diagram was created for all speeds recorded during each of the eight days. The frequency diagram of each day can be found **Appendix A2**. It is important to note that only speeds larger than 0 km/h were included in the frequency diagrams. The results for Thursday, 2 November 2017 is displayed in **Figure 6.10**.

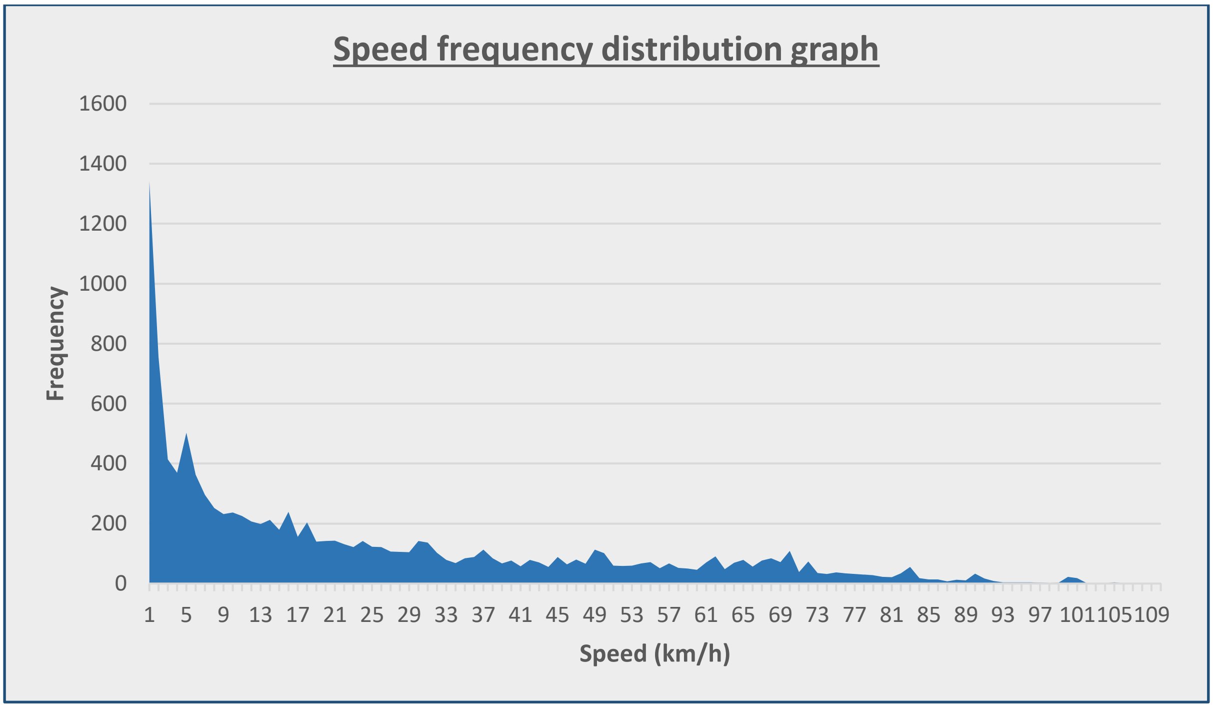


Figure 6.10. *Frequency distribution of speeds recorded on Thursday, 2 November 2017.*

The speed frequency distributions of all days were found to be similar. Therefore, the discussion that follows is applicable to all days in the study period.

It is evident from the speed graphs that the number of entries with speeds equal to 1 km/h was far higher than that of any other recorded speed. Furthermore, the majority of recorded speeds were found to be lower than 10 km/h. The high number of entries with low speeds made sense, since vehicles that travelled slower would most likely be present in the study area for longer periods of time. Additionally, the presence of intersection control in the study area would have forced vehicles to reduce their speeds at various locations. The plotted speed graphs showed that the number of entries with a specific recorded speed decreased as the speed increased up to a speed of approximately 80 km/h. A very small number of entries was recorded with speeds between 80 km/h and 120 km/h, with peaks at approximately 90 km/h and 100 km/h. These observations were reasonable, because the highest speed limit in the study area was 100 km/h. Additionally, most heavy vehicles are required by law to adhere to a speed limit of 100 km/h or lower. No speeds were recorded that were significantly higher than this maximum speed limit.

Because the speed frequency diagrams were deemed reasonable, the entire database received from MiX Telematics was deemed adequately reasonable.

6.10.6. Other results

Table 6.6 shows the percentage of data points left after the refinement process that had speeds of 0 km/h.

Table 6.6. Proportion of datasets with speeds equal to 0 km/h.

Day	Percentage of post-refinement dataset that had speeds = 0 km/h
1. Sunday, 22 Oct	47.83%
2. Tuesday, 24 Oct	49.37%
3. Wednesday, 25 Oct	51.87%
4. Thursday, 26 Oct	52.80%
5. Sunday, 29 Oct	42.43%
6. Tuesday, 31 Oct	53.70%
7. Wednesday, 1 Nov	54.07%
8. Thursday, 2 Nov	51.94%
Average	**50.50%**

From the above table, it can be observed that approximately half of each day's dataset after the refinement process had speeds equal to 0 km/h. This is quite significant, since entries with zero-speeds were omitted from many of the results. The reasons for omitting these data points from the analyses performed are discussed in previous sections.

6.11. Penetration rate of data

The data received by MiX Telematics only represented a sample of the entire heavy vehicle population in the study area, since not all heavy vehicles were tracked by the company. In order to determine the share of the population that was represented by the provided data, volume counts were performed and an analysis was performed. The process followed to determine the penetration rate of the data provided by MiX Telematics and the results of this process are discussed in **CHAPTER 8:**.

6.12. Comparison of fleet management data and floating car data

To verify the results obtained from the fleet management data, a comparison was done with floating car data (FCD) obtained from TomTom. This comparison served two purposes: firstly, to confirm the temporal distribution of heavy vehicles in the study area and, secondly, to confirm the routes that are most used by heavy vehicles.

6.12.1. Data obtained

An area analysis was performed over the same study area as was used for the analysis of the fleet management data. Data was received for twenty-four periods, one period for each hour of the day. This allowed data to be aggregated for each hour separately. Additionally, data was obtained for the proposed banning periods (6 a.m. to 9 a.m. and 5 p.m. to 8 p.m.). This allowed for the aggregation of data within these periods.

To be able to compare the FCD to the fleet management data, the same dates of analysis had to be selected. The comparison was only done for weekdays and, therefore, the six weekdays included in the fleet management data analyses were selected as the dates for the TomTom area analysis. It is important to note that the FCD obtained from TomTom was selected to only include data of fleet vehicles and not of the entire traffic stream.

For each link included in the study area, travel time and speed information was provided for fleet vehicles. It must be noted that, similar to the data obtained from MiX Telematics, this data did not contain the entire heavy vehicles population, but only those that were included in the TomTom probe set.

6.12.2. Temporal distribution of heavy vehicles

The total number of probe hits within the study area during each hour was used to estimate the temporal distribution of heavy vehicles. This included all hits in the study area and did not provide any information on the actual number of vehicles that were present. Additionally, the number of probe hits included in the database was the total number of hits for all six days in the study period. Therefore, the average number of probe hits per weekday was calculated.

Figure 6.11 shows the comparison between the number of TomTom probe hits and the number of fleet management data points recorded in each hour for an average weekday in the study period. It can be observed that the distribution is very similar, with the majority of probe hits being recorded during the daytime. The distribution of TomTom probe hits confirm the temporal distribution that was obtained from the fleet management data analysis. Both data source confirm that heavy vehicles do not experience the typical AM and PM peak periods that are present when considering passenger cars.

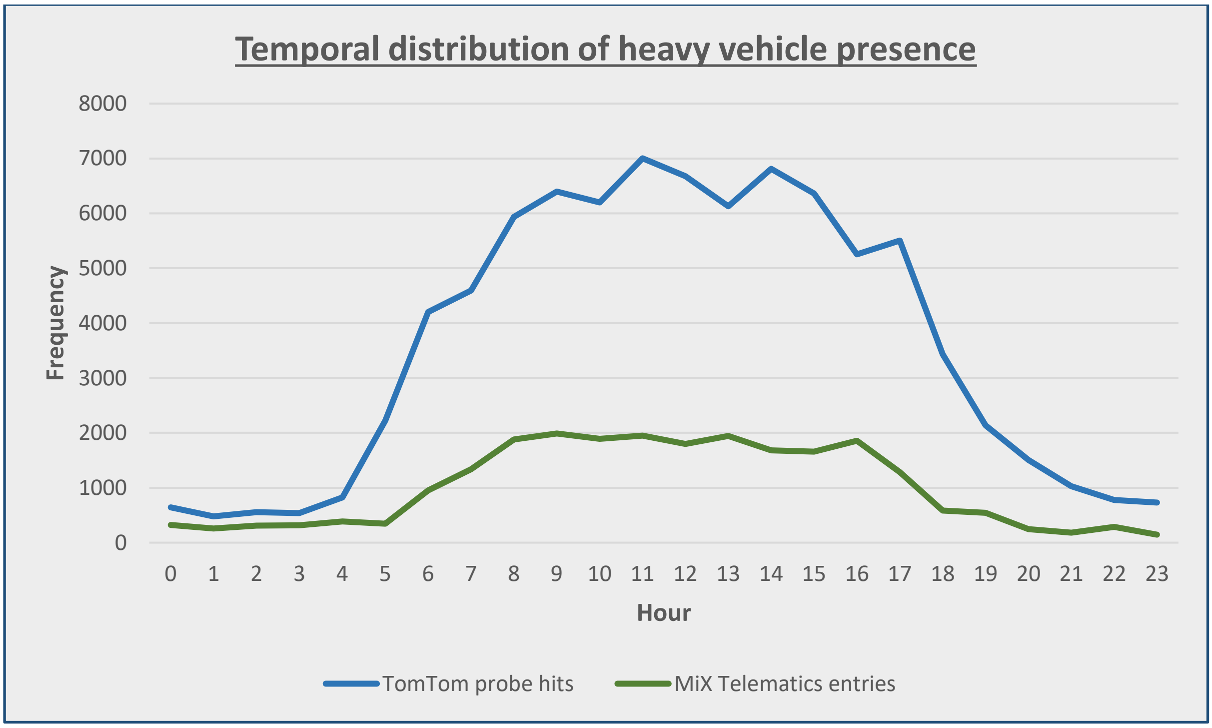


Figure 6.11. *Comparison of temporal distribution of heavy vehicles.*

6.12.3. Most used routes

The analysis of fleet management data provided some insight into the routes that are most used by heavy vehicles in Stellenbosch, but FCD could provide an even clearer image of which roads were most popular. FCD from TomTom was aggregated for the two banning periods over the six weekdays included in the study period. From this, a heat map was created for each period, showing the speeds of heavy vehicles travelling within the study period.

Only links that were included in the top 85% with regards to the number of probe hits per link were included in the heat maps. This allowed for the visual representation of the roads in the study area that were used by the highest number of heavy vehicles. **Figure 6.12** and **Figure 6.13** show the results of these heat maps.

It can be observed that the main routes identified in **Section 6.10.4** from the fleet management data correspond to the figures. The routes with the most heavy vehicle traffic, as identified by the FCD, are listed below:

- R44 (North)
- R44 (South)
- R310 (East)
- R310 (West)
- R304
- George Blake Road
- Bird Street (between R44 and Dorp Street)
- Dorp Street (between Bird Street and Adam Tas Road)
- Merriman Avenue (between R44 and Cluver Road)
- Cluver Road (between Merriman Road and Helshoogte Road)

These identified routes aided in the identification of the network to be created in Vissim later in this research.

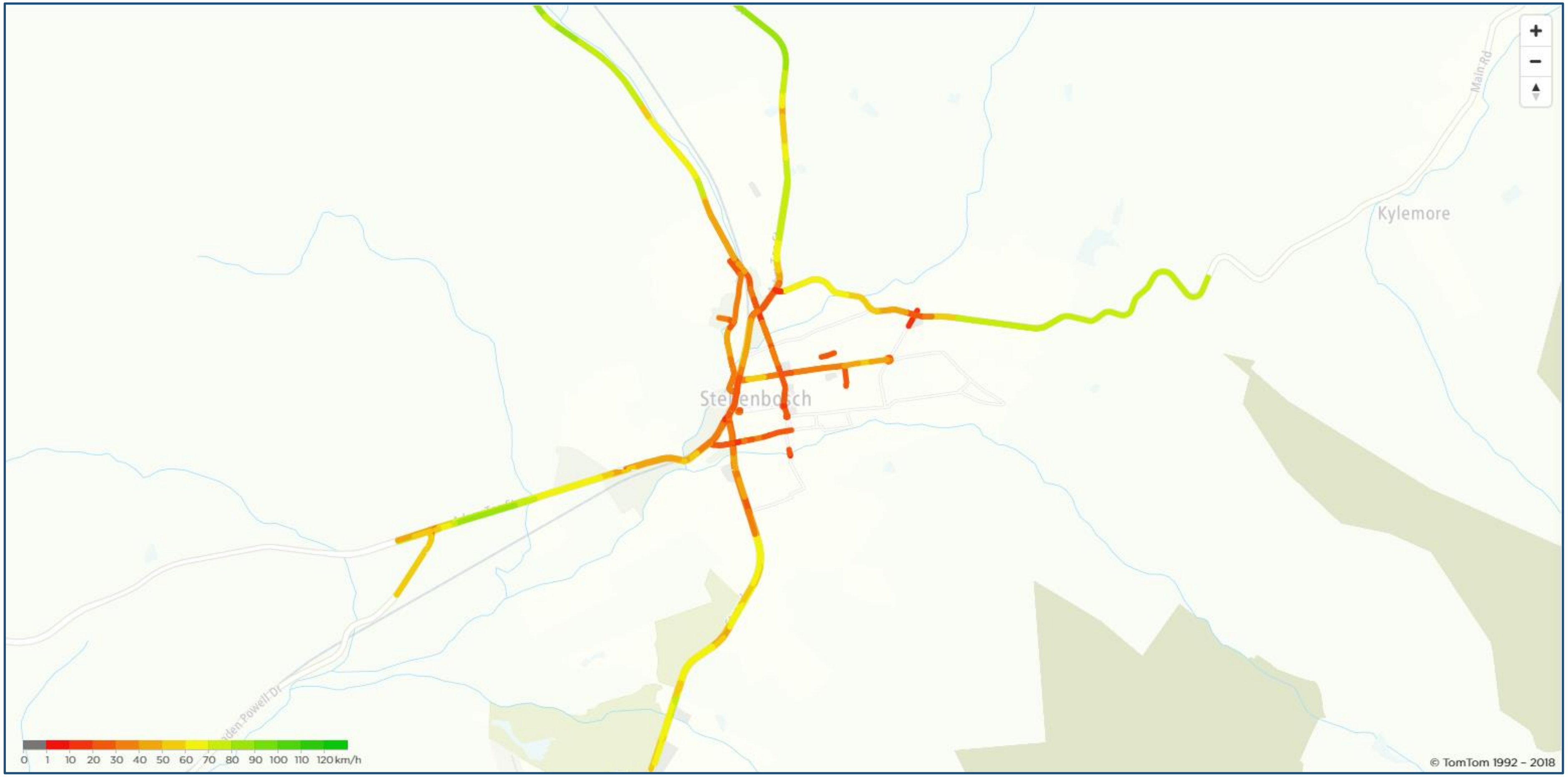


Figure 6.12. *Routes with the highest heavy vehicle probe hits between 6 a.m. and 9 a.m. (TomTom, 2018).*

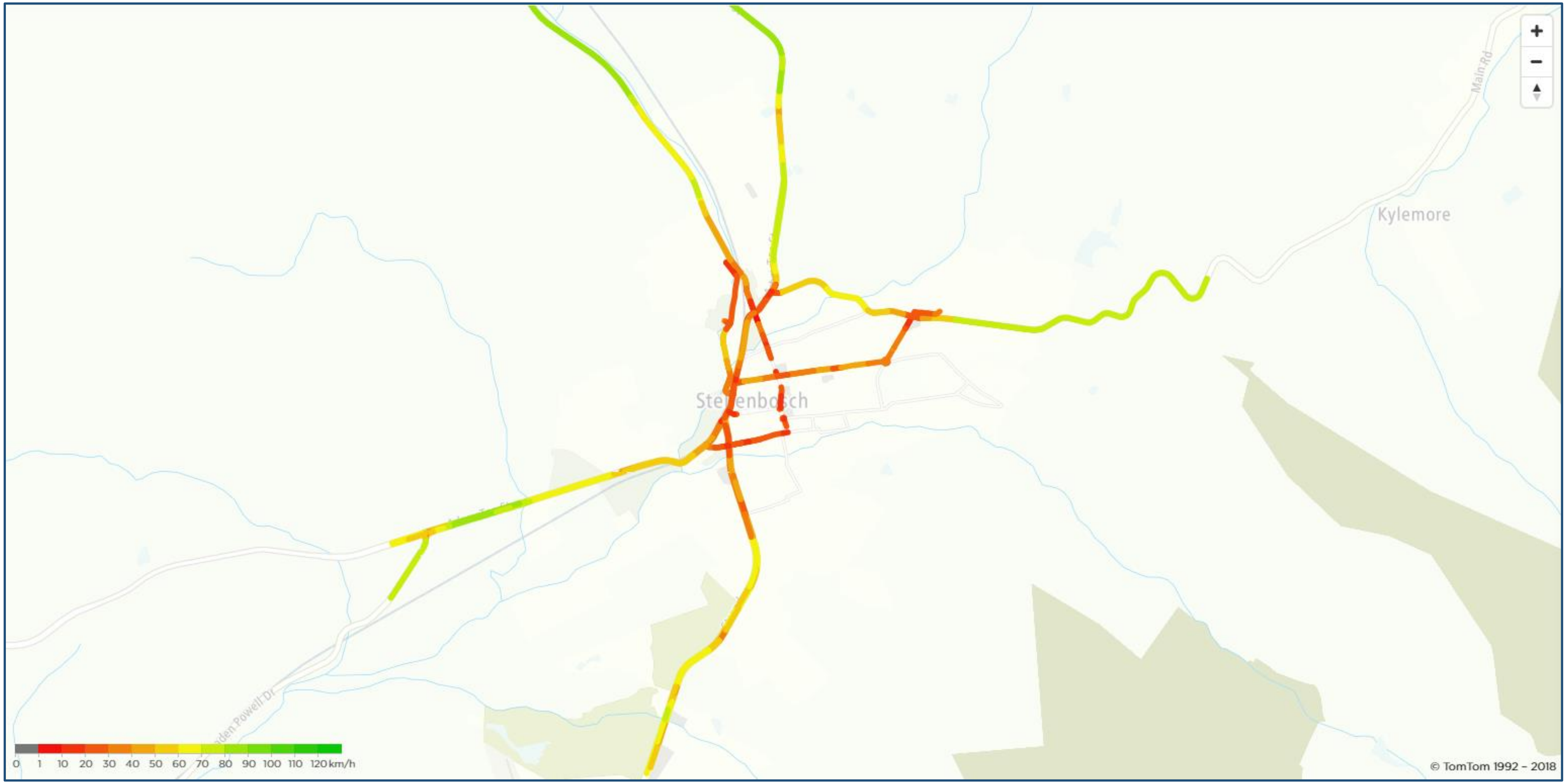


Figure 6.13. *Routes with the highest heavy vehicle probe hits between 5 p.m. and 8 p.m. (TomTom, 2018).*

6.13. Conclusion

The data generated by fleet management systems can very useful in determining the characteristics of fleet behaviour and movement patterns of heavy vehicles, especially in urban areas. It was found that fleet management data is rarely used for engineering applications, although it could provide information regarding the movement of heavy vehicles that would be costly and time-consuming to collect with other methods.

In this chapter, fleet management data provided by MiX Telematics was used to analyse the movements of heavy vehicles in Stellenbosch and a small surrounding area. Tracking data of all vehicles tracked by MiX Telematics in the area was analysed for eight days in 2017. The processing and refinement of the databases are discussed in this chapter, as well as the analyses performed. The results of the analyses are also included. The analyses performed yielded the following main findings regarding the movement patterns of heavy vehicles in the study area:

- The majority of heavy vehicles travelled in the study area during daylight hours between 6 a.m. and 8 p.m.
- The movement patterns of heavy vehicles in the study area were similar on Tuesdays, Wednesdays and Thursdays.
- Much less heavy vehicles were present in the study area during the day on Sundays than on weekdays.
- The number of heavy vehicles on present in the study area during the night did not differ significantly between Sundays and weekdays.
- The investigated banning periods were not ideally timed to include the periods when most heavy vehicles were present in the study area.
- The main routes used by heavy vehicles in Stellenbosch were identified and are indicated in **Figure 6.9**.
- Heavy vehicles were found to travel on roads in Stellenbosch that were not designed to carry a high number of heavy vehicles.

The results of the analysis of the fleet management data was used in processes discussed in following chapters. FCD obtained from TomTom was used to validate the temporal distribution of heavy vehicle presence in Stellenbosch and the routes most used by these vehicles.

CHAPTER 7: VEHICLE MOVEMENT SURVEY ANALYSIS

7.1. Background

Vehicle movement surveys (VMSs) provide helpful information that cannot be acquired from normal traffic counts. It allows for the routes of specific vehicles to be tracked and also enables the data user to determine the time it takes for vehicles to get from one point to another.

The process of collecting VMS data involves the logging of the time that vehicles (in this case only freight vehicles) pass specific VMS locations and their number plates. The VMS data used in this chapter was provided by Kantey & Templer and was recorded during a 3-hour period in the afternoon in June 2018.

The analysis of VMS data provided additional information on the movement of heavy vehicles in Stellenbosch that was not obtained from the fleet management data discussed in the previous chapter.

7.2. Objectives

The objectives of the analysis of VMS data are as follows:

- To determine the number of freight vehicles travelling into and out of Stellenbosch during the study period;
- To determine the ratio between inbound and outbound freight trips on the main routes feeding Stellenbosch;
- To determine the most used routes for freight trips to and from Stellenbosch;
- To estimate where freight trips that pass through Stellenbosch originate and
- To determine the time that freight vehicles take to travel through Stellenbosch.

7.3. Assumptions and limitations

To estimate the origin of freight trips, it was assumed that the town in which the vehicle was registered was where the trip originated. It was possible to determine the town in which a vehicle was registered because the registration system in the Western Cape specifies that the first few letters of registration numbers (with the exception of personalised number plates) must be a code specific to the town of registration. Although it is surely possible that some freight trips could have originated in other towns, it was believed that the majority of trips would have originated where the vehicle was registered. Company freight vehicles are usually registered in the same town where the business is located and this was, therefore, seen as a valid assumption.

The VMS was only conducted for three hours in the afternoon and was, therefore, not inclusive of all freight trips that passed through Stellenbosch. This meant that either the entering or exiting points of through trips that took more than three hours to complete would not have been recorded.

The fact that Point 4 and Point 5 were located at large distances from the town of Stellenbosch meant that it could not always be determined whether a freight trip originated or terminated in Stellenbosch or somewhere else. However, because Stellenbosch was the largest town and most likely destination or origin within the study area, it was deemed safe to assume this for the purposes of the study.

7.4. Study area

The VMSs considered in this study were conducted at five locations around Stellenbosch. This included one point on each of the main roads feeding the town, ensuring that freight vehicles entering and exiting Stellenbosch had the highest probability of being recorded. The five points are shown in **Figure 7.1**.

Figure 7.1. *Points included in the Vehicle movement survey (Google Earth Pro, 2018).*

7.5. Results

7.5.1. Inbound and outbound trips

Figure 7.2 on the next page indicates the number of freight trips recorded at each VMS point during the hours that vehicles were recorded. The average inbound rate of freight vehicles was determined to be 17.6 veh/h and the average outbound rate was 18.47 veh/h. This translates to an average heavy vehicle percentage of 2.5% for inbound traffic and 1.5% for outbound traffic.

It can be noted that the number of inbound and outbound vehicles were very similar at all points during this period. This can be seen as an indication that freight movement into and out of Stellenbosch does not follow the same pattern as the rest of the traffic stream. Contrary to the freight volumes that are similar, the number of inbound passenger cars is usually higher than the number of outbound cars on weekday mornings and the opposite is true in the afternoon.

The routes that are most used by freight vehicles to travel into and out of Stellenbosch could also be determined from **Figure 7.2**. For both cases, the route was determined to be Adam Tas Road in the South-West side of the town.

7.5.2. Origin of freight trips

The registration numbers of the recorded freight vehicles were used to estimate the origins of freight trips. The fact that registration numbers in the Western Cape (WC) indicate the town where the vehicle was registered allowed for this to be possible. **Table 7.1** contains the classification criteria for this process.

Table 7.1. Classification criteria for origin of freight trips.

Category	Number plates included
Local	CL - *Stellenbosch, Franschhoek*
Nearby towns	CA - *Cape Town* CEY - *Strand, Gordon's Bay* CF - *Kuils River, Brackenfell, Kraaifontein* CFM - *Somerset West* CFR - *Kuils River, Brackenfell* CJ - *Paarl* CK - *Malmesbury, Darling* CN - *Wellington* CW - *Worcester, De Doorns, Touws River* CY - *Bellville, Durbanville, Parow, Goodwood, Belhar, Montana, Charlesville, Valhalla Park*
Other towns in the WC	Any other WC number plates
Outside the WC	Any number plates registered outside of the WC

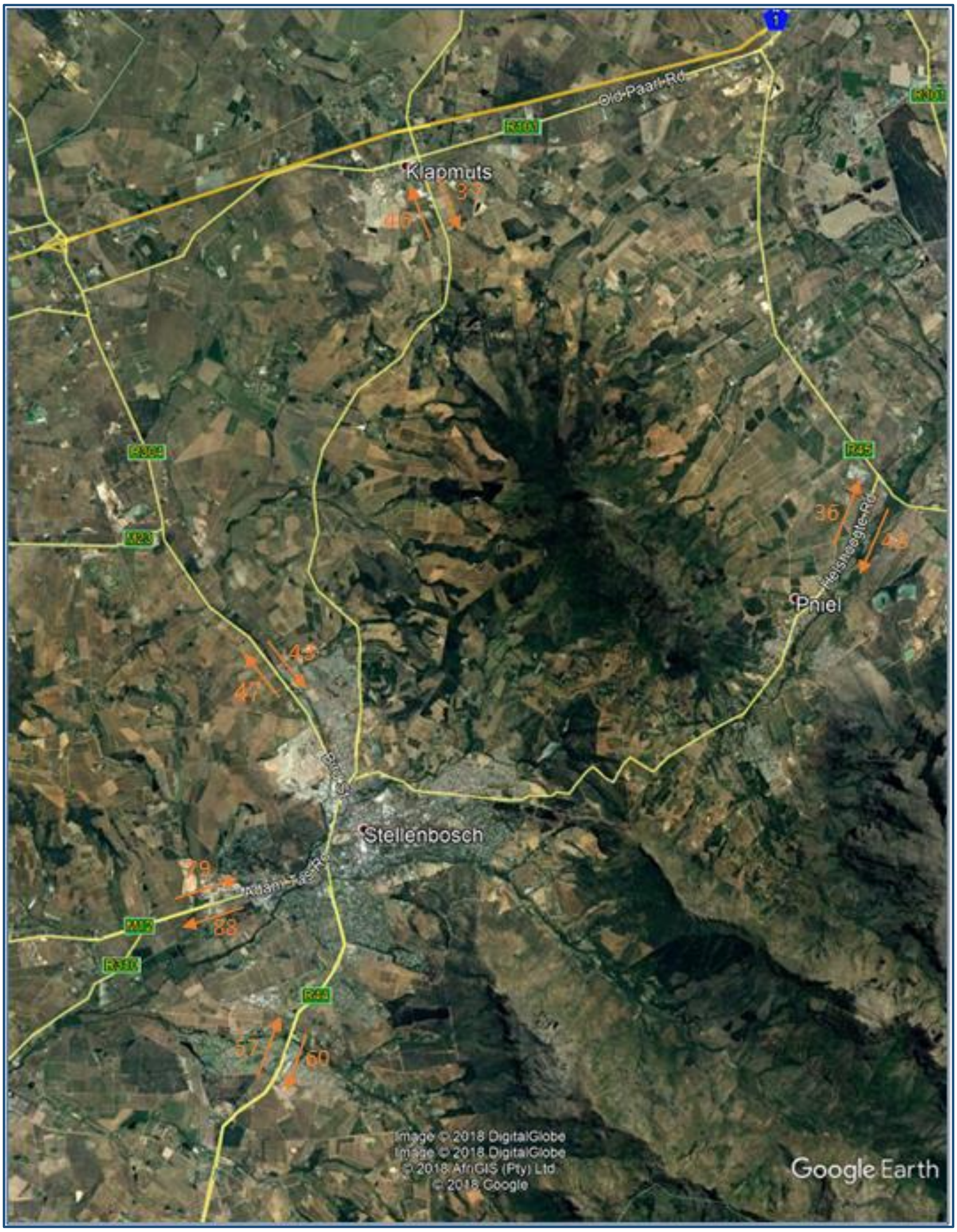


Figure 7.2. *Number of inbound and outbound freight vehicles recorded at VMS points (Google Earth Pro, 2018).*

It was assumed that the town in which a freight vehicle was registered was also the town in which the freight trip originated. **Figure 7.3** shows the percentage of freight vehicles estimated to originate from each category for inbound and outbound trips respectively at the five VMS points.

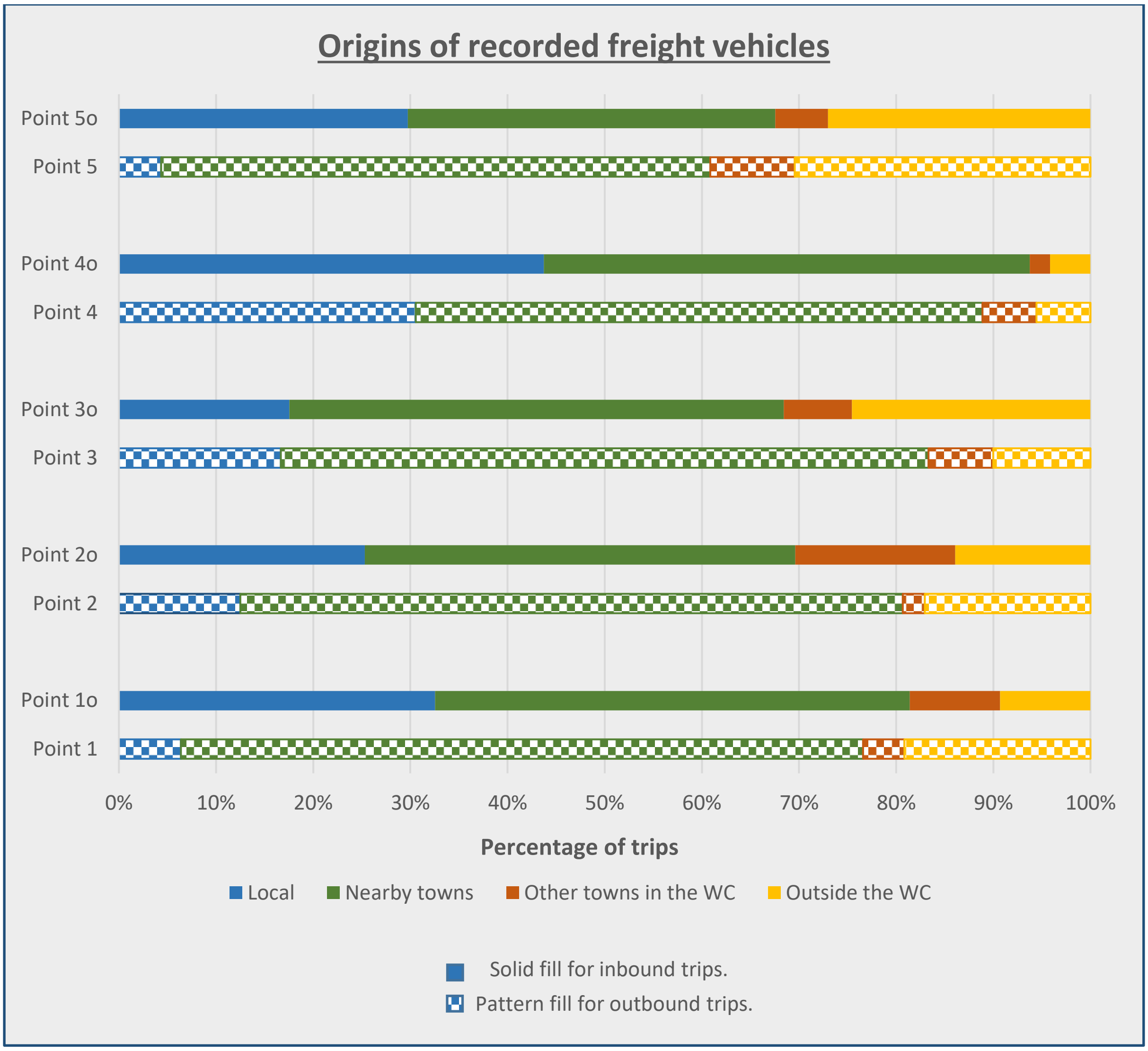


Figure 7.3. *Estimated origins of freight vehicles recorded during the VMS.*

It can be observed that most freight trips were conducted by vehicles that were registered in towns in close proximity of Stellenbosch, followed by local vehicles. Very few long-distance freight trips were recorded during the VMS. It is also interesting to note that very few freight trips originated in WC towns that were located far from Stellenbosch. It is evident from **Figure 7.3** that the majority of freight trips in Stellenbosch (at least those in the afternoon) are short- to medium-distance trips.

7.5.3. Through trips

Although most freight vehicles only passed one point during the VMS, some vehicles were recorded as both entering and exiting Stellenbosch (through trips). The below matrix indicates the number of vehicles that were recorded at two corresponding VMS points.

	1. Outbound	1. Inbound	2. Outbound	2. Inbound	3. Outbound	3. Inbound	4. Outbound	4. Inbound	5. Outbound	5. Inbound
1. Outbound	-	0	0	5	0	4	0	0	0	0
1. Inbound	0	-	3	0	3	0	0	0	0	0
2. Outbound	0	3	-	9	0	3	0	0	1	3
2. Inbound	5	0	9	-	0	0	0	0	1	0
3. Outbound	0	3	0	0	-	4	0	0	0	1
3. Inbound	4	0	3	0	4	-	0	0	5	1
4. Outbound	0	0	0	0	0	0	-	4	0	0
4. Inbound	0	0	0	0	0	0	4	-	0	0
5. Outbound	0	0	1	1	0	5	0	0	-	1
5. Inbound	0	0	3	0	1	1	0	0	1	-

Figure 7.4. *Number of freight vehicles recorded at more than one VMS point.*

Of these through trips, 37 were identified as trips into and then out of Stellenbosch (in-out trips) and six were identified as trips that exited Stellenbosch and returned at a later time (out-in trips). The in-out trips were analysed to determine the time it took freight vehicles to travel between the point where it entered the study area and the point where it exited it. **Figure 7.5** shows the results of this analysis.

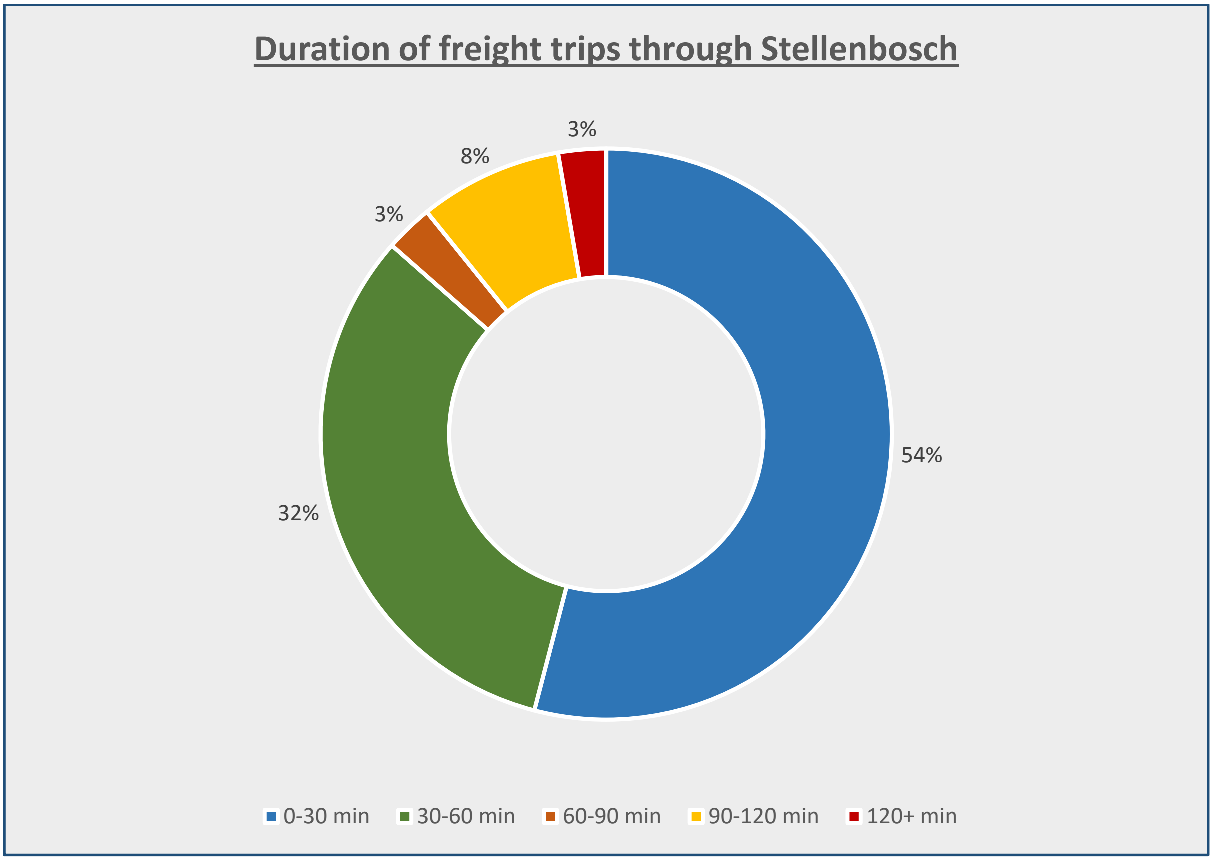


Figure 7.5. *Duration of all in-out trips recorded during the VMS.*

It can be observed from the above graph that the majority of the recorded freight trips through Stellenbosch took less than 1 hour. It can be assumed that through trips that take less than 1 hour did most likely not include a stop in Stellenbosch. It must be noted, however, that through trips that took longer than three hours would not have been recorded because the VMS was only three hours long. Therefore, the conclusion cannot definitively be made that most freight vehicles use Stellenbosch as a thoroughfare to get to other towns. It merely shows that there are indeed freight vehicles that do this.

7.6. Conclusion

This chapter provided an analysis of VMSs that were performed at five points in Stellenbosch. It was found that the average inbound and outbound heavy vehicles percentages for Stellenbosch between 3 p.m. and 6 p.m. are 2.5% and 1.5% respectively. Additionally, it was also determined that the number of inbound and outbound trips do not significantly differ on weekday afternoons. The most used route by freight vehicles to travel into and out of Stellenbosch was identified as the South-Western leg of Adam Tas Road. An analysis of the registration numbers of the freight vehicles revealed that most afternoon freight trips in Stellenbosch originate nearby and very few long-distance trips were recorded during the VMS. Finally, it was established that some freight vehicles use Stellenbosch as a thoroughfare to other destinations without stopping in the town.

CHAPTER 8: LINK TRAFFIC COUNTS ANALYSIS

8.1. Background

Traffic counts were performed at certain locations in Stellenbosch to obtain the data required to perform certain analyses in this study. Traffic counts were conducted on three weekdays in April 2018 at three locations in the town. Vehicles were manually counted and classified during a three-hour period in the morning and a four-hour period in the afternoon. The analyses performed with this data is discussed in this chapter.

8.2. Objectives

The results of the link traffic counts were used to answer three main questions:

- What is the share of the entire heavy vehicle population that is represented by the fleet management data provided by MiX Telematics?
- What percentage of the traffic streams on three major routes into and out of Stellenbosch are heavy goods vehicles (HGVs)?
- Is there latent demand in Stellenbosch?

8.3. Limitations

When more than one lane was present in a direction of travel, no differentiation was made between vehicles travelling in different lanes. Although it would have been possible to record the lane in which these vehicles were travelling in, it was found that it was very difficult when volumes were high and could potentially lead to inaccurate recordings. Additionally, the lane in which vehicles travelled was irrelevant to the objectives of the counts.

While counting, it was not always possible to precisely estimate the Gross Vehicle Mass (GVM) of all vehicles. Since counted vehicles were classified as either passenger cars, heavy vehicles (with a GVM higher than 3.5 tons) or buses, counters had to apply their own judgement over which vehicles were counted as heavy vehicles. This could have led to some inaccurate recordings, but it was noted that the inaccuracies would have been minimal and would not significantly influence the results.

It is important to note that the traffic counts were conducted during a national bus strike in South Africa. However, the selected locations were not found to normally carry a significant number of buses operated by the striking organisations. Therefore, it was concluded that the bus strike did not affect the accuracy of the results obtained from the counts for the purposes that it was used for.

8.4. Penetration rate of fleet management data

When working with a sample of an entire population, it is important to know what the penetration rate of the data is. The penetration rate indicates the share of the entire population that is represented by a sample dataset.

The fleet management data used in **CHAPTER 6:** only represents vehicles that had a contract with MiX Telematics. This means that all freight vehicles travelling through Stellenbosch were not tracked by MiX Telematics and, therefore, the data provided by the company only represents a portion of all the HGVs present in the study area. For this reason, it was required to determine the penetration rate of the dataset. The penetration rate of the database provides an indication of whether the data could be assumed to apply for the entire HGV population.

The penetration rates of the MiX Telematics data was determined by comparing the tracked data to the results of the link traffic counts. However, the traffic counts conducted for this study did not take place on the same days that were analysed in **CHAPTER 6:**. This meant that the datasets could not be compared. For this reason, additional data from MiX Telematics was analysed.

8.4.1. Analysis of additional fleet management data

Fleet management data from the same dates and times as the link traffic counts was analysed to estimate the penetration rates of the data. The process followed during the analysis is very similar to the one covered in **Section 6.9**, but will be briefly discussed in this subsection in order to highlight the key differences.

Dates and periods of analysis

Only data points that were recorded within the periods during which traffic counts were conducted were included in the analysis. A Microsoft Excel document was created for each day included in the analysis. This meant that three different datasets were created, one for each day in the counting period.

Table 8.1 indicates the periods included in each of the three datasets. It is important to note that the data was received with timestamps in Greenwich Mean Time (GMT) and had to be adjusted to local South African time before the data could be used.

Table 8.1. Time periods included in fleet management dataset.

Dataset	Date	Periods included
1	Tuesday, 17 April 2018	6:30 a.m. – 9:30 a.m.
2	Wednesday, 18 April 2018	and
3	Thursday, 19 April 2018	2 p.m. – 6 p.m.

Study areas

Because the fleet management data was compared to the traffic counted at a specific location, the data of each day had to only represent the vehicles that would travel past the location where counts took place. For this reason, a small study area was defined for each dataset to exclude all data points that would not be part of the traffic stream counted during the counts. Figure 8.1 to Figure 8.3 indicate the study areas defined for the three days.

Figure 8.1. *Study area for dataset 1 - 17 April 2018 (Google Earth Pro, 2018).*

Figure 8.2. *Study area for dataset 2 - 18 April 2018 (Google Earth Pro, 2018).*

Figure 8.3. *Study area for dataset 3 - 19 April 2018 (Google Earth Pro, 2018).*

The size of each study area was calculated to allow for all vehicles that passed the counting stations to be recorded at least once. The rationale was followed that a vehicle that passed a counting station would be tracked at least once within a 30-second period (since the location of a tracked vehicle was recorded every 15 seconds on average). This allowed for the inclusion of all vehicles that passed the counting station, but whose position was not recorded very close to the counting station. Although the width of each study area merely had to include the road width as a minimum, the minimum length of each study area had to be calculated according to the expected maximum speed that heavy vehicles would be travelling at on that section of road.

Table 8.2 contains the expected maximum speed and required length of the study area at each location.

Table 8.2. Expected maximum speeds and required study lengths at counting stations.

Location	Expected max. speed	Required length of study area
R304 (North)	80 km/h	670 m
R310 (West)	100 km/h	830 m
R44 (South)	100 km/h	830 m

The expected maximum speed was assumed to be one speed category higher than the speed limit of each road section. The speed limit at all three locations was 80 km/h and therefore, the speed of any vehicle travelling past a counting station was not expected to exceed 100 km/h. It is important to note, however, that the geometry of the road network at Location 1 did not allow for a study area large enough to provide for an expected maximum speed of 100 km/h. The study area had to be located between the access road of a fuel station and the intersection of the R304 and Elsenburg Road, since heavy vehicles could use these roads to turn off from the R304 before passing the counting station. If these intersections were included in the study area, vehicles that were not counted during the traffic counts could have been included in the fleet management data, yielding inaccurate results. For this reason, the expected maximum speed was selected as 80 km/h. This was not seen as a problem, however, since the results in **Section 6.10.4** revealed that the probability of heavy vehicles travelling more than 80 km/h at this location was very low.

Data refinement

The data refinement process that was followed to remove unnecessary or inaccurate data points was similar to the process explained in **Section 6.9**. However, because the study area of each dataset was significantly smaller than the study area used in **CHAPTER 6:**, it was not necessary to remove vehicles that were only present for short periods of time from the dataset. It was assumed that each vehicle would only be recorded once or twice within the study areas because the sizes of the study areas were so small.

After the refinement process, few data points remained in each of the three datasets. **Table 8.3** contains the number of data points that remained in each dataset after refinement. Although these numbers are low, it was not deemed problematic, since the study areas were very small.

Table 8.3. Number of points included in fleet management datasets after refinement.

Dataset	Location	Number of data points after refinement
1	R304 (North)	31
2	R310 (West)	55
3	R44 (South)	13

Data analysis

In order for the fleet management data and the counted traffic volumes to be comparable, the format of the two databases had to be similar. This meant that the number of heavy vehicles recorded by MiX Telematics within each 15-minute counting period had to be determined. Additionally, since the counts were performed separately for each direction of travel, the direction of travel of each of the recorded vehicles had to be determined.

The direction of travel of each vehicle in the fleet management database was determined by using the recorded heading of the vehicle. Each vehicle was classified as either travelling inbound or outbound, depending on its recorded heading in relation to the actual orientation of the road it was travelling on. As illustrated in **Figure 8.4**, if the recorded heading of a vehicle was within a range of 90 degrees clockwise and 90 degrees anticlockwise of the actual heading of inbound traffic, it was classified as travelling inbound. The same logic applied for classifying vehicles as travelling outbound.

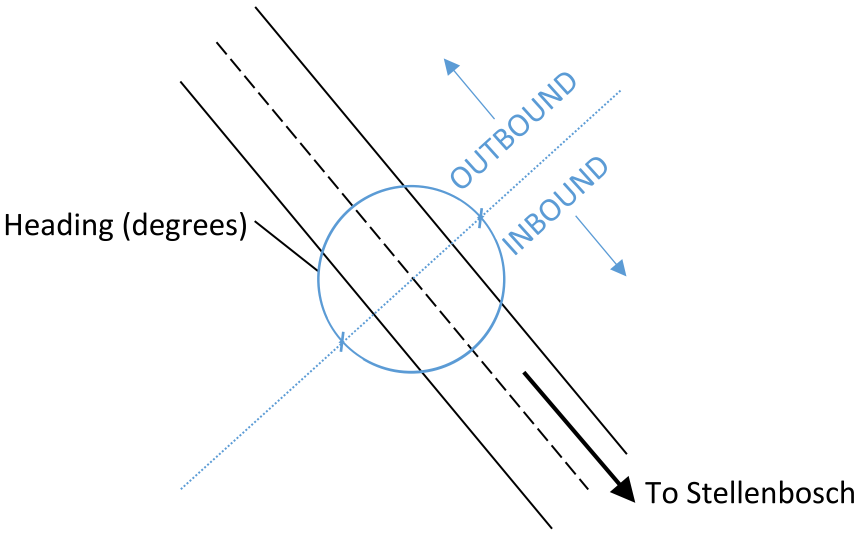


Figure 8.4. *Criteria for determining travel direction of a tracked vehicle.*

A macro was written in VBA that, when executed, counted the number of inbound and outbound vehicles that were tracked within each 15-minute counting period. It is important to note that this macro accounted for vehicles that recorded more than one data point while traveling through a study area by only counting these vehicles once.

8.4.2. Penetration rates

The results of the fleet management data analysis were compared to the conducted traffic counts to determine the penetration rates of the data provided by MiX Telematics. **Table 8.4** below contains the average penetration rate at each location for both inbound and outbound traffic. It will be noted that the outbound penetration rate for the R310 (West) is significantly lower than the other rates. This rate was deemed an outlier and was not considered as an accurate representation of what the penetration rate would usually be. It is possible that there could have been unknown errors or gaps in the fleet management data for that day. Therefore, the penetration rate for outbound traffic at this location was ignored when considering the appropriateness of the fleet management data. The inbound penetration rate for this route was higher than on other routes, but this was anticipated as high numbers of heavy vehicles were observed on the R310 (West).

Table 8.4. Average penetration rates of fleet management data.

Location	Counted vehicles	Tracked vehicles	Penetration rate
Inbound traffic			
R304 (North)	180	10	5.56%
R310 (West)	308	26	8.44%
R44 (South)	203	6	2.96%
Outbound traffic			
R304 (North)	190	12	6.32%
R310 (West)	303	1	0.33%
R44 (South)	191	5	2.62%

As discussed in the literature review, studies have found that penetration rates between 2% and 5% provide sufficient accuracy to represent the entire population. The penetration rates of the fleet management data (with exception of the outlier) varies between 2.62% and 8.44%. Therefore, the penetration rates of the fleet management data used in this study were deemed sufficient.

8.5. Heavy vehicle percentages

For the purposes of the microscopic traffic simulation included in this study, the HGV percentage of the total traffic stream at each of the three counting locations was required. Table 8.5 contains the average HGV percentages for each period during which counts were performed.

Table 8.5. Average HGV percentages at three counting locations.

Location	AM period		PM period	
	Inbound	Outbound	Inbound	Outbound
R304 (North)	3.08%	3.82%	4.11%	3.42%
R310 (West)	3.61%	4.91%	5.06%	4.16%
R44 (South)	1.03%	2.91%	3.71%	2.28%

As can be seen in the table above, the average HGV percentage ranged between approximately 1% and 5%. The results compares well to literature regarding heavy vehicle presence in Stellenbosch.

It was noted that HGV presence is higher during the afternoon than in the mornings at the three counting locations. Additionally, it is noted that the R44 (South) location has lower HGV presence than the other two locations. Furthermore, there are consistently more outbound heavy vehicles in the morning, and more inbound heavy vehicles in the afternoon. This could indicate that a number of trips originate in Stellenbosch in the morning period, and return in the afternoon. This was an important point to take into account when constructing the microscopic traffic model.

8.6. Prediction of latent demand

Latent demand, also known as induced demand, is the phenomenon where capacity on a road network becomes available by some measure and is filled by vehicles that were unable to occupy this space before. Because this study focuses on the effect of essentially removing HGVs from the road network during specific periods, it was important to determine whether latent demand existed during these periods. In other words, it had to be determined whether passenger cars would fill up the capacity that would become available when restricting access to HGVs during the investigated banning periods. The presence of latent demand is especially important to consider when creating scenarios for a microscopic simulation model.

Because latent demand is only observable after capacity becomes available on a road network, it is very difficult to predict the presence of such demand. For the purposes of this study, peak spreading was used to make a prediction over the presence of latent demand on the road network considered. Peak spreading is the phenomenon where the peak travel period on a road becomes longer due to the road operating at capacity during the original peak period. The rationale was followed that, if peak spreading is significant, latent demand most likely exists, since some road users are forced to travel earlier or later than they would desire to travel if there were more capacity available during the original peak period.

It must be noted that there are no fixed measures or equations for the determination of peak spreading and it is a subjective decision whether peak spreading is significant.

8.6.1. Analysis of traffic counts

In order to determine whether peak spreading occurred at the three locations where counts were conducted, the total number of vehicles counted during each 15-minute period was plotted over time. For morning periods, only the inbound traffic counts are shown and for the afternoon periods, only the outbound counts. This was done because the majority of vehicles travel into Stellenbosch in the morning and out of Stellenbosch in the afternoon. The other directions of travel would not indicate congested conditions and would be irrelevant for the study of peak spreading. **Figure 8.5** and **Figure 8.6** indicate the volume distributions at the three locations for the morning and afternoon counting periods respectively.

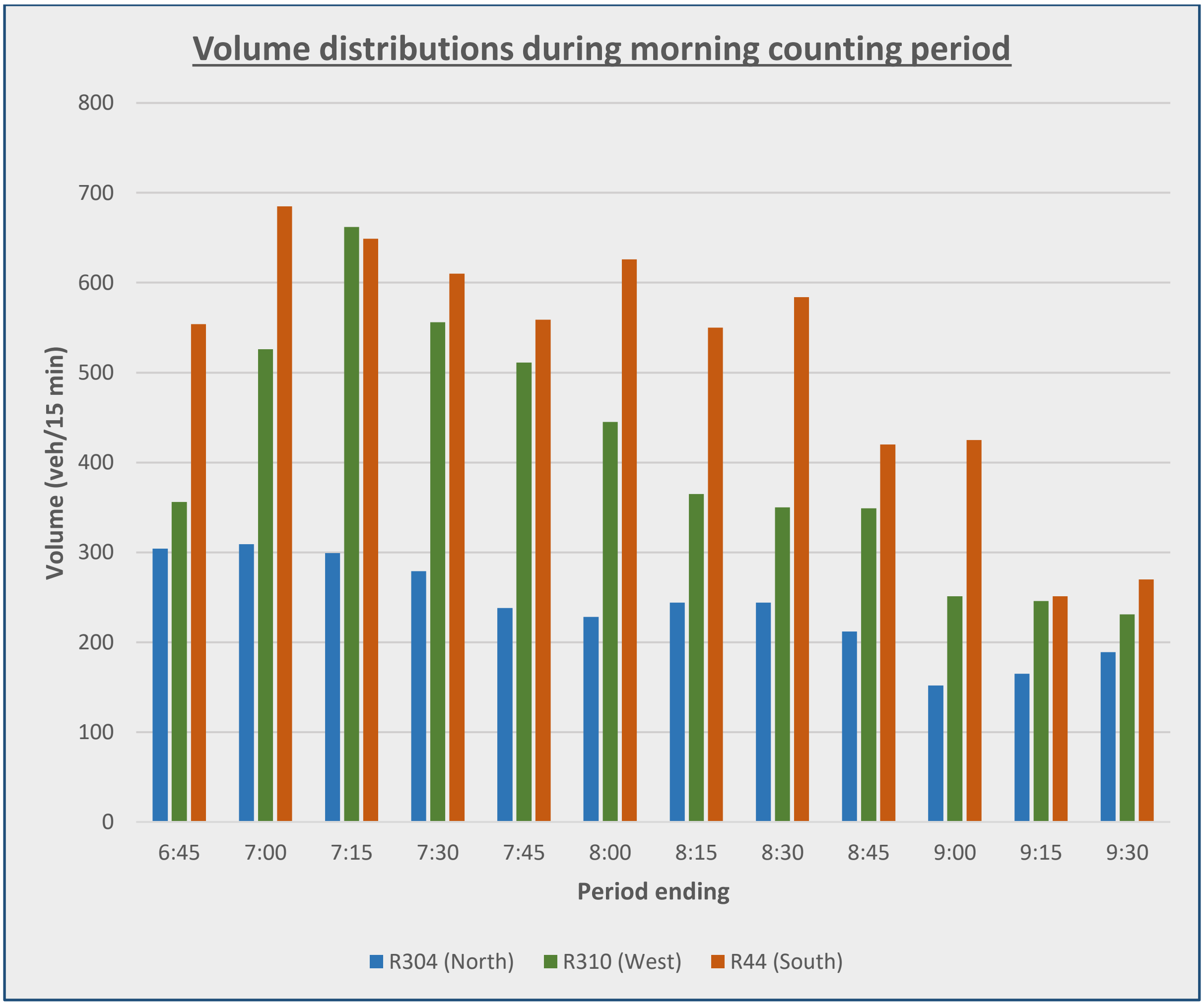


Figure 8.5. *Volume distributions during morning counting period at three locations.*

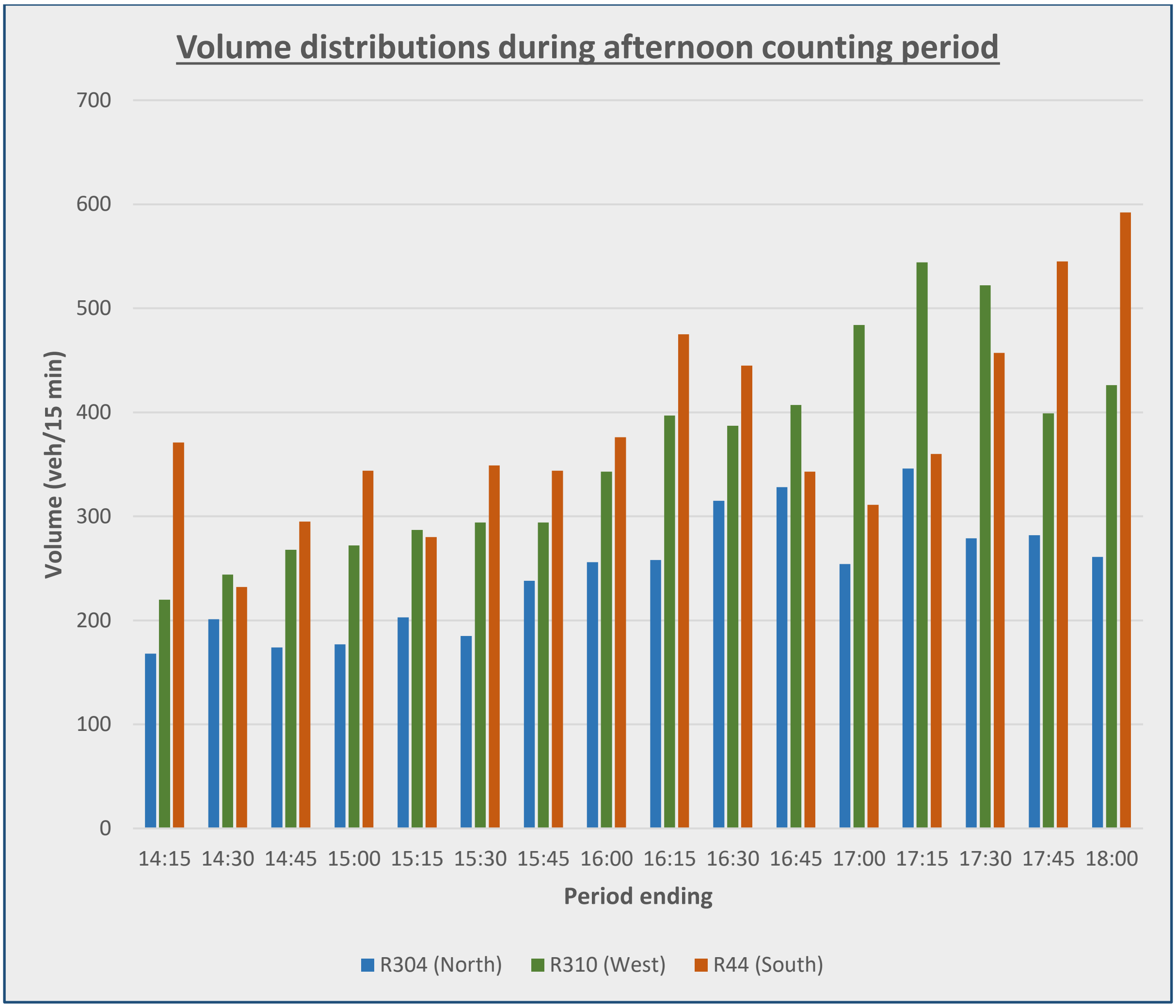


Figure 8.6. *Volume distributions during afternoon counting period at three locations.*

For each route, the duration of the peak period (when most vehicles were present) and the distribution pattern of these periods were analysed. If peak periods were longer than would be expected for Stellenbosch and changes in traffic volumes were gradual, peak spreading was accepted. For example, the morning peak period of the R44 is longer and more spread out than the peak period of the R310 in the same period and, therefore, peak spreading was accepted for the R44 in the morning. **Table 8.6** indicates whether significant peak spreading was accepted or not for each route.

Table 8.6. Assumed peak spreading presence at counting locations.

Location	Period	Peak spreading accepted?
R304 (North)	Morning	No
	Afternoon	Yes
R310 (West)	Morning	No
	Afternoon	No
R44 (South)	Morning	Yes
	Afternoon	Insufficient data*

** It seems that the afternoon peak period on this route extends beyond the period of analysis.*

As can be deduced from the table above, peak spreading is unique to each road and is not always present on all roads within a study area. For the purposes of constructing a microscopic traffic model, however, it is not feasible to apply the presence of latent demand for each road in the network separately. Therefore, an assumption must be made for the entire study area according to the data observed. Because peak spreading was accepted at only some of the locations, the analysis of only traffic count data was not deemed sufficient to accept or reject the presence of latent demand in Stellenbosch.

8.6.2. Analysis of floating car data (FCD)

Because a definitive decision could not be made regarding the presence of latent demand on the entire Stellenbosch road network from only traffic counts, historical floating car data from TomTom was analysed in addition to the traffic counts. This data provided the ability to compare the traffic on a route in Stellenbosch between different years to show the change over time. It was not possible to obtain traffic volumes from the TomTom data, but speed and travel times were obtained.

Route

Traffic data was obtained from the TomTom Traffic Stats portal along a route passing through Stellenbosch. The route is shown in **Figure 8.7**. This route was selected to include two of the major roads feeding Stellenbosch and a section that passed through the centre of town. This route was assumed to represent the average traffic conditions in Stellenbosch during peak periods.

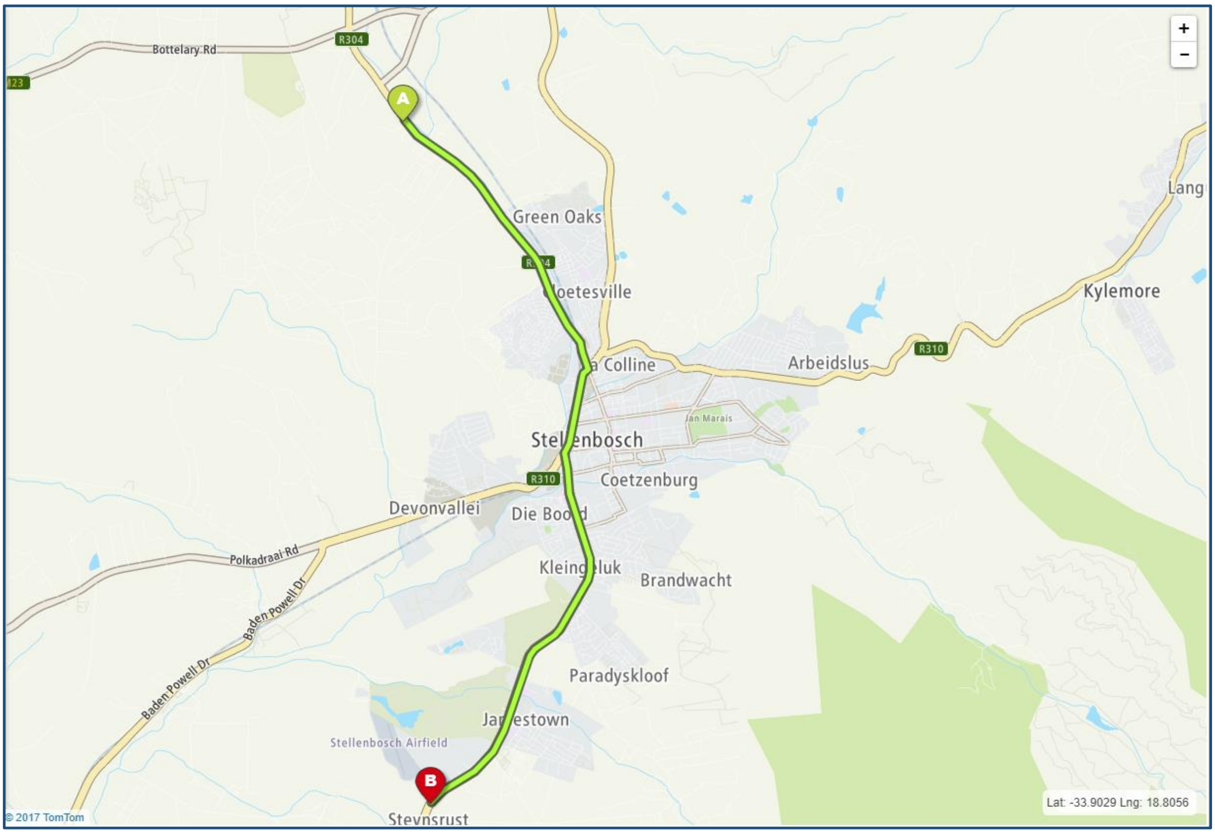


Figure 8.7. *Route defined for determination of latent demand presence by using FCD (TomTom, 2018).*

Sample group

All available probe vehicles were included in the dataset, including passenger cars and heavy vehicles.

Dates

Data was aggregated for all weekdays between 1 February and 31 March for 2013 and 2018. These dates were selected to exclude school holidays, public holidays and university breaks.

Time sets

Data was obtained for 1-hour periods between 4 a.m. and 10 a.m., and between 2 p.m. and 9 p.m.. These periods were assumed to include the morning and afternoon peak periods of Stellenbosch.

Figure 8.8 shows the average travel times on the route selected. When analysing the figure, the peak hours of the route can be determined by establishing where vehicles experience a significant increase in travel time. The peak hours were identified as 7 a.m. to 8 a.m. and 4 p.m. to 5 p.m.

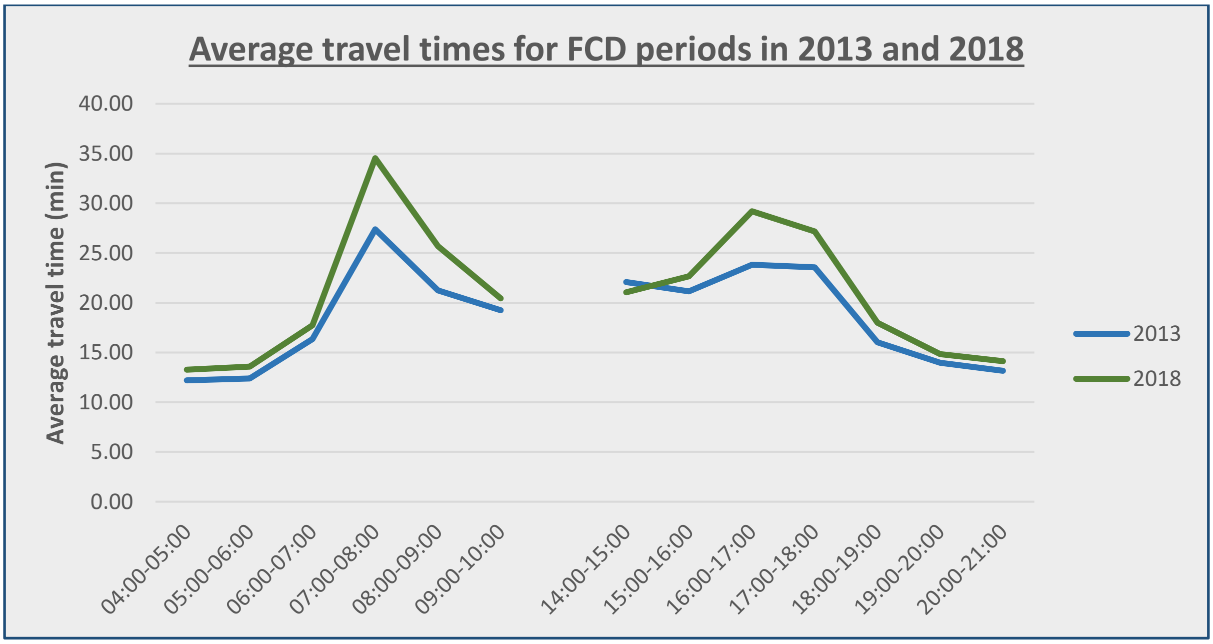


Figure 8.8. *Average travel times for 1-hour periods in 2013 and 2018.*

It can clearly be observed from the figures that travel times on the route worsened between 2013 and 2018. It can also be noted that the pattern of change in travel times stayed relatively the same between the two years. From the change in travel time distribution between 2013 and 2018, it seems that peak spreading is indeed present on this route in Stellenbosch.

8.6.3. Results

Traffic counts and historical floating car data (FCD) were analysed in an attempt to determine whether latent demand was present in Stellenbosch. Both datasets had unique benefits and limitations. The traffic counts provided data for 15-minute periods, which meant that they could indicate variation within an hour, while the historical data was only obtained for 1-hour periods.

The traffic counts, however, were limited to the counting periods. This meant that some peak periods were not fully contained in the datasets. On the other hand, the FCD was obtained for longer periods, including the entire morning and afternoon peak periods.

It is important to note that each dataset represents a different road section in the study area. Latent demand is unique to a specific road and, therefore, cannot be easily aggregated over an entire study area. For the purposes of the microscopic model built for this study, however, a decision had to be made for the entire study area. It was not feasible to assign latent demand to each road individually.

Both data sources yielded varying results. The analysis of traffic counts were deemed insufficient, since some locations and periods indicated that peak spreading is present, while others did not. Additionally, it was difficult to determine whether peak spreading was significant enough to indicate latent demand, since this is a subjective decision. FCD seemed to show that peak spreading, and therefore latent demand, is present, but the results were limited (data was only obtained for 1-hour periods, thus not showing variation within each hour). Additionally, this was only on a single route in the town.

When considering all the factors, it was decided to create two scenarios in the microscopic traffic model: one where latent demand is assumed and one where latent demand is ignored. This would allow for both cases to be investigated.

8.7. Conclusion

Link traffic counts were used for various purposes in this study. Since other data sources were limited or dated, traffic counts could provide recent results that were collected at specifically selected locations.

This chapter provided a detailed discussion of the analyses performed with the use of traffic counts that were performed in April 2018 at three locations. Counts were performed during morning and afternoon periods within 15-minute intervals. Firstly, the penetration rates of the data received from MiX Telematics were determined. It was found that these penetration rates were sufficient for the purposes of this study. Secondly, the HGV percentages in the general traffic stream was calculated from the counts. These were found to correspond to literature on the HGV rates in Stellenbosch. Finally, the traffic counts and FCD were used in an attempt to predict whether there was a presence of latent demand in Stellenbosch. The results were inconclusive and it was decided that the microscopic traffic model would provide for both the presence and absence of latent demand.

CHAPTER 9: MICROSCOPIC TRAFFIC MODELLING

9.1. Background and motivation

Traffic modelling allows for the comparison between different traffic scenarios without the need to implement any changes in the real world. This enables engineers and researchers to investigate the effect of any changes to the operations of a transportation network before investing funds, allowing authorities to better understand whether a project is feasible before implementing it. Especially in the case of policy changes, as is investigated in this study, traffic modelling is very useful for before-and-after studies. This is because it is often very difficult to justify the implementation of a new policy without being sure of what the impact will be.

Traffic models are based on mathematical foundations and rely on different theoretical principles to predict the outcome of changes to a transportation network. As such, models do not predict the exact outcomes of a project, but it provides a realistic prediction of what could occur. Simulation models are stochastic (i.e. they account for randomness and yield different results with every run); while theoretical methodologies are usually deterministic (i.e. they always yield the same results for the same set of input variables). This means that all input variables must be known for deterministic methodologies, severely limiting the capabilities of a method if some variable is unknown or uncertain. The stochastic nature of traffic modelling, on the other hand, allows for the inclusion of unpredictable changes in driver behaviour and other variables in the transportation network.

In this research project, microscopic traffic modelling (through the use of traffic simulation) is used to investigate the impacts of implementing heavy vehicle restrictions in Stellenbosch. Especially when working with urban road networks, the use of microscopic modelling is recommended because of the complexities of the intersections involved.

Microscopic simulation considers each vehicle as an individual entity with its own characteristics and movement choices. After each time step, each individual vehicle updates its properties. This differs from macroscopic simulation models where characteristics are aggregated for entire traffic streams or vehicle types over larger link lengths and time periods. Because the effects of heavy vehicles on the transportation network are studied in this research, microscopic simulation was deemed more appropriate to take into account the differences in the operational characteristics of passenger cars and heavy vehicles. Furthermore, because an urban network was investigated with several complex intersections, a microscopic model could better analyse the effects of restricting heavy vehicle movements on the individual vehicles modelled in the traffic stream.

9.2. Software used

The following software was used for the development of a microscopic simulation model for this study:

- PTV Vissim 10 and
- PTV Visum 16.

9.3. Parameters

9.3.1. Network

Because microscopic simulation models provide much more detailed analyses of traffic movements than macroscopic models, there are certain spatial boundaries to the network that can be modelled. The more links are included in the model, the more time and processing power it requires to run the simulation. Additionally, the data required becomes significantly more when more links are included in the model. For this reason, the network of a microscopic model should include only the most important links and intersections for the final purposes of the model.

The transportation network included in the model was determined from the fleet management data analysis discussed previously. From this analysis, the main routes used by freight vehicles were determined. The final modelled network is shown in **Figure 9.1**. A total of 57 intersections were included in the network, of which 19 were signalised.

It is important to note that several minor roads were omitted from the network to simplify the model. These intersections were believed to have a negligent effect on the rest of the network and the effort to obtain the data required to include them was deemed unfeasible.

9.3.2. Modelling periods

Two modelling periods were defined for the analysis of the model as below:

- **AM period:** 6 a.m. to 9 a.m.
- **PM period:** 5 p.m. to 8 p.m.

It will be noted that the modelling periods correspond to the banning periods of the proposed regulations investigated in this study.

It is important to mention that the response of the freight industry to the heavy vehicle restrictions is extremely complex to estimate. A study of existing literature revealed that the response of the freight industry to new policies is very unpredictable and depends on the details of the policy, the economic climate and the political incentives that are present when a policy is implemented. Extensive research would be required to accurately estimate the response of the freight industry to the implementation of this specific policy; for example, would trucking companies use smaller vehicles in order to allow them to operate during the restricted times, or change their times of operation? This fell outside the scope of this research. For this reason, the model only considers the banning periods and not the influence on heavy vehicle operations outside of the peak times.

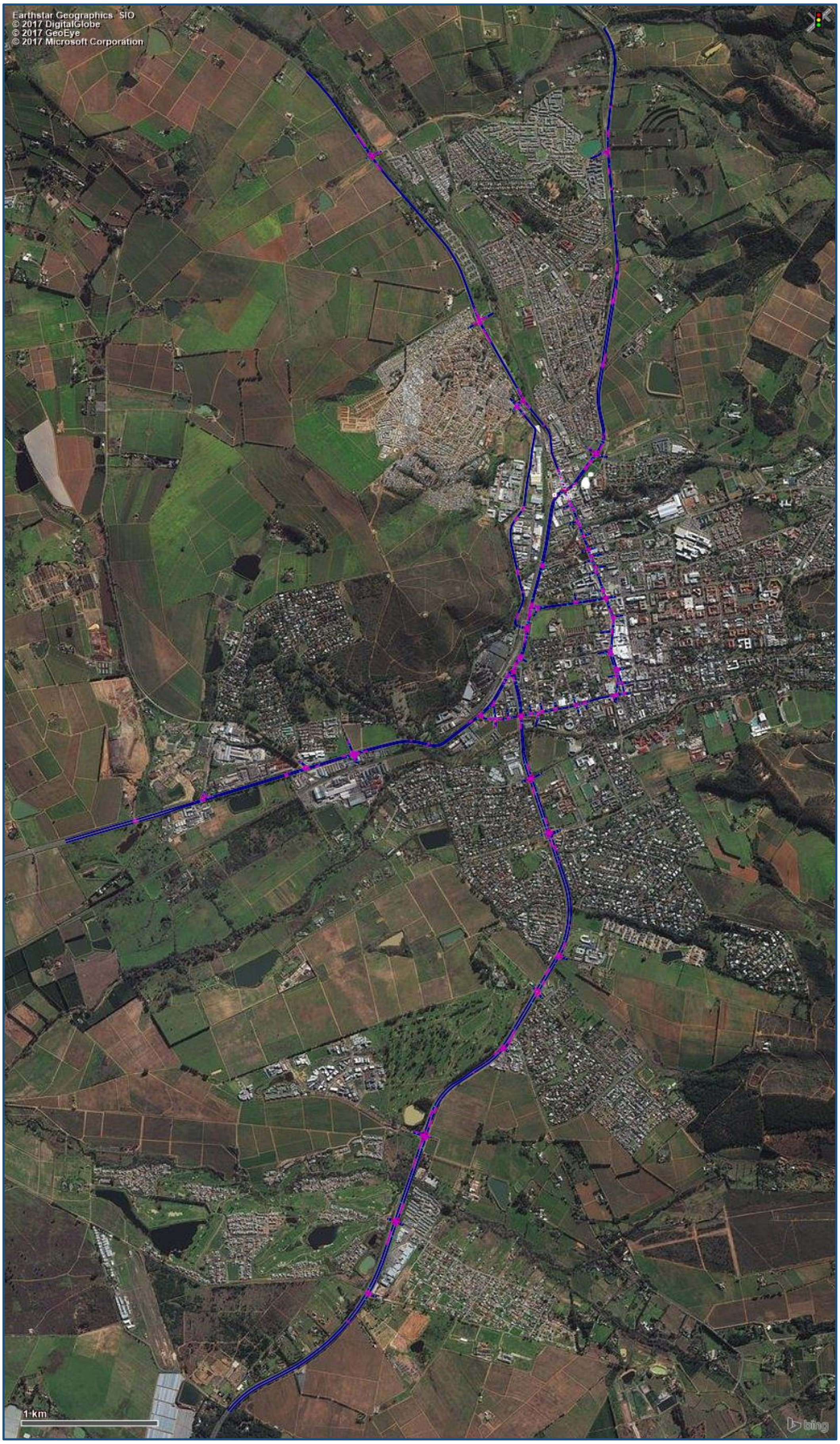


Figure 9.1. *Traffic network modelled in Vissim.*

9.4. Scenarios

9.4.1. Base scenarios

Two base scenarios existed for the model:

1. *AM_Base*

   All normal traffic as observed between 6 a.m. and 9 a.m. on an average weekday in Stellenbosch, including HGVs.

2. *PM_Base*

   All normal traffic as observed between 5 p.m. and 8 p.m. on an average weekday in Stellenbosch, including HGVs.

9.4.2. Alternative scenarios

Four alternative scenarios were included in the model:

3. *AM_No trucks_With latent demand*

   All passenger cars as observed between 6 a.m. and 9 a.m. on an average weekday in Stellenbosch. No HGVs included in any traffic stream in the network (thus, all HGV presence = 0%). The space freed up by removing HGVs is replaced by passenger cars by assuming an average passenger car equivalent (PCE) of E_T = 2.0 (TRB, 2016). That means that each HGV is replaced by two passenger cars.

4. *AM_No trucks_Without latent demand*

   All passenger cars as observed between 6 a.m. and 9 a.m. on an average weekday in Stellenbosch. No HGVs included in any traffic stream in the network (thus, all HGV presence = 0%). The space freed up by removing HGVs is not replaced by passenger cars. The passenger car volumes are equal to the passenger car volumes in the AM_Base scenario.

5. *PM_No trucks_With latent demand*

   All passenger cars as observed between 5 p.m. and 8 p.m. on an average weekday in Stellenbosch. No HGVs included in any traffic stream in the network (thus, all HGV presence = 0%). The space freed up by removing HGVs is replaced by passenger cars by assuming an average passenger car equivalent (PCE) of E_T = 2.0 (TRB, 2016).

6. *PM_No trucks_Without latent demand*

   All passenger cars as observed between 5 p.m. and 8 p.m. on an average weekday in Stellenbosch. No HGVs included in any traffic stream in the network (thus, all HGV presence = 0%). The space freed up by removing HGVs is not replaced by passenger cars. The passenger car volumes are equal to the passenger car volumes in the PM_Base scenario.

9.5. Number of runs required

Microscopic traffic models are stochastic in nature and as such, account for randomness in driver behaviour and other variables in a transportation network. Thus, some parameters in a model are not constant and can vary, depending on the prevailing conditions. For each run, a model will generate random seed numbers that are used to populate these parameters. It must be noted that the values assigned to parameters are related to the original values assigned to them. This means that each run of a model will produce slightly different results, even if the same input variables are provided.

To account for this variability in the results of stochastic models, results are averaged over several runs. The HCM 2016 provides the equation below that can be used to calculate the number of runs required to yield accurate results within a 95% confidence interval:

$$n_{min} = \frac{(1.96s)^2}{{E_T}^2} \qquad \text{(Equation 9.1)}$$

With:

n_{min} = minimum required sample size;

s = standard deviation of Measure of Effectiveness (MOE) and

E_T = maximum tolerable error.

The required number of runs are determined for a specific MOE, as selected by the modeller. In the case of this research, the minimum number of runs was calculated for the average speed of the network of each scenario. In order to calculate the standard deviation for a MOE, a few initial runs have to be executed to yield an estimate of the standard deviation. In the case of this study, an initial number of five runs were executed for each scenario. **Table 9.1** contains the standard deviation of each scenario as calculated from the five initial runs. The minimum number of runs required for each scenario was calculated from the initial sample standard deviations by using **Equation 9.1**. A maximum tolerable error (E_T) of 5 km/h was selected for a 95% confidence level. The results of these calculations can be found in **Table 9.1**.

Table 9.1. Standard deviation of average network speeds for initial runs.

Scenario	s (km/h)	n_{min}
1. AM_Base	0.951429	0.139099
2. PM_Base	0.530714	0.043281
3. AM_No trucks_With latent demand	0.810714	0.100997
4. AM_No trucks_Without latent demand	0.826429	0.10495
5. PM_No trucks_With latent demand	0.672857	0.069569
6. PM_No trucks_Without latent demand	0.673571	0.069717

As can be concurred from the table above, the standard deviations of the five initial runs were very low, leading to the minimum number of runs being less than one for a maximum tolerable error of 5 km/h. This means that the five initial runs were more than sufficient to ensure accurate results. Therefore, results for all scenarios were averaged over five runs. **Table 9.2** indicates the expected maximum error for each scenario when five runs are executed. It can be observed that the errors are very small, indicating that the variability between different runs is negligible.

Table 9.2. Maximum expected error of average network speeds for five simulation runs.

Scenario	E_T (km/h)
1. AM_Base	0.834
2. PM_Base	0.465
3. AM_No trucks_With latent demand	0.711
4. AM_No trucks_Without latent demand	0.724
5. PM_No trucks_With latent demand	0.590
6. PM_No trucks_Without latent demand	0.590

9.6. Accuracy of the model

It is important to note that several of the values assigned to parameters in the model were the default values recommended by the software. This was done for several reasons. Firstly, the scope of this study and the vast size of the modelled network did not allow for all values to be measured in the field. Furthermore, literature did not provide adequate information on which values to use for many parameters. It was, however, not deemed problematic that some default values were accepted. This was because of the fact that the purposes of the model are comparative in nature.

To ensure that all parameters used for the model were accurate, the accuracy of the base models were evaluated. Several methods were used to verify the base models and are discussed later in this chapter.

9.7. Model construction

9.7.1. Network creation

The geometric properties and network data of the model was downloaded from OpenStreetMap (OSM). OSM is an online global map free to use under an open license.

Although Vissim was used in this study to build a microscopic traffic model, Visum (used for macroscopic modelling) had to be used to transform the data from OSM to be able to import the transport network into Vissim. The data imported into Visum from OSM resulted in a detailed transportation network with links, nodes, road characteristics and some other factors already built and defined. This network was refined in Visum by deleting all unnecessary roads, footpaths, cycle routes and information that did not fall within the scope of the microscopic model.

After refining the network, the data was exported to Vissim where it could be further developed.

9.7.2. Validation of network properties

Although the transportation network had been simplified in Visum before being imported into Vissim, the network still had properties that had to be validated after being imported. It is important to note that the data exported from OSM can rarely be used as-is and all properties have to be checked before using it in a model.

By using Vissim's built-in satellite background map (Bing Maps), all links were realigned to fit the existing roads and to better define curvatures where required. Additionally, it was found that some links did not have the correct number of lanes, and therefore this property of all links were checked and corrected where it was found to be inaccurate. A default lane width of 3.5 m was assumed for all links, with the width of certain links being adjusted if deemed necessary after consulting the satellite background map. The use of 3.5 m as a default lane width corresponded to the recommendation of the SANRAL Geometric Design Guide of 2003, which recommends that lane widths of basic lanes should range between 3.1 m and 3.7 m.

9.7.3. Reconstruction of intersections

Many of the intersections contained in the network imported from OSM were found to be either geometrically inaccurate, incorrectly set up for the intersection control present or overcomplicated for the purposes of the model. For this reason, all intersections were rebuilt. This included the reconstruction of all connectors and approaching links, and the redefinition of all movements and parameters according to the intersection control type used. In total, the network contained 57 intersections, of which 19 were signalised. All intersections are shown in **Figure 9.2**. The setup of intersection control parameters (stop-controlled or signalised) is discussed later in this section.

9.7.4. Desired speed decisions

Desired speed decisions are used in Vissim to indicate where the speed limit of a road changes, i.e. where the desired speed of a driver changes. When a vehicle travels over a desired speed decision marker, the driver's desired speed changes to the speed defined by the marker. Desired speed decisions were placed at all locations in the network where the change in speed began. Most of the desired speed decisions were located outside of the centre of Stellenbosch, where speeds changed from 60 km/h to 80 km/h or 100 km/h and vice versa. The speed limits on all links inside the town were 60 km/h.

It is important to note that the desired speeds of all vehicles entering a network is predefined and, therefore, it is not necessary to create desired speed decisions where vehicles enter the network.

Figure 9.2. *Intersections included in microscopic model (Google Earth Pro, 2018).*

9.7.5. Speed distributions

Because driver behaviour is stochastic, it cannot be assumed that all drivers will have the same desired speed when travelling on a road. Therefore, desired speed distributions are used to randomly assign desired speeds to both passenger car and heavy vehicle drivers. Floating car data (FCD) from TomTom was used to determine speed distributions that could be used in the model for average drivers in Stellenbosch. The average percentile speeds along a route (shown in **Figure 9.3**), were used to determine average speed distributions for roads with speed limits of 60 km/h, 80 km/h and 100 km/h respectively. The speeds that were considered included travelling speeds between 12 a.m. and 3 a.m., recorded on weekdays between 7 May 2018 and 8 June 2018. These dates were selected to exclude school holidays, public holidays and university breaks. The speeds during this time period were assumed to indicate free-flow speeds, hence it could be assumed that these speeds would accurately reflect the speeds that drivers desired to travel at when not influenced by congestion.

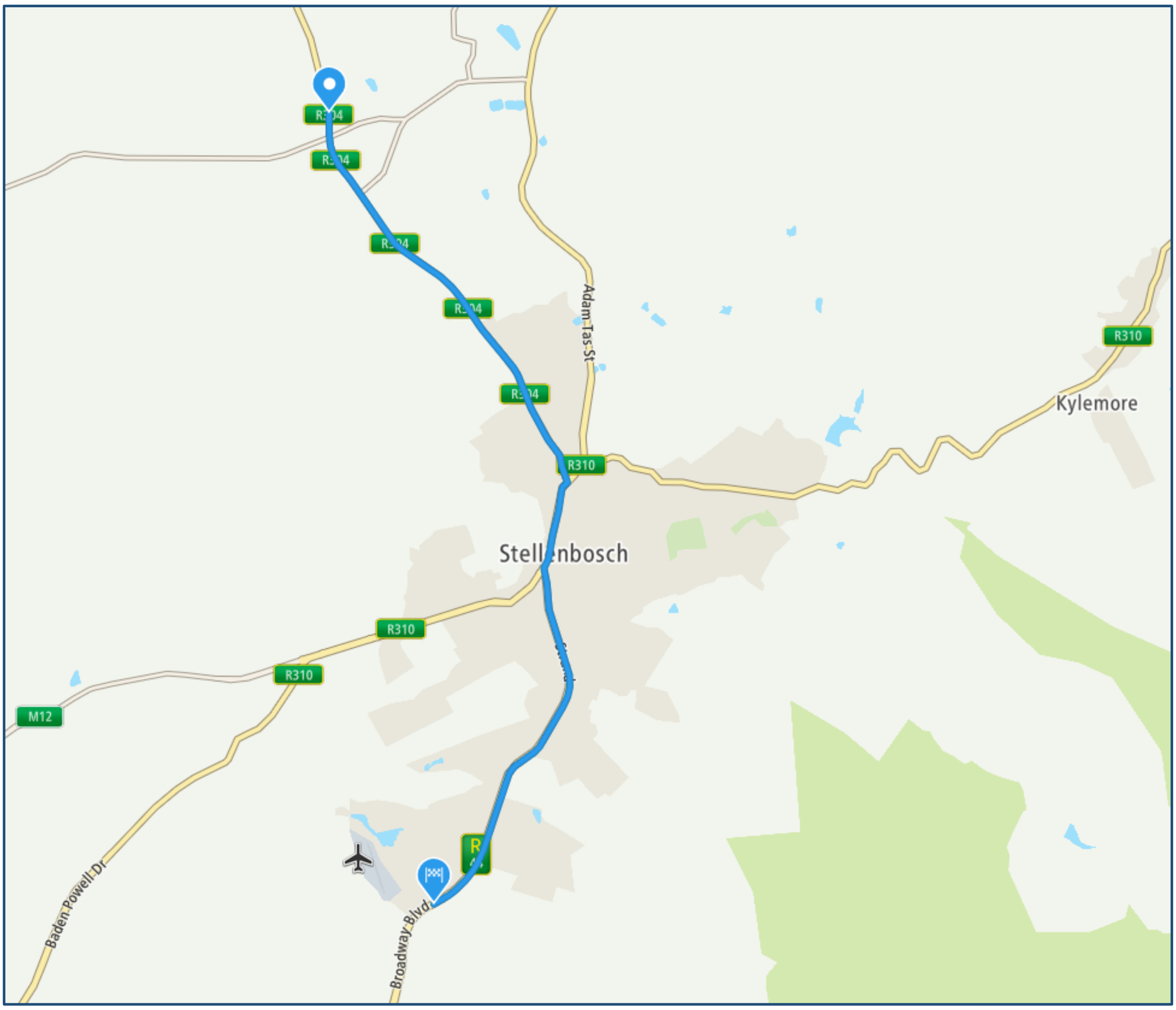


Figure 9.3. *Route along which percentile speeds were received from TomTom (TomTom, 2018).*

The data obtained from TomTom was provided for passenger cars and heavy fleet vehicles separately. Therefore, it was possible to create different speed distribution profiles for these two vehicle classes.

Figure 9.4 shows the speed distribution models that were employed in the traffic model, as derived from the TomTom historical data.

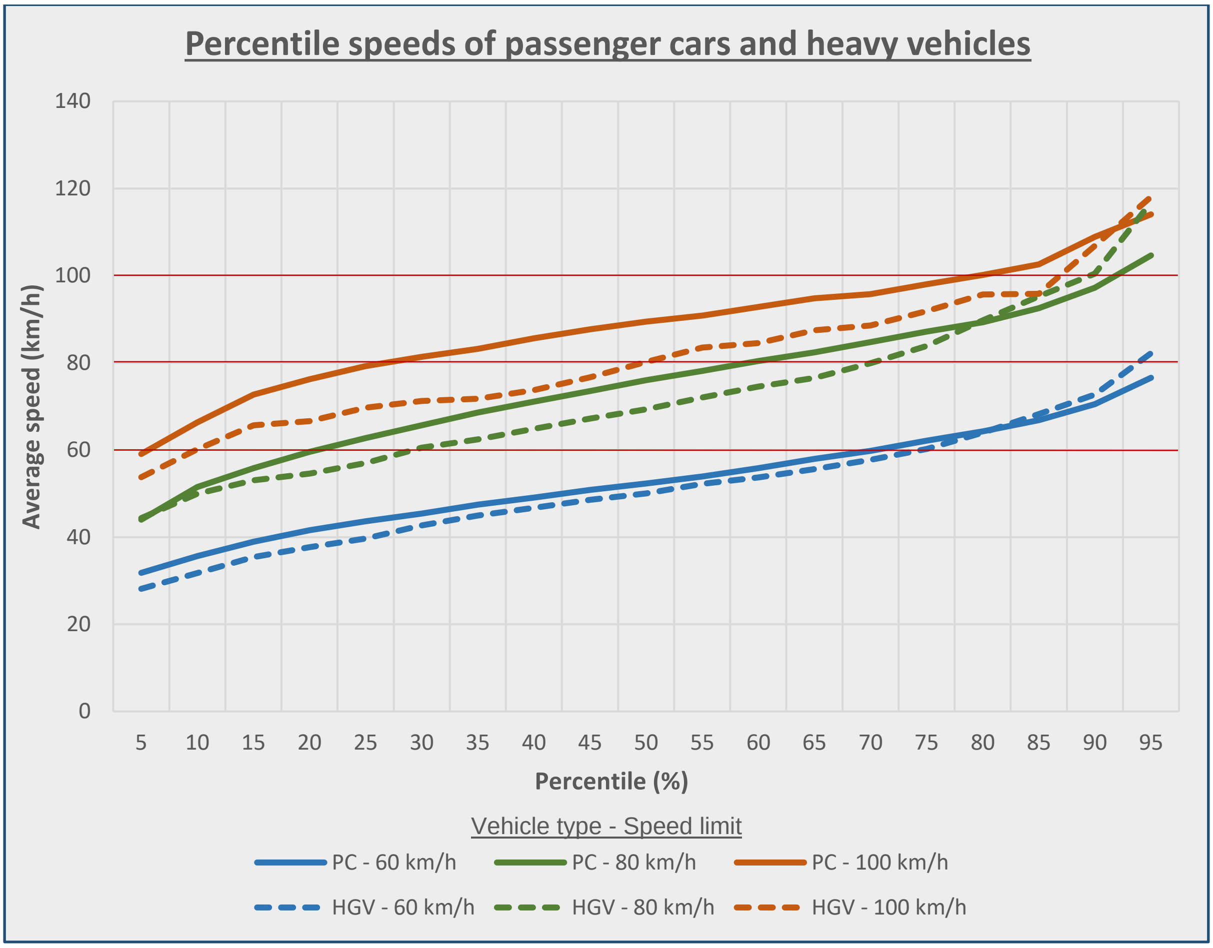


Figure 9.4. *Speed distribution profiles for passenger cars and heavy vehicles for different speed limits.*

9.7.6. Reduced speed areas

Where drivers are expected to travel at speeds lower than their desired speeds, like at speed humps and when performing turning manoeuvres, reduced speed areas need to be included in a microscopic model. Reduced speed areas change the travelling speed of a vehicle but unlike desired speed decisions, the change is not permanent. In Vissim, drivers will decelerate at an assigned deceleration rate as it approaches a reduced speed area. As the vehicle reaches the reduced speed area, its speed will match that of the speed distribution assigned to the area. As it again leaves the area, it will accelerate at a predefined acceleration rate until it reaches its original desired speed. Reduced speed areas were defined at all turning manoeuvres and speed humps in the model.

The SANRAL Geometric Design Guide of 2003 indicates that a turning speed of 15 km/h is safe to assume for vehicles turning left or right without stopping. This turning speed was assumed for all turning movements in the network. An exception was made for vehicles travelling inside roundabout facilities. The design speed recommended for roundabout facilities, according to the SANRAL Geometric Design Guide of 2003, varies between 40 km/h and 50 km/h. For this reason, the speed of vehicles travelling inside these facilities was defined as 40 km/h. For all speed humps in the network, a speed of 30 km/h was defined.

One of the parameters required to create reduced speed areas is the deceleration rate of a vehicle when approaching the area. Default deceleration rates (for comfortable driving) from the SANRAL Geometric Design Guide of 2003 were used for this study. All passenger cars were assigned a deceleration rate of 3 m/s^2 and heavy vehicles were assigned a deceleration rate of 1.5 m/s^2. The acceleration rates of vehicles after leaving reduced speed areas are depends on the driving behaviour model used in Vissim and the properties of the vehicle as defined in the software.

9.7.7. Conflict areas

Conflict areas are automatically created in Vissim wherever a conflict exists between two movements. These areas are used to define the right-of-way of the conflicting movements, indicating which vehicle should yield if two vehicles were to reach the conflict area at the same time.

Vissim initially assigns a passive status to all generated conflict areas in a network. This means that no right-of-way exists at conflict areas until the modeller assigns it to each area. All conflict areas in the model were altered to ensure the actual right-of-way at each intersection according to the intersection control type employed and the rules of the road.

In addition to the right-of-way, conflict areas in Vissim require several input parameters to ensure realistic traffic movement during the simulation. The parameters that had to be defined for each conflict area in the model are contained in **Table 9.3**. Additionally, the value assigned to each parameter is provided and an explanation of each parameter and a justification of the selected value can be found below the table.

Table 9.3. Parameters defined for Vissim conflict areas.

Parameter	Value assigned
VisibLink1	100 m
VisibLink2	100 m
FrontGapDef	0.5 s
RearGapDef	0.5 s
SatDistFactDef	0.6
AddStopDist	0 m, except at yield lines
ObjAdjLns	Not selected
AnticipRout	80%
AvoidBlockMinor	80%
AvoidBlockMajor	Not selected

VisibLink1 *and* ***VisibLink2*** *– Visibility of link 1 and link 2*

The maximum distance at which drivers can observe vehicles travelling on the conflicting link. This value is usually influenced by the presence of buildings or other objects next to the road that block the view of drivers approaching an intersection. A default value of 100 m was assumed for all link visibilities, since there were no objects significantly obstructing the view of drivers at any intersections.

FrontGapDef *– Default front gap*

The minimum gap time that is allowed between the back of a vehicle in the major traffic stream and the front of a vehicle travelling in the minor traffic stream. A yielding vehicle from the minor traffic stream is not allowed to enter the major stream until the front gap is provided, after which the vehicle enters the major traffic stream and ignores the required front gap. All minimum front gaps were defined as 0.5 seconds; the default value proposed by the software.

RearGapDef *– Default rear gap*

The minimum gap time that is allowed between the back of a vehicle crossing the major road and the front of a vehicle in the major stream. After a crossing vehicle has left the conflict area, at least this amount of time needs to pass before a vehicle from the major traffic stream enters the conflict area. All minimum rear gaps were defined as 0.5 seconds; the default value proposed by the software.

SatDistFactDef *– Safety Distance Factor*

A factor that is multiplied with the normal safety distance (defined by the driver behaviour model) between vehicles in the major traffic stream. This factor is only applicable to merging vehicles and dictates whether a yielding vehicle is able to enter the major traffic stream without causing disturbances to the vehicles in the major stream. If a vehicle in the major traffic stream still has at least this distance available in front of it after a merging vehicle has entered the traffic stream, the merge will take place. The safety distance factor was selected as 0.6 in this model. This is the default value recommended by Vissim for the safety distance required when vehicles make lane changes and it was deemed accurate enough to assume this value for merging movements.

AddStopDist *– Additional stop distance*

An additional distance that is added upstream of a conflict area behind which a vehicle must yield. This is used to allow yielding vehicles to stop behind a yield line in cases where an intersection is controlled by a yield sign. This was not used frequently in the network, since most unsignalised intersections had stop signs and not yield signs. Thus, this value was mostly set to 0 m. In cases where yield signs were present, the value dependent on the location of the yield line in reference to the conflict area.

ObjAdjLns *– Observe adjacent lanes*

An option that allows merging vehicles to consider vehicles in the major traffic stream that switch to the conflicting lane from a non-conflicting lane. If this option is selected, the simulation speed decreases. For this reason and the fact that the network did not contain many places where this would be required, this option was not selected.

***AnticipRout** – Anticipate routes*

The proportion of the yielding traffic stream that will be able to foresee that vehicles in the major traffic stream will turn off upstream of the yielding vehicle and will not reach the conflict area. These vehicles will not wait unnecessarily for approaching vehicles that will not reach the conflict area. This value was set to 0.8 to allow for drivers with low concentration levels, drivers that do not feel confident enough to anticipate what other drivers will do and vehicles in the main traffic stream that do not use their indicators.

***AvoidBlockMinor** – Avoid blocking the minor flow*

The proportion of the major traffic stream that will keep the conflict area clear for yielding vehicles to cross when queuing exists on the major link. It must be noted that this is only applicable to crossing movements and not merging or branching conflicts. Additionally, this will only occur if the space downstream of the conflict area is less than the length of the non-yielding vehicle plus 0.5 m and if the vehicle is travelling at less than 5 m/s and less than 75% of its desired speed. This value was set to 0.8 to allow for drivers that are more aggressive and do not want to leave space for yielding vehicles to cross and for drivers that accidentally block the yielding stream.

***AvoidBlockMajor** – Avoid blocking the major flow*

An option that, when selected, restricts yielding vehicles from entering conflict areas if they cannot immediately leave the conflict area. If this option is not selected, a yielding vehicle can sometimes block vehicles in the major flow because it cannot move out of the conflict area due to another vehicle that is in the way. In this case, vehicles in the major traffic stream will slow down and stop in front of the conflict area. This option was not selected because it was believed that some drivers in the study area would travel into conflict areas without being sure that they could immediately leave it. Therefore, this possibility cannot be completely excluded.

9.7.8. Avoiding tailbacks at a junction

When using conflict areas, vehicles in the major traffic stream will only avoid blocking the minor stream for crossing movements. In order to avoid blocking the minor stream for merging and branching movements, priority rules are used. By defining priority rules at intersections, yielding vehicles will be able to travel into and through the conflict area when the major traffic stream is queueing. If this is not built into the model, the yielding traffic stream will not be able to travel into the conflict area until the entire queue has dissipated. This is very unlikely to be the case in reality.

Priority rules allow yielding vehicles to enter the major traffic stream if two conditions are met:

1. The **minimum headway** before the next vehicle in the major stream is available.
2. The **minimum gap time** is provided. This means that the time before the next vehicle in the major traffic stream arrives should be more than the time required for a merging vehicle to perform the merging manoeuvre.

For each priority rule, the minimum headway and minimum gap time is defined by the modeller. These values can be defined separately for passenger cars and HGVs. It is important to note that the minimum gap time is the ruling factor in normal traffic flow, while the minimum headway is more important when traffic is slow on the major link. Since priority rules were used in this case to accommodate for only cases where queues form, the ruling factor was the minimum headway. The minimum gap time was, therefore, set to 0 s. in all cases.

The minimum headway is defined as the length of the area that should be kept open plus the length of the longest vehicle in the major traffic stream minus 0.5 m. For traffic streams that contain HGVs, Vissim recommends that a minimum headway of 20 m be defined in order to accommodate for these long vehicles. This ensures that a vehicle in the major traffic stream would not cross into the conflict area if there were not space for it to clear the conflict area. This concept is shown graphically in **Figure 9.5**.

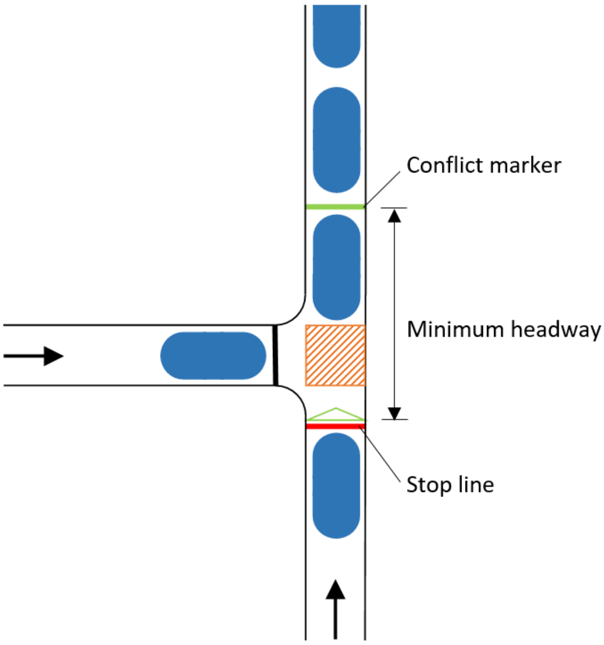


Figure 9.5. *Using a priority rule to avoid tailbacks at a junction (after PTV GROUP, 2016).*

By setting up priority rules in this way, congestion at the intersection is minimised and the model portrays more realistic driver behaviour. The priority rules in this model was set up to only apply to vehicles that travel less than 20 km/h in the major traffic stream. This was done because it was believed that vehicles travelling more than 20 km/h would not be as willing or able to keep the intersection clear as vehicles travelling at slower speeds.

9.7.9. Stop lines

Stop lines force all vehicles to stop behind the line for at least one predefined time step, even if there are no conflicting traffic movements. Stop lines were included in the model wherever they were located in reality.

It is important to note that Vissim automatically applies a first-come-first-serve principle at intersections with more than one stop sign. Vehicles with the longest waiting times at an intersection are allowed to go first. This ensures that multi-stop intersections operate realistically.

9.7.10. Signalised intersections

Although most of the signal plans in Stellenbosch were found to be vehicle actuated or semi-vehicle actuated, the process of including these plans are much more complicated to build into a microscopic model than fixed-time signal plans. Therefore, all signal plans for the model were approximated as fixed-time plans. It was deemed unnecessarily complex and time-consuming to write the code required to accommodate vehicle actuation for the purposes that the model would be used for. Additionally, since the modelled periods included the peak periods, it was believed that vehicle actuation would play a minor role in the operation of the signals when congestion levels were high.

All vehicle actuated or semi-vehicle actuated signal plans were approximated as fixed-time plans by assuming the green times of each phase to be equal to the maximum green times of the actuated plans. Since pedestrians were ignored in this model, all pedestrian signal control phases were excluded from the signal plans.

To model the signal plans in Vissim, a signal-control add-in, called Vissig, was used. Vissig provides a graphical platform that allows users to set up stage-based signal plans for fixed-time signals. Vissig was used to define the phase sequence of each signal plan and compile the signal timings of each phase within a signal program. **Figure 9.6** shows a screenshot of the setup of one of the signal plans in Vissig.

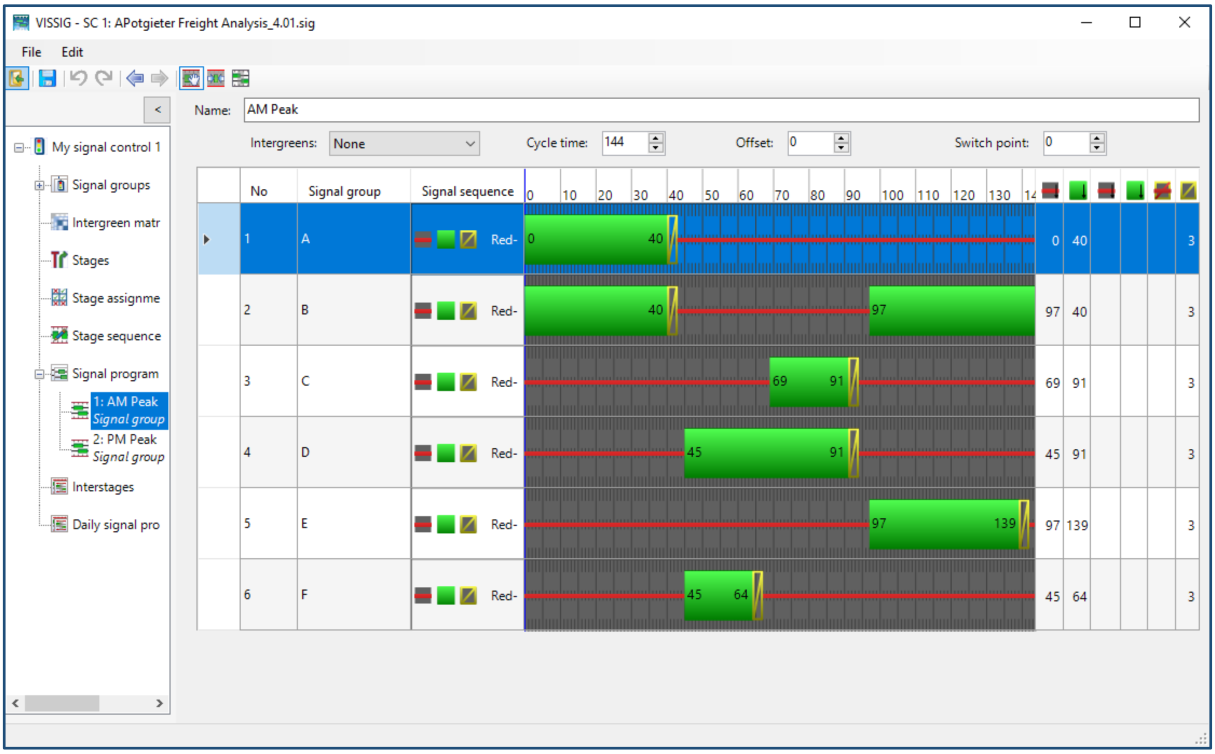


Figure 9.6. *Screenshot of a signal group created in Vissig.*

After all signal plans were compiled in Vissig, they were assigned to signal heads which were in turn assigned to intersection links in the Vissim model.

It must be noted that two different signal programs were created for each of the 19 intersections; one for each of the modelled periods.

9.7.11. Vehicle inputs

In Vissim, vehicle inputs must be provided wherever a link in the network starts. For each vehicle input, the composition of the traffic stream is defined according to the types of vehicles that are present on that link. For the purposes of the model created, only passenger cars and HGVs were taken into account. All other modes of transport, such as buses, bicycles and pedestrians were ignored.

The vehicle compositions of all vehicle inputs were derived from the traffic volumes on each link that required an input. **Section 5.6.3** explains how traffic volumes for the network were obtained. For each inbound traffic stream with a different HGV percentage, a different vehicle composition must be created in Vissim for which the vehicle proportions must be defined. Because it would be illogical to create a different vehicle composition for every single one of the 1 632 vehicle inputs included in the model, the HGV percentage of each vehicle input was rounded to the nearest half percent. This reduced the number of vehicle compositions that had to be created significantly. Where HGV presence was found to be zero, the HGV percentage of vehicle inputs was set equal to 0.5% to allow for the possibility of a HGV wanting to use the route.

Each modelling period was divided into 15-minute time periods. These time periods allowed for volumes, routing decisions and vehicle compositions to be changed every 15 minutes, which allowed for more accurate modelling. Two additional 15-minute periods were included before and after each 3-hour modelling period. These periods were *warm-up* and *cool-down* periods. A warm-up period is included in a microscopic model to populate the network before the analysis period starts and a cool-down period allows all vehicles that entered the network during the last period of analysis to exit the system. Thus, each scenario included fourteen 15-minute time periods.

For the base scenarios, the counted volumes were entered into the model as-is. For the alternative scenarios, however, the volumes were entered according to the scenario considered. For Scenario 4 and 6, latent demand was ignored. In these cases, passenger car volumes were entered to be the same as in the base scenarios. HGV volumes, however, were set equal to zero in all periods. For Scenario 3 and 5, it was assumed that additional passenger cars would fill the volumes freed up by the banned heavy vehicles. Passenger cars replaced the volumes of the HGVs in the base scenarios by using a PCE of 2.0. This meant that the number of passenger cars that would replace the HGVs would be double the number of HGVs. These passenger cars were added to the base volumes of passenger cars and then modelled.

9.7.12. Vehicle routes

Vehicle routes in Vissim are defined wherever a vehicle can travel onto more than one link, for example at intersections. When defining vehicle routes, the proportion of vehicles that will travel in each direction from a point on a link must be provided. These proportions are obtained from traffic volumes and can be entered for each vehicle class separately.

Vehicle routing decisions need to be defined for each time period and can be dynamic or static. Dynamic routing decisions change according to the conditions present on the modelled network, while static routing decisions are defined as constant proportions that do not change for the duration of one time period. Since time periods were defined to be short (only fifteen minutes), static routing was deemed sufficient for the purposes of the model since significant routing changes were not believed to occur in such a short period. In total, the network contained 832 possible routing directions per modelling period for which the proportion of movements in each direction had to be defined for fourteen 15-minute periods.

It is important to note that the number of HGVs on several links in the network was equal to zero during some time periods. In these cases, the routing proportions of passenger cars were accepted as the routing proportions of HGVs.

9.8. Results

Results were obtained from the model on two levels: network-wide and on an individual intersection basis. This section summarises the main results obtained for all six scenarios. It is important to note that results were only obtained for passenger cars. Since no heavy vehicles were present in four of the six scenarios, results for these vehicles could not be compared. Additional results were obtained for specific pre-defined routes. These were used for validation purposes and are discussed in the next section.

9.8.1. Network results

Speeds

Figure 9.7 shows the average speeds of all passenger cars in the network during each time period for all six scenarios. During both modelling periods, the removal of heavy vehicles from the network did not have a significant effect on travel speeds when it was assumed that there was latent demand in the town. Although the average speeds in these scenarios were slightly lower than in the base scenarios during some time periods, the differences were negligible. The insignificance of the change in travel speeds is confirmed when considering the average difference in speeds for the entire AM and PM periods, shown in **Table 9.4**. On average, it was found that the absence of heavy vehicles (when latent demand was present) resulted in a less than 1% change in average travel speeds.

Network travel speeds were found to improve in the scenarios where heavy vehicles were banned without the presence of latent demand. This was to be expected, since less vehicles were present on the road network which would most likely lower congestion levels. What needs to be examined, however, is the degree to which travel speeds were found to improve. On average, the difference in travel speeds were found to be approximately 5% higher during the AM period and 1% higher during the PM period for these scenarios as shown in **Table 9.4**.

It is important to note that the change in travel speeds for scenarios with and without latent demand present was found to be larger during periods where the road network was congested in the base scenarios. This can be attributed to the fact that travel speeds are much more dependent on the rest of the traffic stream during congested conditions than during uncongested conditions. When the network is not congested, vehicles might already be travelling at their desired speeds, with only intersection control exerting an influence on their travel speeds. However, when there are more vehicles on the network their travel speed is much more influenced by congestion and the density of a road. Therefore, changes in the traffic stream are much more likely to affect travel speeds during congested periods.

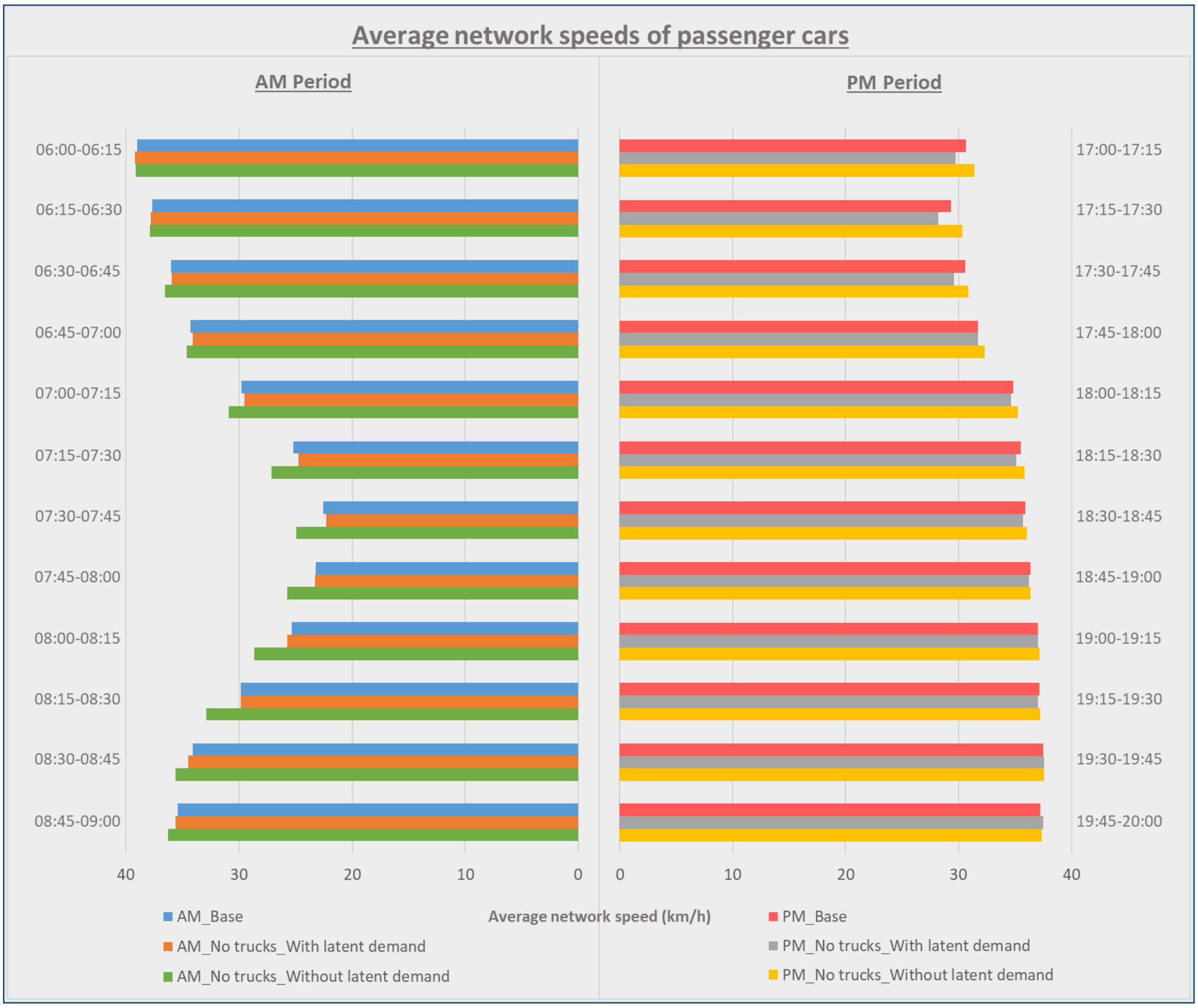


Figure 9.7. *Average network speeds of passenger cars.*

Table 9.4. Difference in average network speeds from base scenarios.

Scenario	Average network speed [km/h]	Difference from base
AM_Base	31.04	
AM_No trucks_With latent demand	31.04	-0.01%
AM_No trucks_Without latent demand	32.52	+4.76%
PM_Base	34.49	
PM_No trucks_With latent demand	34.17	-0.91%
PM_No trucks_Without latent demand	34.82	+0.97%

Travel times

Similar to the network speeds, network travel times were aggregated over the entire modelled network. The measured travel times of all passenger cars in the six scenarios can be observed in **Figure 9.8**. Travel times were found to be consistently higher in scenarios where heavy vehicles were banned while latent demand was present. When latent demand was not present, travel times were found to be lower. Additionally, as with the average speed results, changes in travel times were most noticeable during periods where congestion levels were high in the base scenarios. Overall, the travel time results echoed the conclusions reached through the analysis of the average speed results, that is, traffic conditions improve when heavy vehicles are removed from the network *if* there is no latent demand, but it worsens when latent demand is present.

Table 9.5 indicates the average difference in travel time between the scenarios where heavy vehicles were banned and the base scenarios. For both the AM and PM modelling periods, travel times increased by approximately 5.5% when latent demand was assumed. When latent demand was not assumed to be present, travel times decreased by approximately 6% during the AM period, but only by 1% during the PM period. The maximum potential travel time saving when latent demand was not present was identified as 14.19% between 6:45 a.m. and 7 a.m.

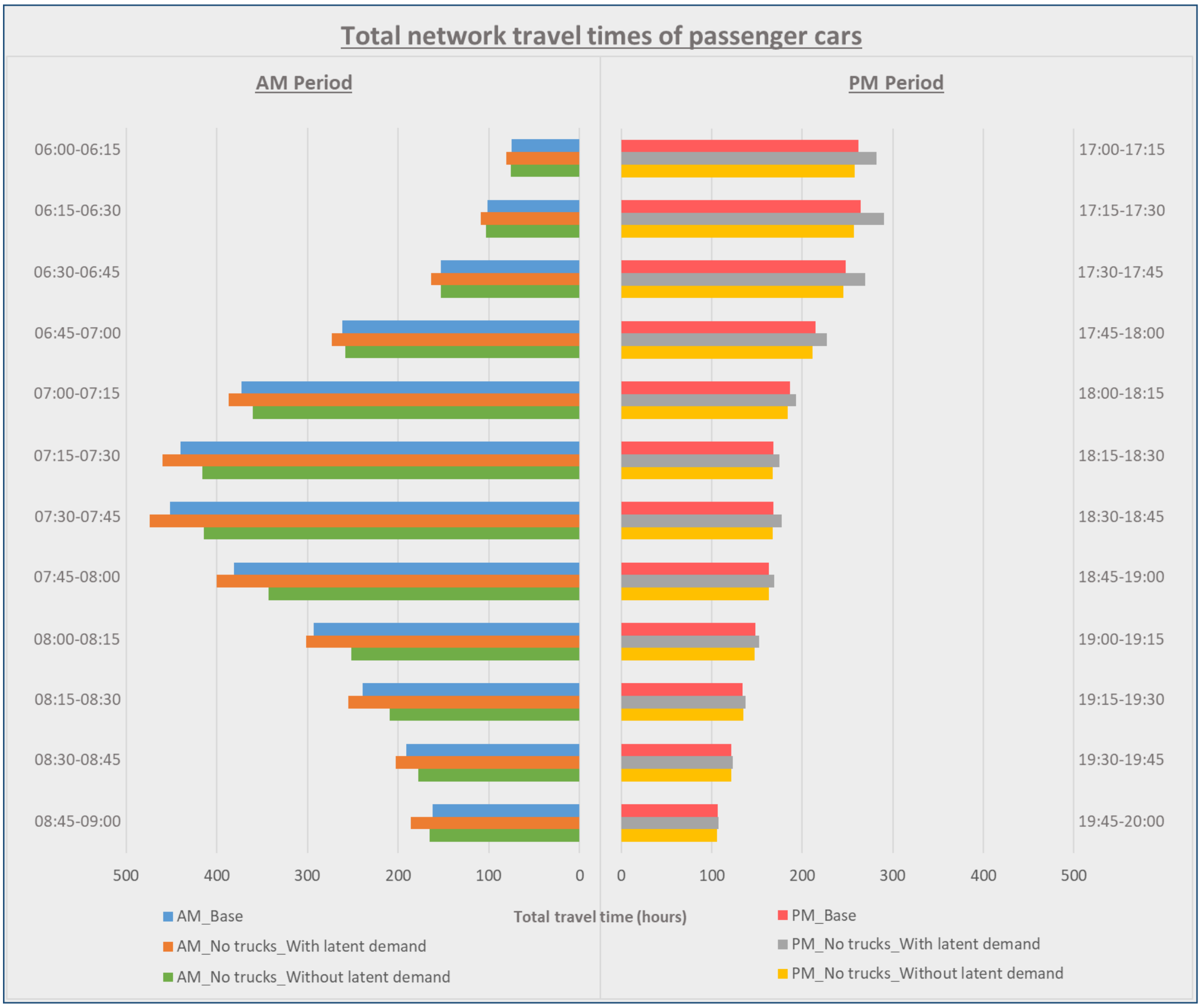


Figure 9.8. *Total network travel times of passenger cars.*

Table 9.5. Difference in average network travel times from base scenarios.

Scenario	Average network travel time [h]	Difference from base
AM_Base	260.06	
AM_No trucks_With latent demand	274.33	+5.49%
AM_No trucks_Without latent demand	243.96	-6.19%
PM_Base	182.04	
PM_No trucks_With latent demand	191.89	+5.41%
PM_No trucks_Without latent demand	180.32	-0.95%

Delays

The average delay per vehicle was evaluated in each scenario to investigate the effect that the heavy vehicle bans would have on individual road users. The results of this evaluation can be found in **Table 9.6**.

From **Table 9.6**, it can be observed that the average delays were lower during most time periods when heavy vehicles were banned and no latent demand was present. During the AM period, the average delay per vehicle could decrease by up to 18.82%. The decrease in vehicle delay was also present during the PM period, but was not as significant as during the AM period. This can be attributed to the fact that the PM base period had smaller delays on average. Delay reductions are more easily achieved if base delays are high to begin with, since delays during off-peak periods are most likely not majorly affected by the traffic stream, but by intersection control measures. Therefore, improving traffic flow will have a larger impact during periods with high initial congestion levels.

When considering the case where latent demand was present, delays were found to be larger during both the AM and PM modelling periods after removing heavy vehicles from the network. The change in delay from the base cases were, however, much smaller than the changes that occurred when latent demand was not present. On average, the increase in delay was only approximately 1% during the AM period and 3% during the PM period. As mentioned before, congestion levels during the PM period was much lower than during the AM period. Therefore, it makes sense that an increase in delay would be more significant during the PM period.

Overall, it was found that the heavy vehicle bans would be significantly beneficial to individual passenger car drivers in terms of delay provided there was no latent demand present on the network. For an individual passenger car, the average delay savings were 8.82% during the AM period and 2.11% during the PM period. However, if there was latent demand, the delay to individual road users would increase.

Table 9.6. Average delay per vehicle in the network for all time periods.

Period ending	AM_Base	AM_No trucks_With latent demand	AM_No trucks_Without latent demand	Period ending	PM_Base	PM_No trucks_With latent demand	PM_No trucks_Without latent demand
	Average delay per vehicle (s)	Difference from base	Difference from base		Average delay per vehicle (s)	Difference from base	Difference from base
06:15	77.28	-0.08%	+0.05%	**17:15**	102.79	+6.01%	-4.67%
06:30	79.23	+1.77%	+0.23%	**17:30**	111.94	+8.49%	-6.17%
06:45	86.97	+1.47%	-3.30%	**17:45**	104.4	+7.45%	-1.92%
07:00	97.72	+1.47%	-2.56%	**18:00**	96.14	+0.73%	-3.65%
07:15	126.76	+1.36%	-6.80%	**18:15**	76.58	+1.84%	-3.11%
07:30	157.22	+2.96%	-10.01%	**18:30**	70.49	+2.81%	-1.89%
07:45	184.44	+1.91%	-13.56%	**18:45**	70.04	+2.97%	-1.03%
08:00	165.48	+2.40%	-13.75%	**19:00**	69.19	+0.90%	-0.97%
08:15	138.08	-2.01%	-18.82%	**19:15**	64.83	+1.06%	-1.14%
08:30	112.47	-0.19%	-18.40%	**19:30**	63.52	+1.64%	+0.58%
08:45	83.7	-2.34%	-11.28%	**19:45**	63.37	-0.68%	-0.58%
09:00	76.02	+2.53%	-4.30%	**20:00**	61.91	-1.15%	-0.76%
Average	**115.45**	**+0.94%**	**-8.54%**	**Average**	**79.6**	**+2.67%**	**-2.11%**

9.8.2. Intersection results

Four different intersections were analysed individually to investigate the effects that the proposed heavy vehicle bans would have on the operations of intersections in the study area. **Figure 9.9** shows the location of the four intersections. The specific intersections were selected because it was believed that the bans would have the largest impact at these locations. All intersections selected for investigation were signal-operated.

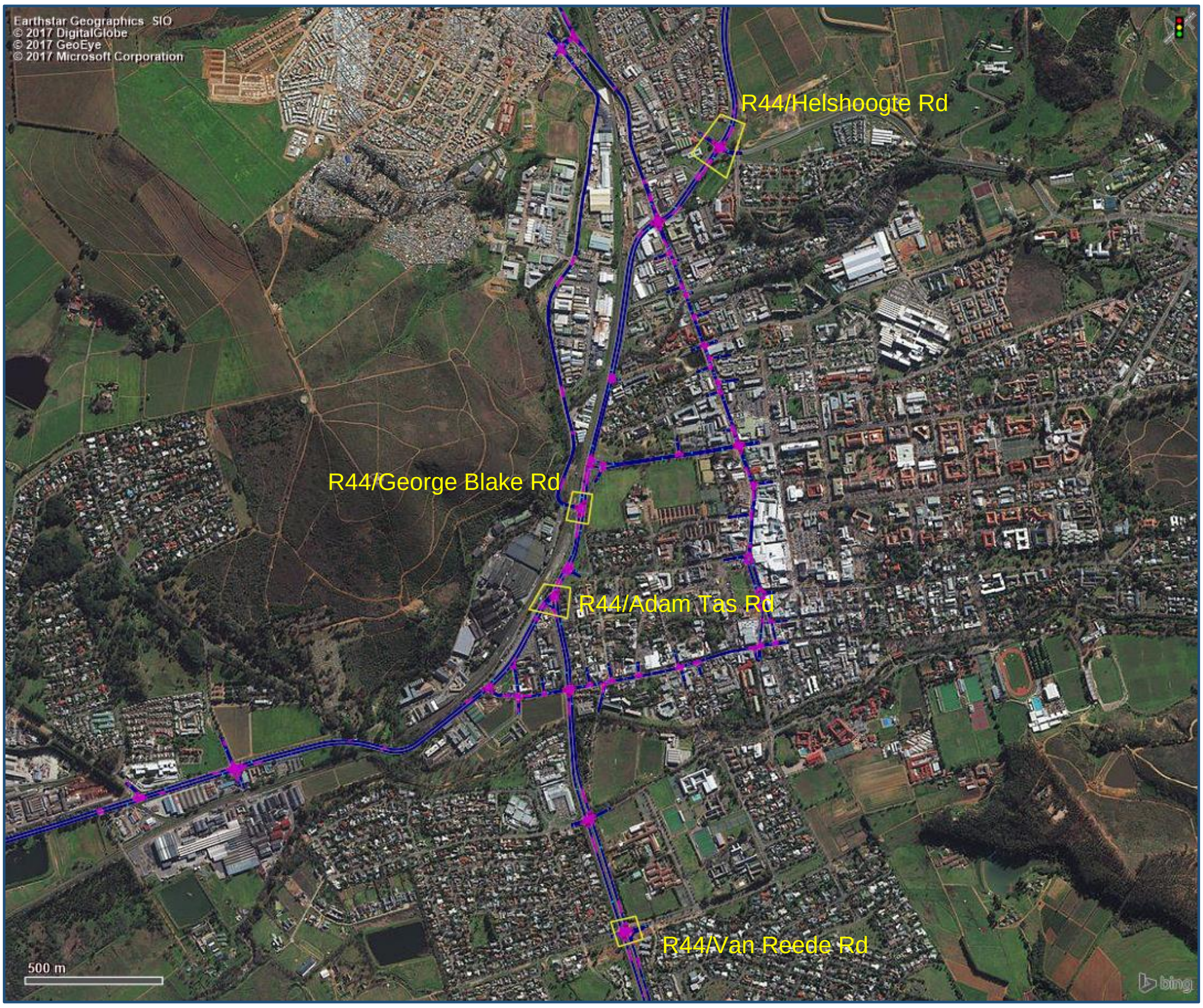


Figure 9.9. *Intersection nodes included in the model evaluation.*

Level of Service (LOS)

The LOS of each intersection was evaluated during the AM and PM peak hours for each of the six scenarios. It is important to note that, when referring to the peak hours, it means the hour during each *modelling period* that was identified to have the highest congestion levels and not necessarily the actual peak hour of traffic in the study area. This resulted in the evaluated PM peak hour (which is 5 p.m. to 6 p.m.), not corresponding with the actual peak hour identified for Stellenbosch (which is 4 p.m. to 5 p.m.). However, the evaluated AM peak hour did correspond to the actual AM peak hour of Stellenbosch.

It was found that the banning of heavy vehicles in the study area did not have significant effects on the LOS of the four evaluated intersections. During the AM modelling period, the peak hour

LOS of all intersections were the same for all scenarios. For the PM period, however, the LOS of the R44/George Blake Rd intersection improved from LOS C to LOS B when heavy vehicles were banned and no latent demand was assumed to be present. The results of the LOS evaluation for the AM and PM peak hours can be observed in **Figure 9.10** and **Figure 9.11**, respectively.

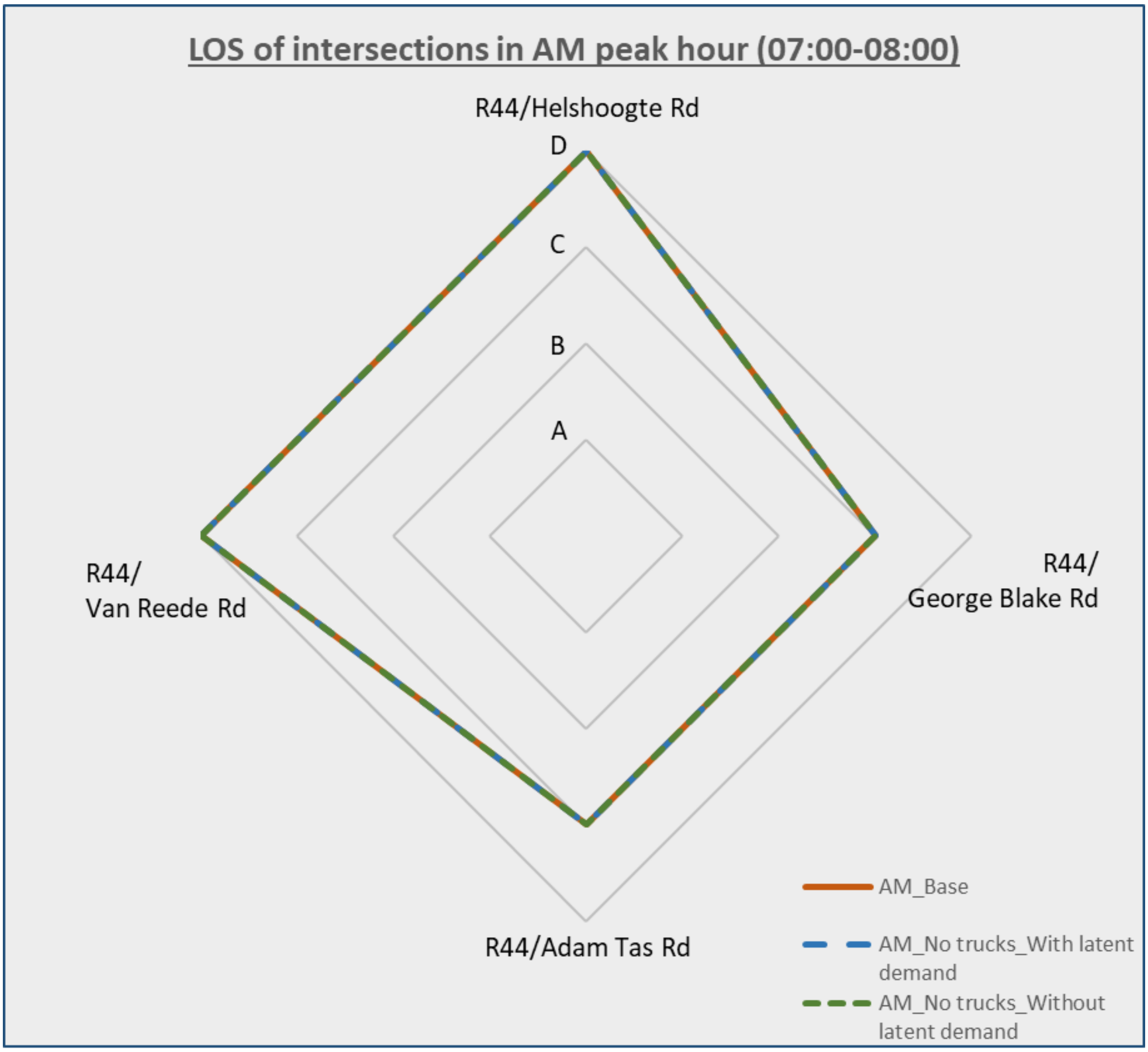


Figure 9.10. *LOS of intersections in AM peak hour.*

<u>Stopped Delay</u>

The average stopped delay at each intersection was compared between different scenarios in order to establish whether the removal of heavy vehicles from the road network would lead to passenger car drivers having to spend less time stopped at intersections. As with the analysis of LOS, results were compared for the peak hours of the modelling periods.

The average stopped delay per vehicle at each intersection can be observed in **Figure 9.12** and **Figure 9.13** in each scenario. During the PM peak hour, the absence of heavy vehicles (with and without latent demand) did not have any effect on the average stopped delay at any intersection.

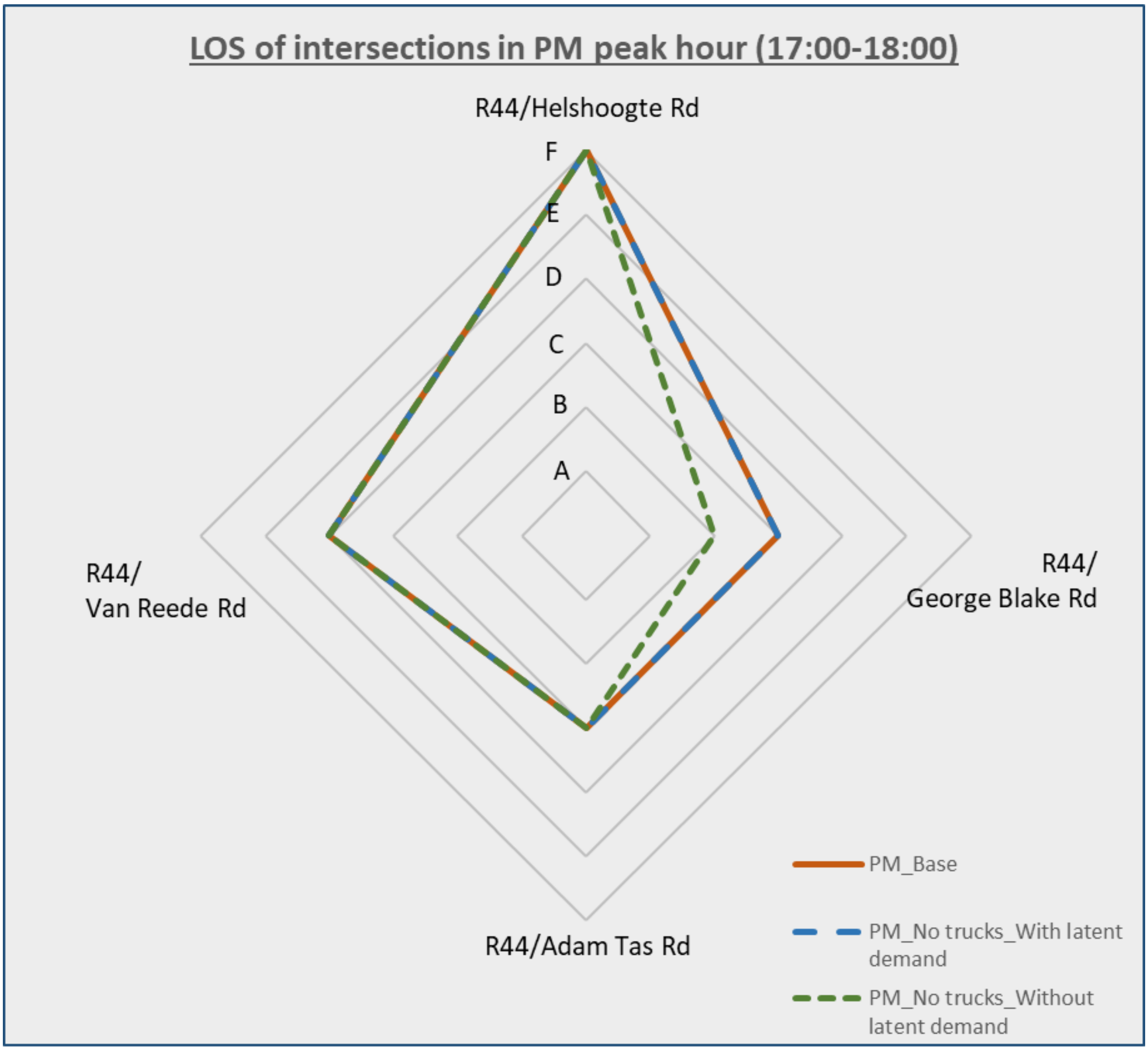


Figure 9.11. *LOS of intersections in PM peak hour.*

The banning of heavy vehicles had a significant impact during the AM peak period at three of the four intersections. This is most likely due to the fact that the road network was much more congested during the AM peak hour than during the PM peak hour and changes to the traffic stream would have a higher probability of yielding differences in traffic conditions. At all intersections, average stopped delay was lower when heavy vehicles were removed, regardless of whether latent demand was present or not. This means that even when more vehicles were present on the road network (when latent demand was assumed to be present), there was still less stopped delay at these intersections.

The decrease in stopped delay, even though more vehicles are present, can be attributed to the composition of the traffic stream. Passenger cars have much better acceleration capabilities than heavy vehicles and are, therefore, able to travel through an intersection quicker. This means that when there are only passenger cars on the network, more vehicles would be able to clear an intersection during green times, leading to shorter queues and shorter stopped delays.

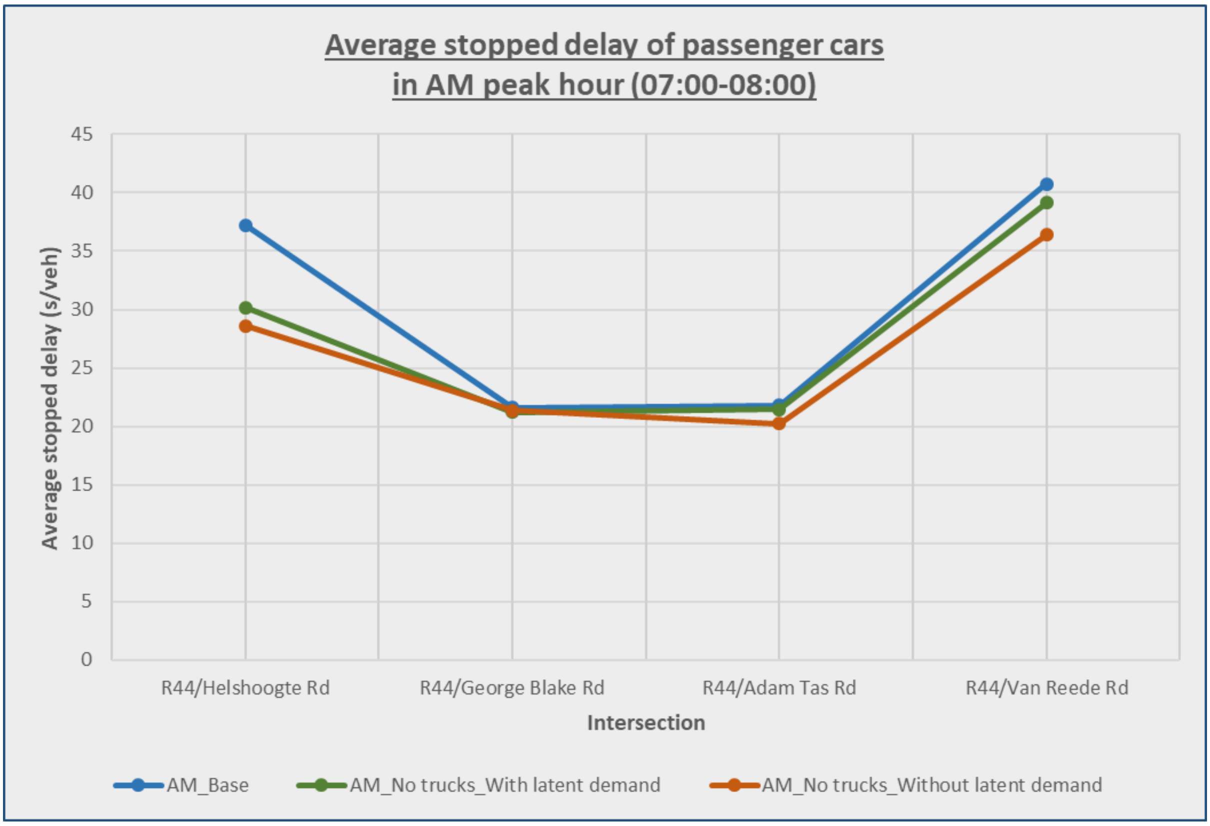


Figure 9.12. *Average stopped delay of passenger cars in AM peak hour.*

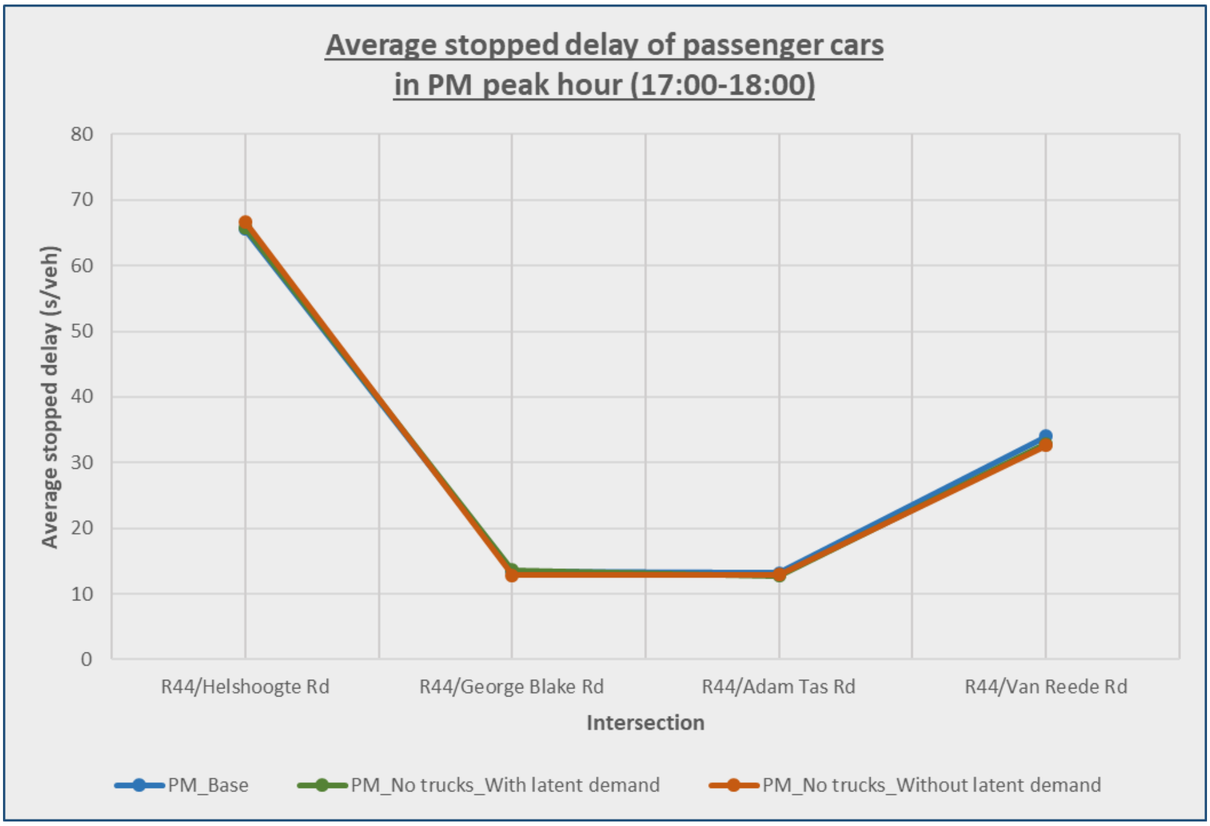


Figure 9.13. *Average stopped delay of passenger cars in PM peak hour.*

It is interesting to note that the results of the intersection analyses seem to contradict the findings of the network-level results. When considering the entire network, results consistently indicate that the removal of heavy vehicles would improve traffic conditions only if there were no latent demand present. Contrary to this, the results of the intersection analyses indicate that conditions at the investigated intersections would either remain the same or improve if heavy vehicles were banned, irrespective of whether latent demand is present or not.

The main reason for this contradiction is the fact that heavy vehicles do not have the acceleration capabilities and manoeuvrability that passenger cars have. Over the entire network, the effect of the inferior acceleration capabilities of heavy vehicles are negligible, but when only considering an individual intersection (where acceleration capabilities play a big role), the effect can be large. Therefore, when considering an entire network, one heavy vehicle can be assumed to have almost the same impact as a passenger car. Therefore, when there is latent demand and more passenger cars travel on the network, aggregated traffic conditions over the entire network will be worse. However, the impact of a heavy vehicle on the intersection level is much larger than a passenger car. Even if two passenger cars replace each heavy vehicle, traffic conditions at an intersection could still be better than before.

Maximum queue lengths

At each investigated intersection, the maximum queue length in each scenario was measured. **Figure 9.14** to **Figure 9.17** show the actual maximum queues that formed in each scenario as well as the leg on which the queue was present.

It was found that during the AM period, maximum queue lengths at all intersections decreased when heavy vehicles were removed from the traffic stream for both cases when latent demand was present and when it was not. However, queues were longer when latent demand was present compared to when not at three of the intersections. This makes sense when considering that more vehicles would be present on the road network when latent demand was present.

Maximum queue lengths were shorter overall during the PM period than during the AM period. Contrary to what was found during the AM period, the maximum queues at three of the four intersections increased when heavy vehicles were removed with latent demand present. When latent demand was not present, however, queues were shorter. The fact that queues became longer when latent demand was present could be an indication that heavy vehicles have a smaller impact than passenger cars on intersection operations when congestion levels are lower and queues are shorter.

Figure 9.14. *Maximum modelled queue lengths at the intersection of R44 and Helshoogte Rd (Google Earth Pro, 2018).*

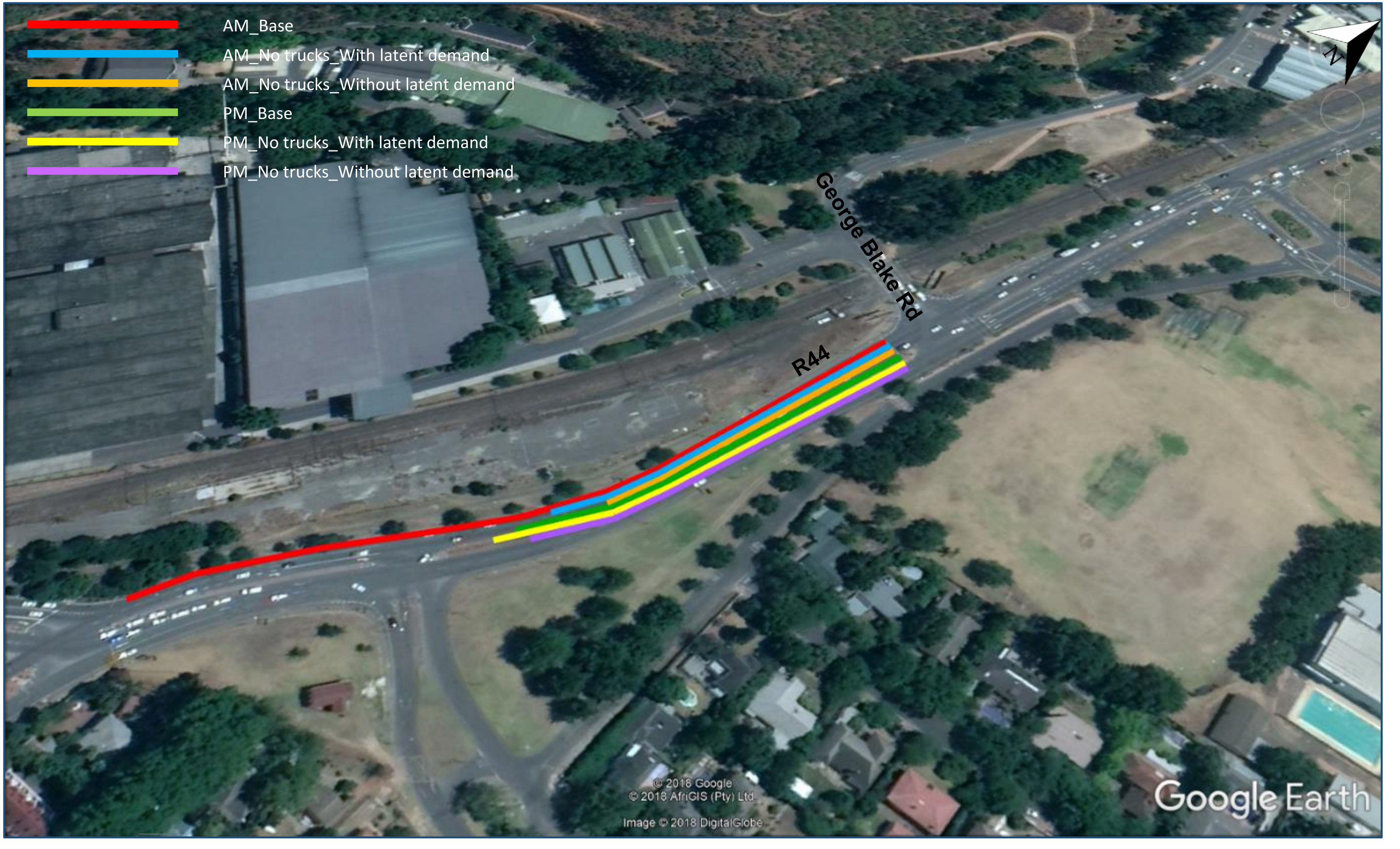


Figure 9.15. *Maximum modelled queue lengths at the intersection of R44 and George Blake Rd (Google Earth Pro, 2018).*

Figure 9.16. *Maximum modelled queue lengths at the intersection of R44 and Adam Tas Rd (Google Earth Pro, 2018).*

Figure 9.17. *Maximum modelled queue lengths at the intersection of R44 and Van Reede Rd (Google Earth Pro, 2018).*

9.9. Model validation

9.9.1. Travel times

In order to ensure that a microscopic traffic model is accurate, the base scenarios must be validated against real-life data. In the case of this study, the average travel times on four major paths into/out of the centre of Stellenbosch were compared to measured travel times on these routes as provided by TomTom. **Figure 9.18** indicates the four paths for which travel times were compared. The specific routes were selected because it was believed that most vehicles crossing Point A would use the indicated route to reach Point B. In the centre of town, it was more likely that vehicles could pass the starting point of a route and use a different route to reach the end point. These vehicles would also be included in the final results, even though they did not use the investigated route. Therefore, routes passing through the centre of Stellenbosch were avoided.

Floating Car Data (FCD) was obtained from the TomTom Stats portal for all weekdays between 1 August 2018 and 31 October 2018 for all vehicle types. It is important to note that public holidays and school holidays during this period were excluded from the dataset. From this data, the actual average travel time per vehicle during each hour of the modelling periods was extracted. These travel times were only calculated for vehicles that traversed the entire route under consideration.

It is important to note the direction of travel that was taken into account during the validation process. It is better to compare travel times on routes that experience congestion, since this would more accurately measure whether the vehicle load on a network is accurate than when considering a route with free-flow conditions. Therefore, the direction of travel considered during the morning banning period was inbound and during the afternoon period, outbound traffic was considered.

The Main Roads Operational Modelling Guidelines (Main Roads Western Australia, 2018), recommend that Vissim modelled travel times should be within 15% of the actual travel times on a route. As such, the average modelled travel times (in the base scenarios) on the four routes during each hour of analysis were compared to the travel times obtained from TomTom. The results of these analyses can be found in **Figure 9.19** and Figure 9.20 for the AM period and PM period respectively. It can be observed from the figures that only three out of the twenty-four modelled average travel times were found to fall outside of the recommended range. Therefore, the modelled travel times were deemed sufficiently accurate.

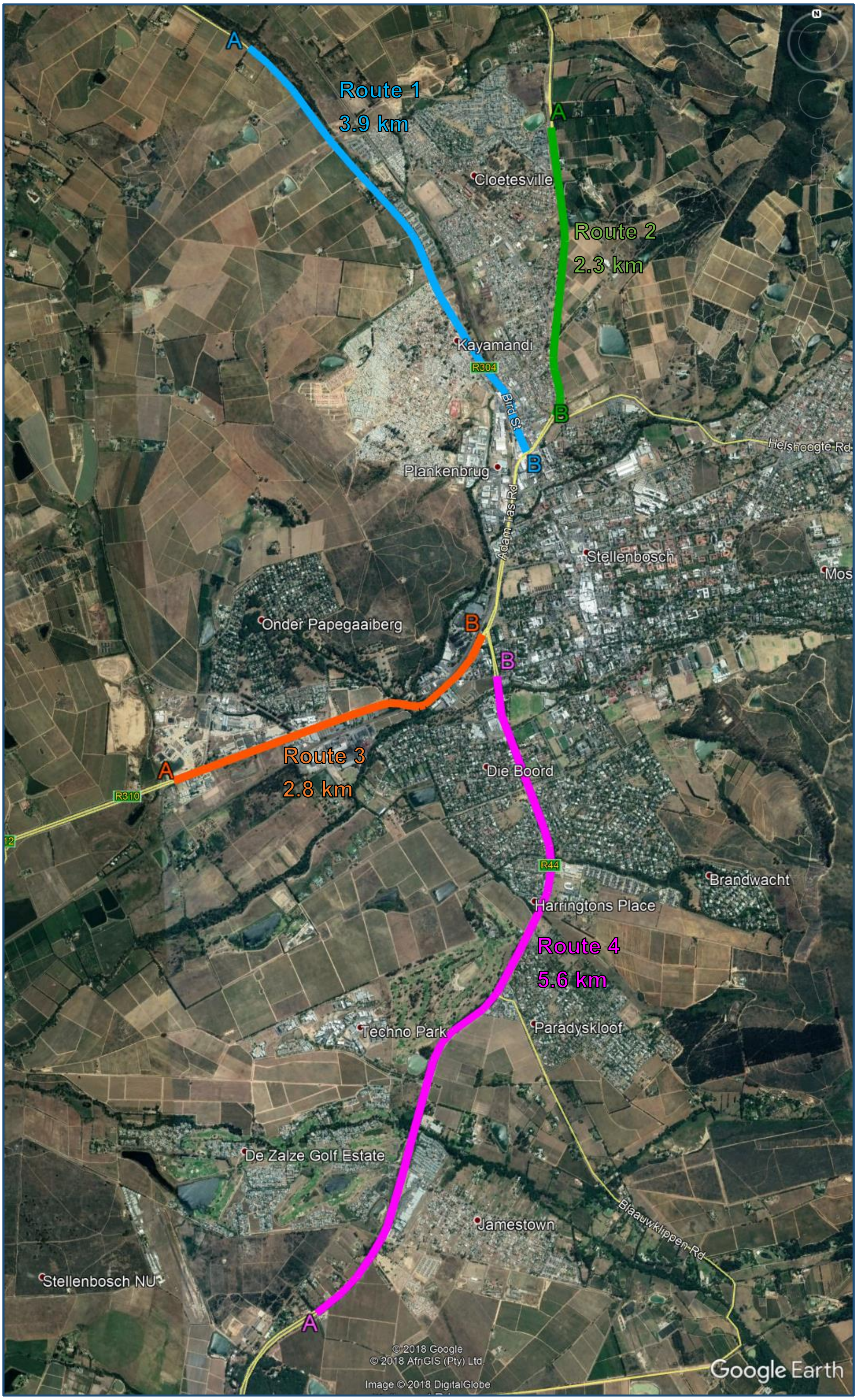


Figure 9.18. *Routes defined for validation of model results (Google Earth Pro, 2018).*

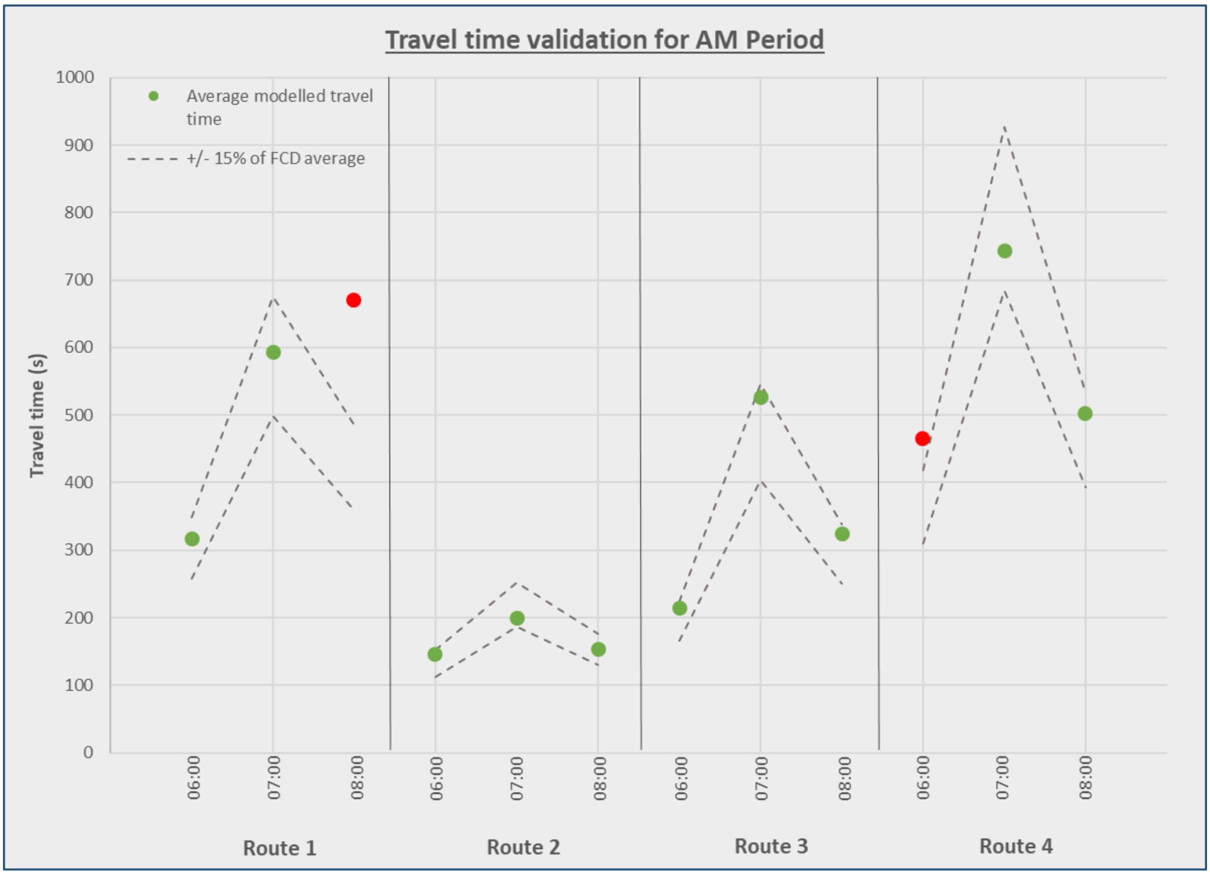


Figure 9.19. *Validation of travel times for AM period (inbound direction).*

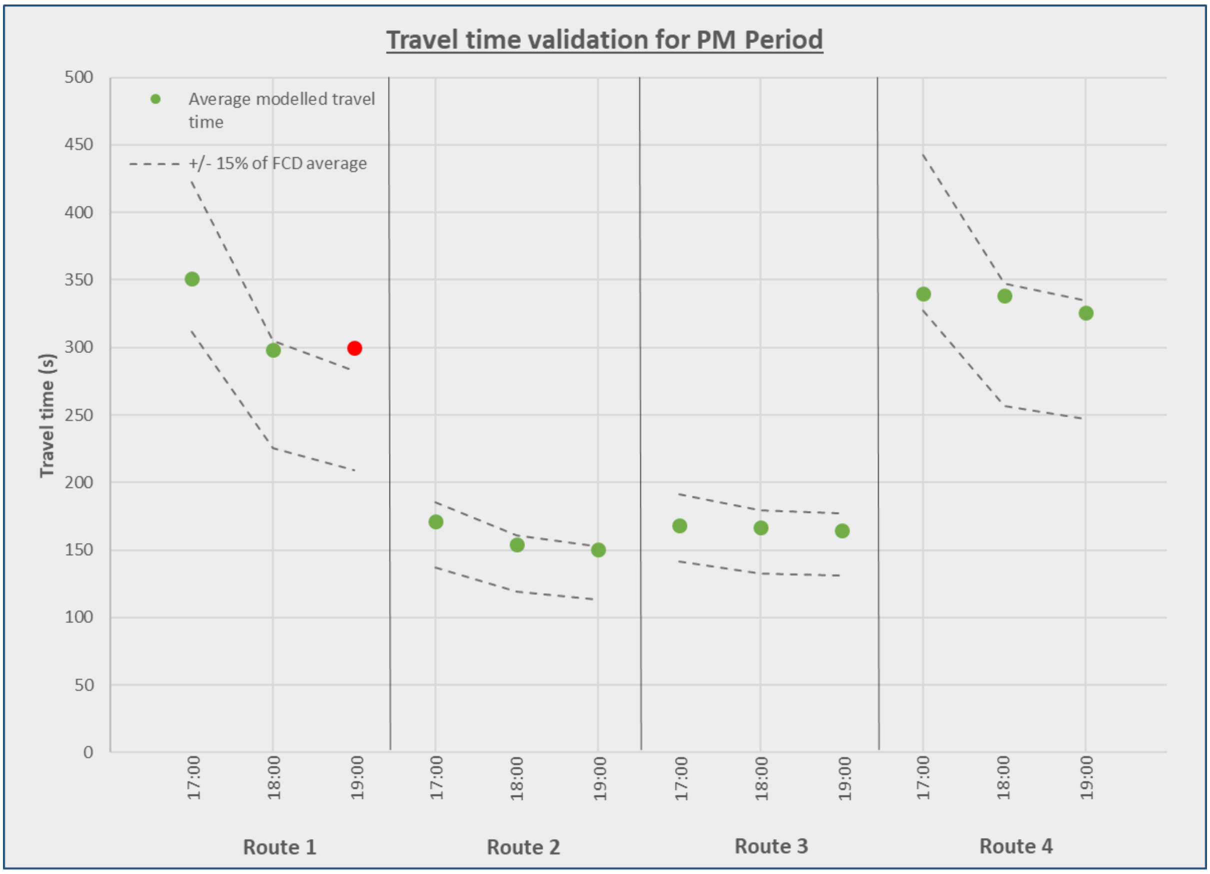


Figure 9.20. *Validation of travel times for PM period (outbound direction).*

9.9.2. Speeds

In addition to using average travel times to validate the output of a microscopic traffic model, travel speeds can also provide clarity on the accuracy of a model. In the case of this study, speed heat maps were created to compare the speeds of vehicles travelling along the four investigated routes. These heat maps show the relative average speed of all vehicles travelling along a path, with the fastest speed on a route being bright green and the slowest speed bright red. All speeds in between these two boundaries are assigned a colour on a spectrum between green and red, depending on the speed's relativity to the upper and lower boundaries. By creating these heat maps, it is possible to establish whether modelled vehicles slow down at the same places where the actual traffic stream travels slower and vice versa.

Heat maps were created for all four routes defined in **Figure 9.18**. A separate heat map was created for each base period for both the FCD and the model results. The same FCD set that was used for the travel time validation process was used to create the FCD heat maps. As with the evaluation of travel times, the direction under consideration during the AM period was inbound traffic and during the PM period, outbound traffic was considered. It is important to note that there were no heat maps created for Route 4 during the PM period because the FCD data had an insufficient probe sampling rate to create accurate speed profiles.

Figure 9.21 and **Figure 9.22** show the heat maps created for each route during each period. Important intersections are indicated with dashed lines. It can be observed that the heat maps of most periods look very similar for FCD and the Vissim outputs. Overall, the modelled vehicle movement along the four routes seem to mirror reality to a sufficient degree.

It will, however, be noted that slow speeds are present for longer distances behind some intersections when considering the heat maps of the modelled results, especially at the Oude Libertas St intersection on Route 3 and the Webersvallei Rd intersection on Route 4 during the AM period. This can be attributed to the fact that signal plans were approximated as fixed-time plans when, in reality, they were vehicle actuated. It is believed that some intersections in the modelled network possibly do not operate at capacity during the morning peak period to such an extent where they can accurately be approximated as fixed-time operating signals. Therefore, longer queues would form at these intersections than in reality, leading to the longer red sections observed in the Vissim heat maps. Additionally, some variability in speeds along a route is expected, since many assumptions were made during the construction of the model that could have differed from reality.

Figure 9.21. *Speed heat maps for AM period (inbound direction).*

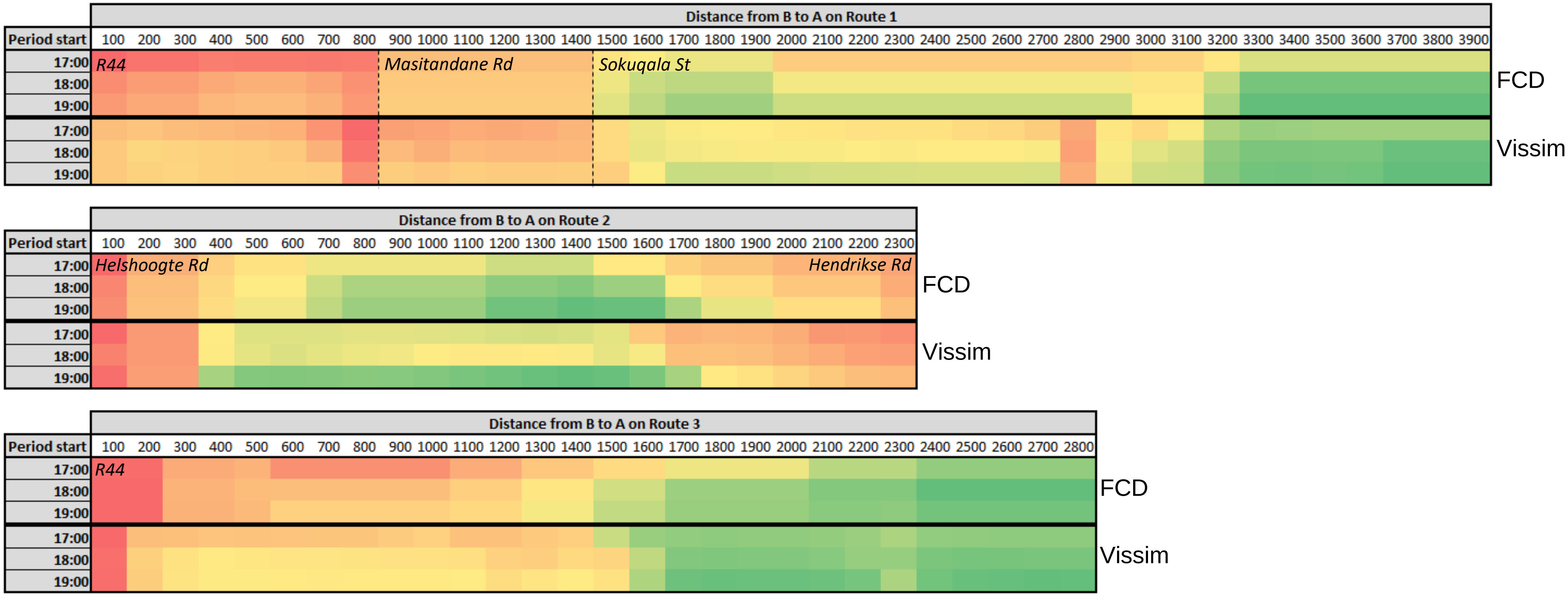


Figure 9.22. *Speed heat maps for PM period (outbound direction).*

9.10. Conclusion

This chapter discussed the construction of a microscopic traffic model in PTV Vissim, used to investigate the effects of proposed heavy vehicle bans on the traffic network of Stellenbosch. This included the steps required to construct the network, simulate realistic traffic operations and input realistic traffic streams. Additionally, the results and validation of the model were analysed and discussed.

Two modelling periods were investigated, each divided into twelve 15-minute time periods for analysis and input purposes. This included an AM period (6 a.m. to 9.a.m.) and a PM period (5 p.m. to 8 p.m.) that corresponded to the proposed heavy vehicle banning periods investigated in this study. During each modelling period, three scenarios were modelled and analysed: a base scenario, a scenario where heavy vehicles were banned with latent demand present, and a scenario where heavy vehicles were banned without latent demand present. The network was investigated with and without latent demand because it could not be definitively determined whether latent demand is present for the entire investigated road network. In addition, it was deemed valuable to obtain results for both cases.

Results were obtained on two levels, namely network-wide and on an intersection level, for all passenger cars in the network. The network-level results indicated that average travel speeds, total travel times and individual vehicle delays all improved when heavy vehicles were removed from the network with no latent demand present. Conversely, when latent demand was present, traffic conditions were worse. It must be noted that traffic conditions in both cases did not improve or worsen by a very significant margin.

On an individual intersection level, results yielded somewhat different conclusions. Four intersections were investigated and it was found that the LOS of these intersections all stayed the same in all scenarios. The only exception was when heavy vehicles were banned during the PM period and no latent demand was present. In this case, the LOS of one intersection improved from LOS B to LOS C. Other intersection-level results generally indicated that traffic conditions at intersections would stay the same or improve slightly if heavy vehicles were removed from the network, regardless of whether latent demand were present or not.

The base scenarios of the model were validated against FCD from TomTom. It was found that average travel times and speed profiles for four major routes of the model were realistic. The model was deemed sufficiently accurate during the validation process.

CHAPTER 10: ECONOMIC EVALUATION

10.1. Background

When considering the impact of a new traffic policy or regulation, it is not enough to consider only the changes that will be experienced in terms of traffic and congestion. For example, finding that the travel time of a road user will change does not mean much if it cannot be evaluated in comparison to all the other costs and benefits that will be incurred.

In order to better understand and quantify the total effects that the investigated heavy vehicle restrictions will have in the study area, a cost-benefit analysis (CBA) was performed for each of the banning periods investigated. This chapter includes a discussion of the methodology followed and the results obtained.

10.2. Required data

The following data had to be extracted from the microscopic traffic model in order to perform the CBAs:

- Total travel time of all passenger cars;
- Total number of passenger cars in the network and
- Average speed of passenger cars in the network.

10.3. Assumptions and limitations

The CBAs performed in this study are only basic economic evaluations and not in-depth, detailed analyses of all aspects involved. As such, several factors are simplified and ignored as discussed in the relevant sections.

For the purposes of this study, it was assumed that all vehicles had an occupancy rate of 1. In addition, for simplification purposes, it was assumed that all drivers were commuting and not traveling for leisure. These assumptions were not deemed problematic, as the objectives of the CBAs are comparative in nature and the assumptions would apply to all base cases and project alternatives.

Because it is not known what the split is between vehicles that operate with petrol and vehicles that operate with diesel, it was assumed that all vehicles in the study operated with petrol. The cost difference between these two fuel types are negligent and, therefore, this assumption would not have a significant impact on the results.

All evaluations are performed for passenger cars only. This is because no heavy goods vehicles (HGVs) are present in an of the project alternatives and, therefore, there is nothing to measure for these vehicles. In any case, the detailed financial impacts that the researched policies will have on the freight industry was not investigated. This is a complex field that requires much research and did not form part of this study. Additionally, the analyses were performed for the entire network of passenger cars and not on an agent-based level. For the comparative objectives of this study, it was not deemed necessary to do such a detailed and labour-intensive analysis.

Because the future growth and development of the travel patterns of passenger cars and freight movements in the study area could not be accurately determined, only the base year of analysis (2018) was analysed. It was determined that the uncertainty and shear number of assumptions that would have to be made to analyse future dates would lead to results that could not be trusted. This would render any findings for future dates irrelevant and meaningless. This was, however, not seen as an issue because a policy implementation does not usually have initial capital expenditures that are large enough to require a very long period of analysis. Additionally, the CBAs performed in this study ignored the initial capital expenditure that would be required to implement the policy.

10.4. Base case and project alternatives

Essentially, two separate CBAs were performed during this study: one for the morning banning period and one for the afternoon banning period. Each of these CBAs had one base case and two project alternatives. It must be noted that each project alternative included the implementation of the same policy, but assumed a different change to the travel patterns of the study area. Table 10.1 contains a brief definition of each base case and project alternative.

Table 10.1. Summary of base cases and project alternatives.

CBA 1 (AM period)	
AM_Base	Existing traffic operations in Stellenbosch between 6 a.m. and 9 a.m. on an average weekday.
AM_No trucks_ With latent demand	No HGVs present on the network. The volume freed up by removing HGVs is replaced by passenger cars by assuming an average passenger car equivalent (PCE) of $E_T = 2.0$.
AM_No trucks_ Without latent demand	No HGVs present on the network. No latent demand is assumed.
CBA 2 (PM period)	
PM_Base	Existing traffic operations in Stellenbosch between 5 p.m. and 8 p.m. on an average weekday.
PM_No trucks_ With latent demand	No HGVs present on the network. The volume freed up by removing HGVs is replaced by passenger cars by assuming an average passenger car equivalent (PCE) of $E_T = 2.0$.
PM_No trucks_ Without latent demand	No HGVs present on the network. No latent demand is assumed.

10.5. Parameters

This section provides a short overview of each parameter that was included in the CBA.

10.5.1. Value of Time (VOT)

The time that road users spend on the road is usually time when productivity, that could have been used elsewhere, is lost. Travel time is a very important aspect to consider. In the 2013 National Household Travel Survey, the biggest determinant for the choice of travel mode was determined as travel time (Statistics South Africa, 2014).

The value of travel time depends on the opportunity cost of the value of income that could have been generated in that time. Therefore, there is a direct link between the salaries of drivers and the VOT. Even if travel is for leisure and not for commuting, VOT will most likely still be linked to salaries because the alternative to leisure time is usually work.

AASHTO recommends using 50% of the salary of a driver that is commuting alone to determine his VOT (AASHTO, 2010). It was believed that the traffic stream considered in this study consisted of mostly commuters, because the studied periods were believed to be the times that most people in Stellenbosch would be travelling to and from work. For the sake of simplicity and the fact that the economic evaluations were performed for comparative reasons, it was assumed that all drivers in the network could be approximated as single commuters.

Other factors such as household income, personal willingness to pay for uncongested conditions and whether a person is a driver or passenger have also been found to affect the VOT but these factors are not considered in this study.

The average monthly salary of employees in the formal non-agriculture section of South Africa was estimated as R19 858 in February 2018 (Statistics South Africa, 2018). This includes bonuses and overtime payments. By assuming a number of 160 working hours for this month, this translates to an average hourly wage of R124.11/h. Therefore, as recommended by AASHTO to use half the salary, the VOT assumed for all drivers in this study was defined as **R62.06/h/veh**.

10.5.2. Vehicle Operating Costs (VOC)

Vehicle operating costs are carried directly by the road user and can be significantly influenced by projects that result in a change in travel speeds, delays and road geometry. Several models have been developed that attempt to estimate the value of VOC for the use in a CBA. In this study, a model developed by the Division of Transport Economics in the Department of Logistics at Stellenbosch University was used. The model was developed to estimate the VOC per vehicle km from the average travel speed of a vehicle. What follows is a brief explanation of the theory behind the model. It must be noted that only the part of the model that is applicable to passenger cars is discussed.

Fuel consumption costs

The average fuel consumption of a passenger car is calculated with either **Equation 10.1a** or **Equation 10.1b**, depending on the average speed of the vehicle.

$$F = 31 + 3\,600\left(\frac{0.687}{V}\right) \quad if \quad [V \leq 63 \text{ km/h}] \qquad \text{(Equation 10.1a)}$$

$$F = 118 - 1.6897V + 0.01479V^2 \quad if \quad [V > 63 \text{ km/h}] \qquad \text{(Equation 10.1b)}$$

With:
F = fuel consumption in ml/km and
V = average travel speed in km/h.

From the fuel consumption, the total fuel consumption cost is calculated:

$$VOC_F = F \times \frac{RC_F}{1\,000} \qquad \text{(Equation 10.2)}$$

With:
VOC_F = fuel consumption cost in R/veh.km;
F = fuel consumption in ml/km and
RC_F = resource cost of fuel in R/l.

Oil consumption costs

The average oil consumption of a vehicle is calculated depending on the value of the average travel speed:

$$O = 0.591759 + \frac{5.761595}{V} \quad if \quad [V \leq 60 \text{ km/h}] \qquad \text{(Equation 10.3a)}$$

$$O = 0.70585714 - 0.00225659V + 0.00002846V^2 \quad if \quad [V > 60 \text{ km/h}] \qquad \text{(Equation 10.3b)}$$

With:
O = oil consumption in ml/km and
V = average travel speed in km/h.

From the oil consumption, the total oil consumption cost is calculated:

$$VOC_O = O \times \frac{RC_O}{1\,000} \qquad \text{(Equation 10.4)}$$

With:
VOC_O = oil consumption cost in R/veh.km;
O = oil consumption in ml/km and
RC_O = resource cost of oil in R/l.

Tyre wear costs

With distance, the tyres of a vehicle wears out until they eventually need to be replaced. The following equation is used to determine the percentage of tyre wear per km travelled:

$$T = \frac{1.6739 + 0.057445V - 0.000933V^2 + 0.000003846V^3}{100} \quad \text{(Equation 10.5)}$$

With:
T = tyre wear in % per km and
V = average travel speed in km/h.

The average price of a set of tyres for passengers is then used to calculate the total tyre wear costs:

$$VOC_T = T \times \frac{RC_T}{1\,000} \quad \text{(Equation 10.6)}$$

With:
VOC_T = tyre wear cost in R/veh.km;
T = tyre wear in % per km and
RC_T = resource cost of a set of tyres in R.

Vehicle depreciation costs

As a vehicle travels, its value decreases. The vehicle depreciation rate of a passenger car can be estimated by using **Equation 10.7**.

$$D = \frac{-0.4570725 + \left({}^{4.862234}\!/\!{}_{\ln(V)}\right)}{100} \quad \text{(Equation 10.7)}$$

With:
D = vehicle depreciation in % per km and
V = average travel speed in km/h.

From the rate of depreciation, the vehicle depreciation cost is calculated from the following equation:

$$VOC_D = D \times \frac{RC_{PC}}{1\,000} \quad \text{(Equation 10.8)}$$

With:
VOC_D = vehicle depreciation cost in R/veh.km;
D = vehicle depreciation in % per km and
RC_{PC} = resource cost of an average passenger car in R.

Vehicle maintenance costs

It has been found that the maintenance costs of a vehicle can be expressed as a percentage of the value of the vehicle per km travelled. The equations below can be used to estimate the percentage of the vehicle value that represents the maintenance costs:

$$M = 0.21992218 + \frac{7.119918}{V} \qquad if \qquad [V \leq 55\ \mathrm{km/h}] \qquad \text{(Equation 10.9a)}$$

$$M = 0.45465856 - 0.00351217V + 0.000027149V^2 \ \ if\ [V > 55\ \mathrm{km/h}] \qquad \text{(Equation 10.9b)}$$

With:
M = vehicle maintenance value in % per km and
V = average travel speed in km/h.

From this, the vehicle maintenance cost per km is calculated:

$$VOC_M = M \times \frac{RC_{PC}}{1\,000} \qquad \text{(Equation 10.10)}$$

With:
VOC_M = vehicle maintenance cost in R/veh.km;
M = vehicle maintenance value in % per km and
RC_{PC} = resource cost of an average passenger car in R.

Total VOC

The total VOC is calculated by adding all the costs discussed in this section:

$$VOC = VOC_F + VOC_O + VOC_T + VOC_D + VOC_M \qquad \text{(Equation 10.11)}$$

With:
VOC = total VOC in R/veh.km and
VOC_x = VOC component as defined previously.

10.5.3. Road maintenance costs

Road maintenance costs can form a large part of a CBA. When more vehicles are expected to travel on a road network after a project has been implemented, especially if these vehicles are heavy vehicles, the road surface can degrade at a faster rate and require more frequent maintenance. The opposite is also true.

In the case of this study, the absolute number of passenger cars and heavy vehicles are not expected to change significantly when considering an entire day. It is believed that the heavy vehicles that are banned from using the roads during the investigated periods would simply travel during other times of the day. For this reason, it was not believed that road maintenance costs would differ between different alternatives and this cost was thus ignored.

10.5.4. Accident costs

No accident data was acquired for the study area and the accident rate for the area was not known. In addition, it was not believed that the investigated policy would have a significant effect on the number or severity of accidents that occur because it was not believed that the absolute number of passenger cars and HGVs would change during an entire day. As previously mentioned, it was assumed that vehicles would merely travel at different times. Therefore, it was not believed that the overall costs of accidents would change and the accident costs were ignored in this study.

10.5.5. Emission costs

In the case of this study, only CO_2 emissions were considered, since this is the main pollutant generated by vehicles. For the calculation of emission costs, the total CO_2 is calculated from the fuel consumption of the entire network. **Equation 10.1a** or **Equation 10.1b** is used to determine the total fuel consumption of the network during the calculation of VOC.

From the molecular content of petrol, it has been estimated that the combustion of 1 litre of petrol produces approximately 2.3 kg of CO_2 (Natural Resources Canada, 2014). A global term that is often used is the Social Cost of Carbon (SCC). This term is used for the cost of carbon emissions on a global scale so that the cost is not limited to a specific location (Van den Bergh and Botzen, 2015). This is important to mention, since the effects of carbon emissions are not contained to a region, but are felt worldwide. Even so, studies have estimated that carbon-based emissions will not affect all countries equally. **Figure 10.1** shows the estimated SCC of different countries in 2018.

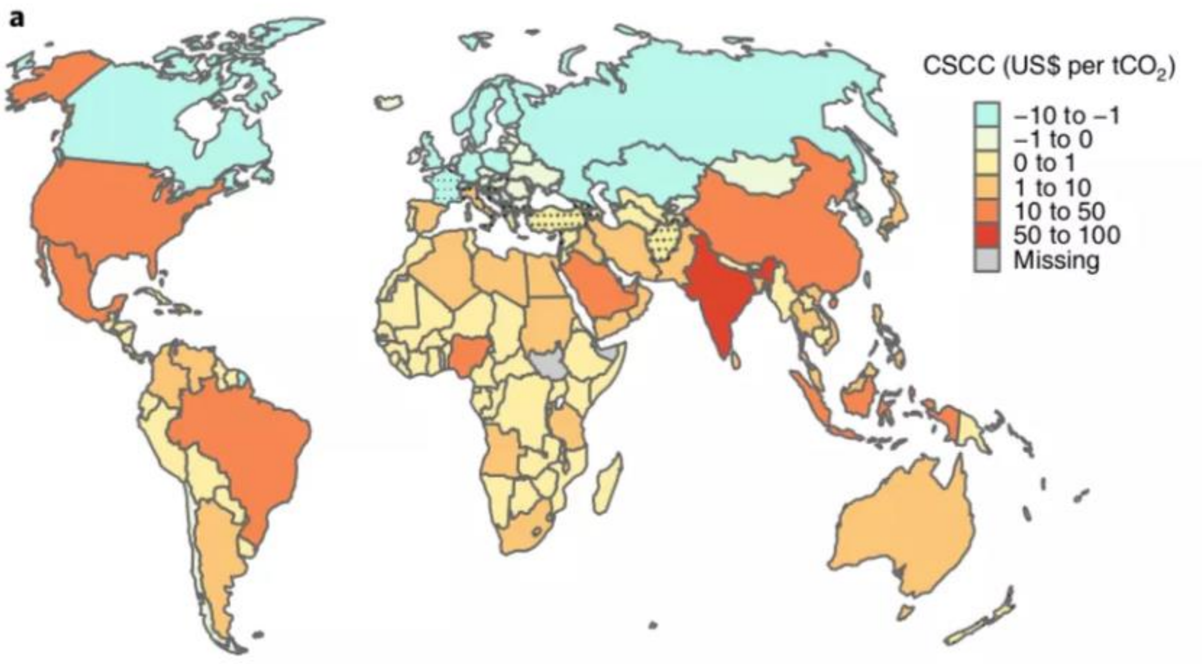


Figure 10.1. *SCCs for different countries in 2018 (Ricke et al., 2018).*

From this research, the worst-case SCC for South Africa was accepted for this study ($10 per ton CO_2). At the time of this study, this translated to approximately **R145 per ton CO_2.**

From the total fuel consumption, the amount of CO_2 produced and the cost of CO_2, the total emission costs for the network could be determined.

10.5.6. Other costs

Except for the costs discussed earlier in this section, some other costs are involved when considering the project alternatives. These costs were, however, not included in the CBAs that were performed. It must also be noted that no data was available to indicate how the freight industry would respond to the policies if they were implemented. It would require extensive research to determine the response of the industry and this was not included in this study. Additionally, no indication was provided on how the policies would be implemented, including whether parking structures for heavy vehicles would have to be constructed and who would be responsible to construct, operate and maintain these facilities. Below is a list of the costs that were not taken into account:

- Construction of parking structures for heavy vehicles during the banning period;
- Additional enforcement measures required to enforce the new policy;
- Marketing costs to make the public aware of the new policy;
- Costs to businesses having to be open earlier or later to receive deliveries outside of the banning periods;
- The change in liveability of the urban area and
- Additional costs to the freight industry including:
    - The purchase of small delivery vehicles to make deliveries during the banning periods;
    - The cost of overtime to be paid to drivers and
    - The cost of lost productivity.

10.6. Results

The results of the calculation of the economic evaluation parameters can be found in **Table 10.2**, **Table 10.3** and **Table 10.4** on the next page. It is important to note that results were determined for all passenger cars over the entire network for each banning period.

Similar trends were observed for the calculated VOT, VOC and emission costs for both CBA 1 and CBA 2. In all cases, costs were approximately 5% higher than the base case for the project alternatives where heavy vehicles were banned with the presence of latent demand. Conversely, costs were lower than in the base case for project alternatives where latent demand was not present. The difference between costs for the base case and this project alternative during the PM period was, however, found to be very small.

Figure 10.2 on page 181 shows the total NPV of the base case and the project alternatives for both CBA 1 and CBA 2. It can be seen that the project alternatives where latent demand was present yielded lower NPVs than the other alternatives. If latent demand is not present, however, the NPV values were higher than for the base cases.

Table 10.2. VOT evaluation results.

	CBA 1			CBA 2		
	AM_Base	AM_No trucks_ With latent demand	AM_No trucks_ Without latent demand	PM_Base	PM_No trucks_ With latent demand	PM_No trucks_ Without latent demand
VHT (hours)	3 120.79	3 292.03	2 927.61	2 184.50	2 302.68	2 163.85
VOT (R)	R193 676.23	R204 303.20	R181 687.75	R135 570.14	R142 904.49	R134 288.47
Difference from base case		**5.49%**	**-6.19%**		**5.41%**	**-0.95%**

Table 10.3. VOC evaluation results.

	CBA 1			CBA 2		
	AM_Base	AM_No trucks_ With latent demand	AM_No trucks_ Without latent demand	PM_Base	PM_No trucks_ With latent demand	PM_No trucks_ Without latent demand
Average network speed (km/h)	31.04	31.04	32.52	34.49	34.18	34.83
VOC rate (R/veh.km)	R4.77	R4.77	R4.66	R4.53	R4.55	R4.51
VKT (km)	89 131.66	94 012.97	89 296.53	73 568.50	76 359.15	73 780.07
VOC (R)	R425 542.83	R448 860.00	R416 435.64	R333 217.48	R347 416.04	R332 596.45
Difference from base case		**5.48%**	**-2.14%**		**4.26%**	**-0.19%**

Table 10.4. Emission costs evaluation results.

	CBA 1			CBA 2		
	AM_Base	AM_No trucks_ With latent demand	AM_No trucks_ Without latent demand	PM_Base	PM_No trucks_ With latent demand	PM_No trucks_ Without latent demand
Fuel consumption (ml/km)	110.67	110.67	107.05	102.71	103.36	102.02
CO_2 production (kg)	22 687.51	23 930.92	21 985.69	17 378.63	18 153.30	17 311.85
Emission Cost	R3 289.69	R3 469.98	R3 187.92	R2 519.90	R2 632.23	R2 510.22
Difference from base		**5.48%**	**-3.09%**		**4.46%**	**-0.38%**

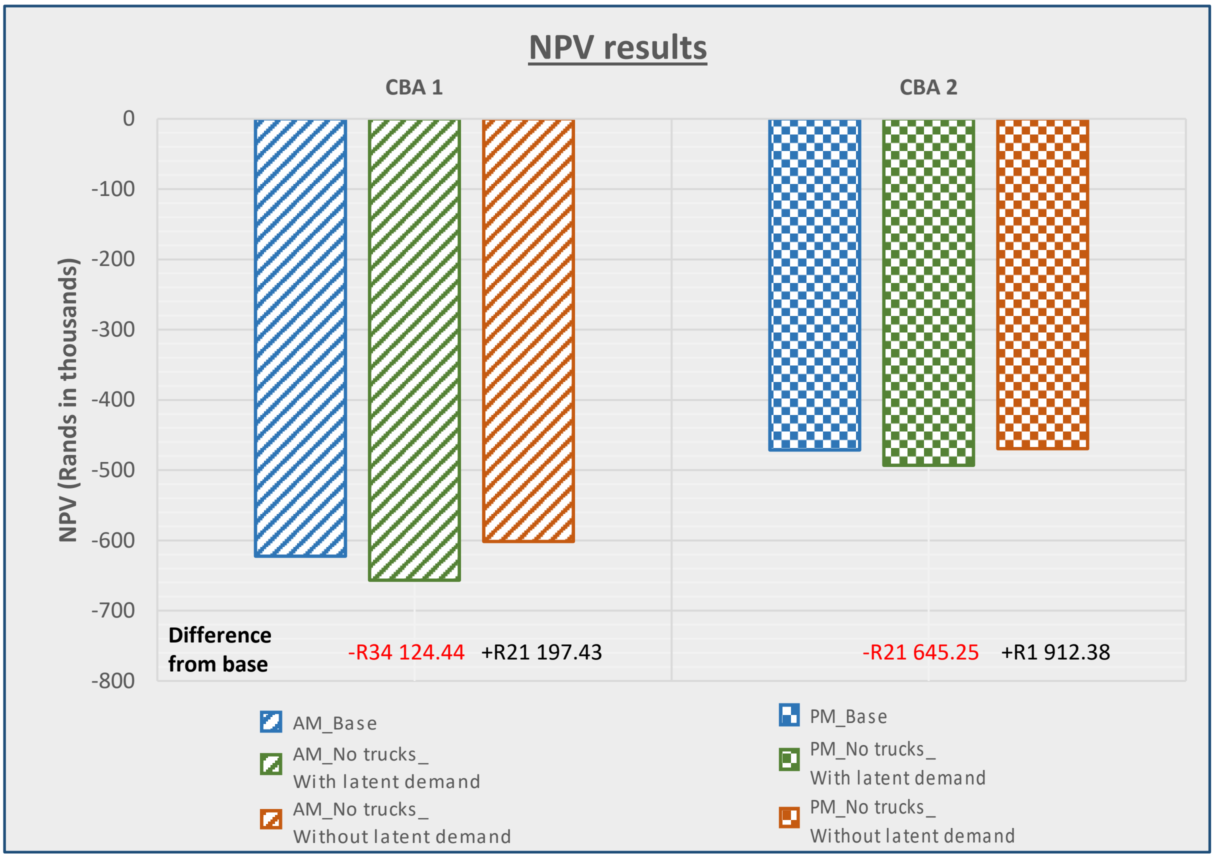


Figure 10.2. *NPV results of CBA 1 and CBA 2.*

Over the entire network, for the six hours investigated, the bans have the potential to result in a cost saving of R23 109.81 if there is no latent demand in Stellenbosch. This is a very small saving when considering the fact that this must be distributed over all passenger car users in the network. In addition, the difference in NPVs must be considered in the context of the entire investigated project. It is important to remember that the NPVs only represent the costs that were taken into account during the economic evaluation performed for this study. As mentioned before, several costs were ignored during the evaluation, including the costs of implementation and enforcement of the proposed bans. If it were deemed necessary to construct rest areas for heavy vehicles to park during the bans, the construction costs would most likely far outweigh the potential savings that the bans could hold. Either way, it can be argued that the potential losses to the freight industry because of lost productivity could be far larger than the potential cost savings to passenger car drivers.

Furthermore, the bans will only be economically beneficial in the case that no latent demand is present in Stellenbosch. As discussed elsewhere in this report, it is very likely that latent demand is indeed present on at least some of the town's roads. Great caution must, therefore, be taken before accepting that the bans could be economically feasible, since this would most likely not be the case. The differences in costs between the base cases and project alternatives are simply not large enough to result in definitive and significant economic savings. More research would have to be performed into the other costs and benefits involved in the project, but it is believed that it would not be economically beneficial overall to implement the proposed heavy vehicle bans in Stellenbosch.

10.7. Conclusion

This chapter contains a discussion of the economic evaluation, in the form of a CBA, that was performed for this study. An economic evaluation was performed in order to obtain a monetary estimate of the benefits or disbenefits that the proposed banning of heavy vehicles could hold for Stellenbosch.

Two CBAs were performed, one for the AM banning period and one for the PM banning period. Each CBA considered a base case and two project alternatives. One of the project alternatives involved the removal of heavy vehicles from the road network with latent demand present and the other involved the removal of heavy vehicles without the presence of latent demand. Only passenger cars were considered during the CBAs, since no heavy vehicles were present in the project alternatives and, therefore, heavy vehicle costs during the base period could not be compared to anything.

It must be noted that all costs and benefits were not considered during the CBAs. Several costs were ignored, either because they were not believed to be significant, or there was not sufficient information available to accurately analyse them.

It was found that all costs decreased when heavy vehicles were banned without the presence of latent demand. On the other hand, when latent demand was present, all costs increased. In total, for the costs considered, the banning of heavy vehicles were found to hold slight economic benefits if no latent demand was present. It is very important to note, however, that these benefits are believed to be far outweighed by costs that were not considered in the economic analysis like implementation costs and the losses to the freight industry due to lost productivity.

CHAPTER 11: CONCLUSIONS AND RECOMMENDATIONS

11.1. Summary of findings

This research study attempted to determine the movement patterns of heavy vehicles in Stellenbosch, South Africa and the impact that heavy vehicle restrictions would have in the town. The findings of the study are summarised in the table below.

Table 11.1. Summary of research findings.

Chapter	Findings
CHAPTER 6: FLEET MANAGEMENT DATA ANALYSIS	• The routes most used by heavy vehicles in Stellenbosch were identified. • Most heavy vehicles in Stellenbosch travel during the daytime. • The number of heavy vehicles in Stellenbosch is much lower on weekends than during the week. • Many of the freight trips in Stellenbosch are local trips or long-distance trips passing through the town without stopping. • The conclusions of the fleet management data analysis was confirmed by floating car data (FCD).
CHAPTER 7: VEHICLE MOVEMENT SURVEY ANALYSIS	• The number of incoming and outgoing trips during the VMSs were almost equal. • In the afternoon, most freight trips in Stellenbosch originate in the town or nearby. • Approximately half of the through trips included in the study took less than 30 minutes to complete.
CHAPTER 8: LINK TRAFFIC COUNTS ANALYSIS	• The penetration rate of the fleet management data ranged between 2.62% and 8.44%. This was deemed sufficient for accuracy. • The heavy vehicle presence on the three main roads feeding Stellenbosch ranged between 1.03% and 5.06%. • Latent demand is present on some roads in Stellenbosch, but it could not be definitively determined whether the whole town experiences latent demand or not.

CHAPTER 9: MICROSCOPIC TRAFFIC MODELLING	• On an overall network level, traffic conditions improved when heavy vehicles were removed from the network and there was no latent demand present. If there was latent demand present, traffic conditions were worse. • On an intersection level, traffic conditions improved or stayed the same when heavy vehicles were removed, regardless of the presence of latent demand. • Changes in traffic conditions were relatively small on all levels with and without heavy vehicles.
CHAPTER 10: ECONOMIC EVALUATION	• When heavy vehicles were removed from the road network and there was latent demand present, the total costs increased. • If no latent demand was present, total costs slightly decreased from the base cases.

Table 11.2 below indicates whether the objectives of this study were achieved and which chapters are relevant in meeting each objective.

Table 11.2. Achievement of research objectives

Objective	Objective achieved?	Relevant chapters
i. To evaluate what the impact of restricting trucks from travelling in the urban area of Stellenbosch during morning and afternoon banning periods would be on traffic flow and the economy.	☑	ALL
ii. To investigate the current heavy vehicle movement patterns in Stellenbosch.	☑	CHAPTER 6 CHAPTER 7 CHAPTER 8
iii. To create a microscopic traffic model of critical routes in Stellenbosch, with and without the heavy vehicle restrictions in place.	☑	CHAPTER 9
iv. To perform an economic evaluation of the implementation of the heavy vehicle restrictions in Stellenbosch.	☑	CHAPTER 10

11.2. Conclusions

The research statement investigated in this study was:

Restricting heavy goods vehicles from travelling on public roads in the urban areas of Stellenbosch, South Africa between 6 a.m. and 9 a.m., and 5 p.m. and 8 p.m. on weekdays (excluding public holidays) will improve traffic flow in the town and hold significant economic benefits.

The research statement was proven untrue. Although the study revealed that, in very specific circumstances, the heavy vehicle bans could result in improvements in traffic conditions, the improvements were insignificant. Additionally, traffic conditions were only found to improve on a network level if no latent demand is present on the road network of Stellenbosch. During this research study, it was determined that latent demand is indeed present on some routes in the town and, therefore, the implementation of the proposed bans in Stellenbosch would likely lead to traffic conditions becoming worse during the investigated banning periods.

Although it can be argued that one must consider the potential benefits to passenger car drivers if latent demand could be managed, it is crucial to consider these potential benefits in the context of the scope of this study. First, it must be remembered that this study considered the banning of all HGVs with a GVM of 3 500 kg and above. The regulations proposed for implementation only include HGVs with a GVM of 9 000 kg and above. Therefore, the effects (whether positive or negative) of the heavy vehicle restrictions determined in this study would be much smaller when considering the implementation of the actual proposed regulations.

Secondly, the benefits considered are only applicable to passenger car drivers, since the impact on heavy vehicles were not considered. The impact of the proposed bans on the freight industry was not determined in this study, but is believed to be negative. This raises the dilemma where one must consider whether it is fair to disadvantage the freight industry only to improve traffic conditions for passenger cars by less than 10%.

Thirdly, it must be noted that this study only investigated the effects that the bans would have during the banning periods. Depending on the response of the freight industry, more heavy vehicles may be present on the road network during times outside of the banning periods. This could lead to some, if not all, of the benefits achieved during the banning periods to be cancelled out.

When considering the economic benefits that the heavy vehicle bans could hold, it is important to remember that only certain costs were considered during the economic evaluation. When this point is taken into account, the potential benefits (if there were no latent demand present in the town) are extremely small. It is believed that the costs that were not considered, such as implementation costs, enforcement costs and the loss of productivity of the freight industry, far outweigh the potential benefits that could be achieved by the implementation of the bans.

It is also interesting to note that the proposed banning periods (at least in the case of Stellenbosch) were poorly selected if the goal was to have the biggest impact. As part of this study, it was concluded that the majority of freight traffic occurs outside of the banning periods.

Overall, the potential benefits of implementing heavy vehicles bans in Stellenbosch, as determined in this study, will only be realised in very specific conditions that have a large probability of not existing in the town. This research study was designed to provide the best case scenario for the proposed regulations to be beneficial, and still the benefits were extremely small. Additionally, in the rare circumstances that the conditions could exist, the potential benefits would be much too small to warrant the other logistical problems that come with the implementation of the bans.

11.3. Summary of contributions

The research contained in this document holds significant theoretical and practical contributions. First, valuable information is provided on the movement patterns of heavy vehicles in Stellenbosch. According to the Stellenbosch Municipality, no significant research had ever been performed into this field. The data provided by this study is of great use by the relevant authorities, allowing them to make more informed decisions when managing and implementing transportation policies in the town. As such, it would be beneficial to include these findings in the Comprehensive Integrated Transport Plan (CITP) of Stellenbosch.

Secondly, this study contributes significant data on the effects of implementing heavy vehicle bans in urban areas. Especially in the South African context, very little research has been performed into the effects of such bans. The bans investigated in this study were proposed for implementation in South Africa in 2015 but as far as is known, no research had been undertaken that looked into the effects of these bans. The results of this study, therefore, contribute knowledge for the relevant authorities when considering whether to implement the bans or not. In addition, the results of the study can inform the public on the effects that such restrictions would have on them.

Thirdly, this study contributes to the field of transportation engineering by providing insights into the use of fleet management data for engineering purposes. It has been found that fleet management data has not frequently been used to analyse traffic movements in a town and, therefore, this study contributed by investigating the feasibility of this. This study confirmed that fleet management data could indeed provide valuable information on the movement patterns of heavy vehicles in an area if the penetration rate is acceptable.

11.4. Recommendations for implementation

After considering the results of this research study, it is recommended that the proposed heavy vehicle bans must not be implemented in the form in which it is currently proposed. It is believed that, although the heavy vehicle bans could potentially lead to slight improvements in traffic conditions, this would be negligible in size. Additionally, it is believed that the implementation of such bans, especially if it is implemented on a national level, would most likely hold significant economic losses to the South African economy. The proposed banning periods were also poorly selected (at least when considering Stellenbosch), as these times were not the periods when most heavy vehicles are present in the town. Therefore, the maximum impact of the bans are not achieved.

It is recommended that more research be performed into the use of urban consolidation centres (UCCs) in South African towns. It is believed that UCCs could decrease the number of heavy vehicles in urban areas without having as a significant impact on the freight industry as the proposed restrictions do.

11.5. Future research

This study did not address all areas of this research topic. The following areas of research are recommended for future studies into this field:

- Investigate the impact of the proposed heavy vehicle bans on the freight industry and the manner in which operations and productivity would be affected.
- Investigate the effects of the same heavy vehicle bans in other towns in South Africa.
- Investigate the effects that the restrictions would have if the bans were enforced for different periods.
- Investigate the economic and traffic impacts of the heavy vehicle bans on periods outside of the bans.
- Perform a more detailed economic analysis that includes all relevant costs, including all vehicles on the network.
- Investigate the impact of the heavy vehicle bans on road safety.
- Investigate the feasibility of implementing a UCC in Stellenbosch.
- Investigate the degree and extent of the presence of latent demand in Stellenbosch.

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Restricting freight traffic in urban areas:

The economic and traffic impact of banning heavy vehicle movement in Stellenbosch during peak periods

APPENDICES

by Alicia Potgieter

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

Supervisor: Mrs. Megan Bruwer

Co-supervisor: Prof. Nagui Rouphail (North Carolina State University)

Department of Civil Engineering

April 2019

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FIGURES

APPENDIX A1: **PROPOSED REGULATIONS**

Government Notice

DEPARTMENT OF TRANSPORT

No. 411 **11 May 2015**

NATIONAL ROAD TRAFFIC ACT, 1996 (ACT NO. 93 OF 1996)

PUBLICATION OF THE NATIONAL ROAD TRAFFIC REGULATIONS FOR COMMENTS

The Minister of Transport intends to amend the National Road Traffic Regulations, 2000, and acting in terms of section 75 (6) of the National Road Traffic Act, 1996 (Act No. 93 of 1996) herewith publish the regulations in the Schedule for comments; All interested parties who have any objections, inputs or comments to the proposed amendments are called upon to lodge their objections, inputs or comments, within four weeks from the date of publication of this Notice to:

Mr JOHN MOTSATSING
DEPARTMENT OF TRANSPORT
PRIVATE BAG X 193
PRETORIA
0001

Tel: (012) 309 3574
Fax (012) 309 3962
E-mail: motsatsj@dot.gov.za

Mr PHILLIP MAGAGANE
DEPARTMENT OF TRANSPORT
PRIVATE BAG X 193
PRETORIA
0001

Tel: (012) 309 3684
Fax (012) 309 3962
magaganp@dot.gov.za

SCHEDULE

Definition

1. In this Schedule "the Regulations" means the National Road Traffic Regulations published in Government Notice No. R. 225 of 17 March 2000, as amended by

Government Notice No's. R. 761 of 31 July 2000, R. 941 of 22 September 2000, R. 726 of 3 August 2001, R. 2116 of 5 October 2001, R. 779 of 4 June 2002, R. 1341 of 25 September 2003, R. 881 of 23 July 2004, R. 871 of 2 September 2005, R. 1066 of 23 November 2005, R. 1318 of 2 December 2005, R. 1319 of 2 December 2005, R. 891 of 4 September 2006, R. 964 of 29 September 2006, R. 404 of 4 May 2007 and R. 865 of 28 September 2007, R. 589 of 27 May 2009, R. 359 of 12 May 2010, R. 541 of 29 June 2011, R. 209 of 9 March 2012 R. 758 of 9 October 2013, R. 890 of 19 November 2013 and R. 846 of 31 October 2014.

Insertion of regulation 107D in the Regulations

2. The following regulation is inserted after regulation 107C of the Regulations:

"107D. Manner and contents on which an applicant for the renewal of a driving licence card is to be evaluated

(1) An applicant for the renewal of a driving licence card shall before obtaining a new driving licence card be evaluated by an examiner for driving licences.

(2) The examiner for driving licences shall by observation, inquiry and practical test, satisfy himself or herself that the applicant—

(a) holds a driving licence which authorises him or her to drive the class of motor vehicle to which his or her application relates;

(b) knows and understands the road traffic signs;

(c) has a sound knowledge of the rules of the road and the different signals which a driver of a motor vehicle is required to give when driving on a public road;

(d) is not subject to any disqualification referred to in section 15 of the Act or regulation 102; and

(3) For the purposes of subregulation (2) an applicant shall not be required to undergo a written test.".

Amendment of regulation 247 of the Regulations

3. Regulation 247 of the Regulations is hereby amended by the substitution for regulation 247 of the following regulation:

"247. Circumstances under which persons may be carried on goods vehicle

(1) No person shall operate on a public road a goods vehicle conveying persons unless that portion of the vehicle in which such persons are being conveyed is enclosed to a height of—

(a) at least 350 millimetres above the surface upon which such person is seated;or

(b) at least 900 millimetres above the surface on which such person is standing,

in a manner and with a material of sufficient strength to prevent such person from falling from such vehicle when it is in motion.

(2) No person shall convey more than 5 persons in the goods compartment of a goods vehicle, the gross vehicle mass of which is less than 3 500 kilograms.

(3) The provisions of this regulation shall only apply in respect of a person conveying

persons as their employer during the scope of employment of such persons.

Provided that no person shall be conveyed in the goods compartment together with any tools or goods, except their personal effects, unless that portion in which such persons are being conveyed is separated by means of a partition, from the portion in which such goods are being conveyed.".

Amendment of regulation 250 of the Regulations

4. Regulation 250 of the Regulations is hereby amended by the substitution for regulation 250 of the following regulation:

"250. Persons not to be carried in goods compartment for reward

No person shall on a public road convey—

(a) school children; or

(b) any person for reward, unless an exemption is issued to such person in terms of the provisions of the NLTA,

in the goods compartment of a motor vehicle.".

Amendment of regulation 292 of the Regulations

5. Regulation 292 of the Regulations is hereby amended by the substitution for regulation 292 of the following regulation:

"292. General speed limit

A general speed limit of -

(a) 40 kilometres per hour shall apply in respect of every public road or section thereof, situated within an urban area;

(b) 80 kilometres per hour shall apply in respect of every public road or section thereof, other than a freeway, situated outside an urban area; and

(c) 120 kilometres per hour shall apply in respect of every freeway: Provided that a speed limit of 100 kilometres per hour shall apply in cases wherein such freeway passes through a residential area.".

Insertion of regulation 318A in the Regulations

6. The following regulation is inserted after regulation 318 of the Regulations:

"318A. Prohibition of operating on the public road of a goods vehicle the gross vehicle mass of which exceeds 9 000 kilograms at certain times

(1) No person shall operate on the public road in an urban area a goods vehicle the gross vehicle mass of which exceeds 9000 kilograms between the hours of 06h00 to 09h00 and 17h00 to 20h00 Monday to Friday except weekends and public holidays.

(2) The provisions of subregulation (1) shall not apply in case of emergencies, to the driver of a fire -fighting vehicle, a fire-fighting response vehicle, an emergency medical response vehicle, a rescue vehicle or an ambulance, who drives such vehicle in the performance of his or her duties, a traffic officer or a person appointed in terms of the South African Police Service Act, 1995 (Act No.68 of 1995), who drives a vehicle in the carrying out of his or her duties, any person driving a vehicle while responding to a

disaster as contemplated in the Disaster Management Act, 2002 (Act No. 57 of 2002) or a person who drives a vehicle while it is used in connection with the construction or maintenance of a public road or the rendering of an essential public service.".

Short title and commencement

These Regulations are published for comments.

APPENDIX A2: **FLEET MANAGEMENT DATA RESULTS**

A2.1. Temporal distribution of entries

Sunday, 22 October 2017

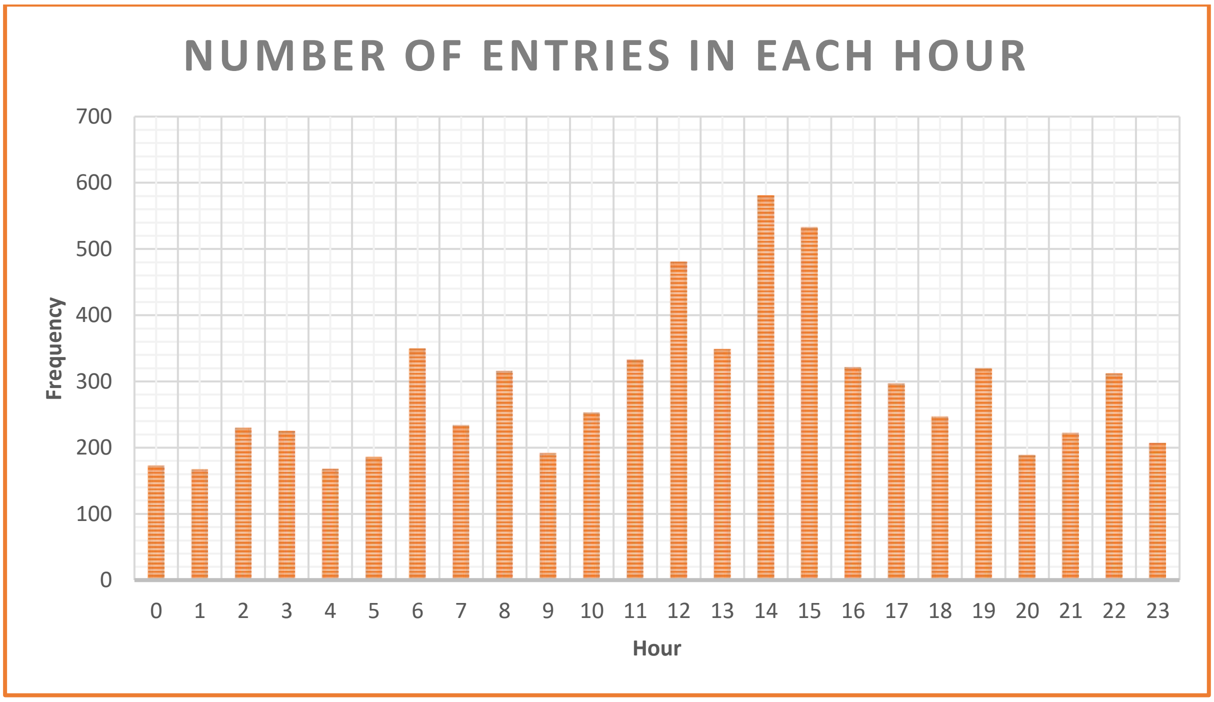

Figure A2.1. *Number of entries recorded in the study area during each hour of 22 October 2017.*

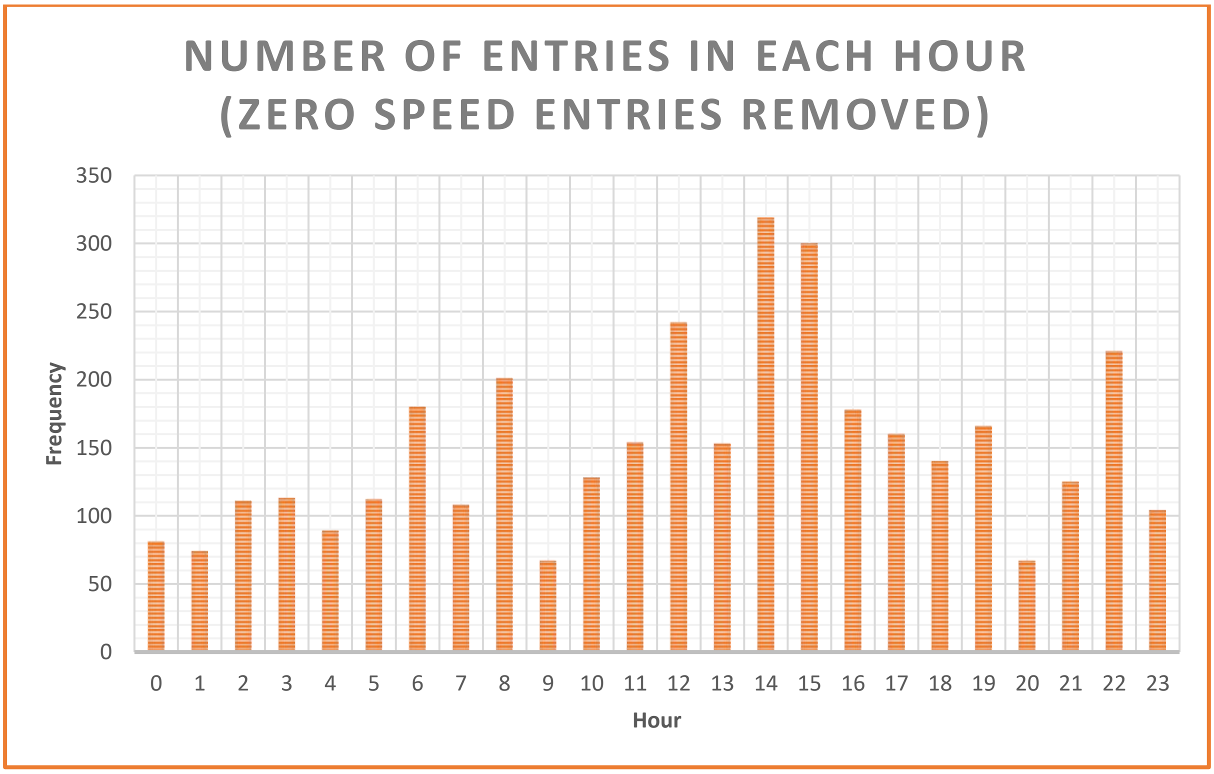

Figure A2.2. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 22 October 2017.*

Tuesday, 24 October 2017

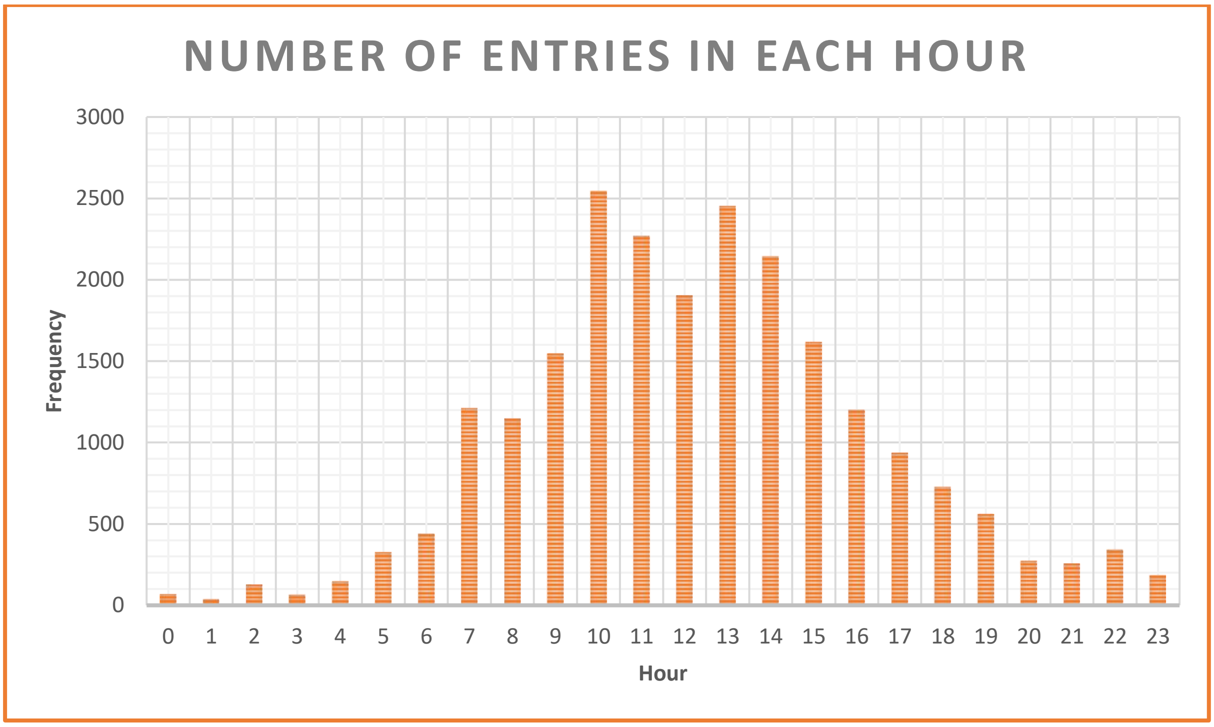

Figure A2.3. *Number of entries recorded in the study area during each hour of 24 October 2017.*

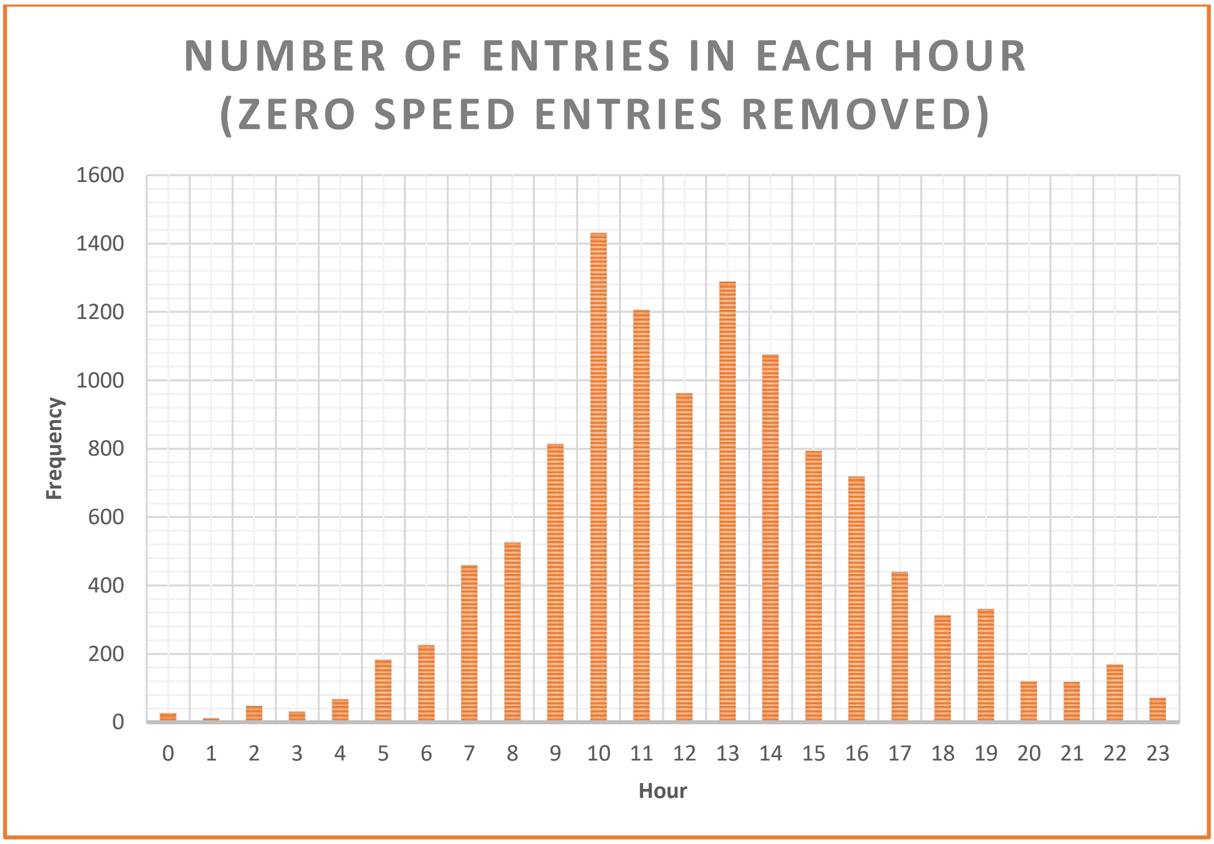

Figure A2.4. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 24 October 2017.*

Wednesday, 25 October 2017

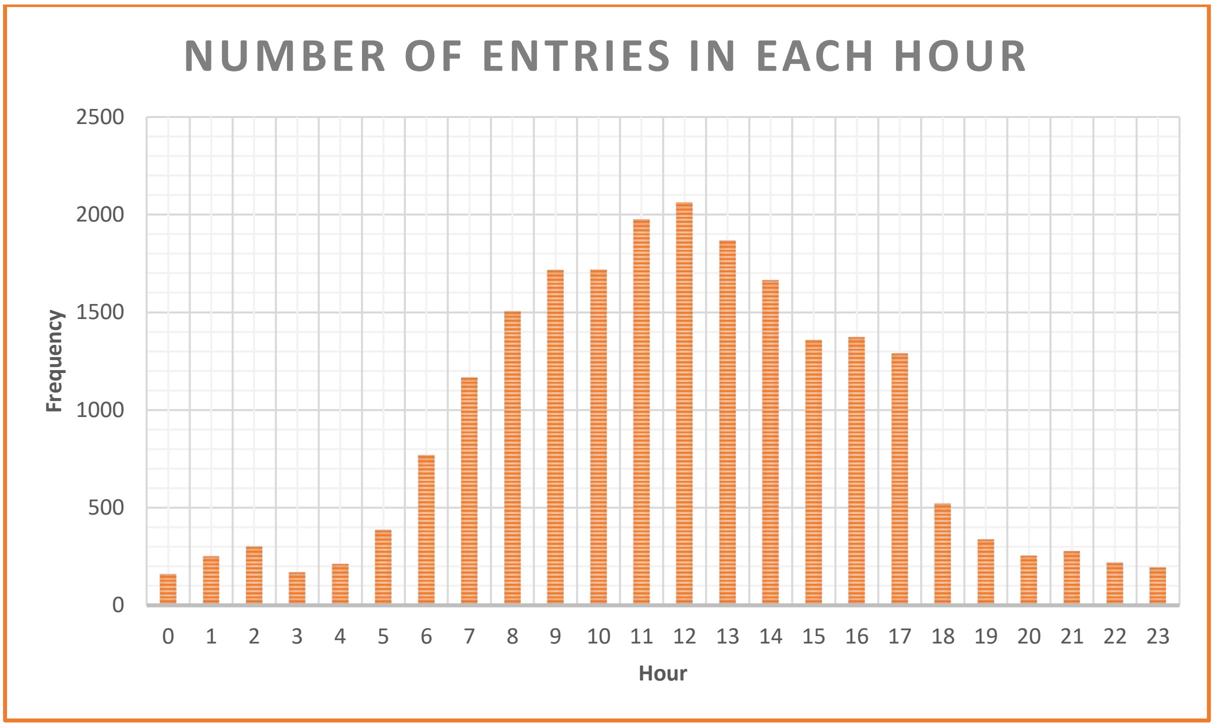

Figure A2.5. *Number of entries recorded in the study area during each hour of 25 October 2017.*

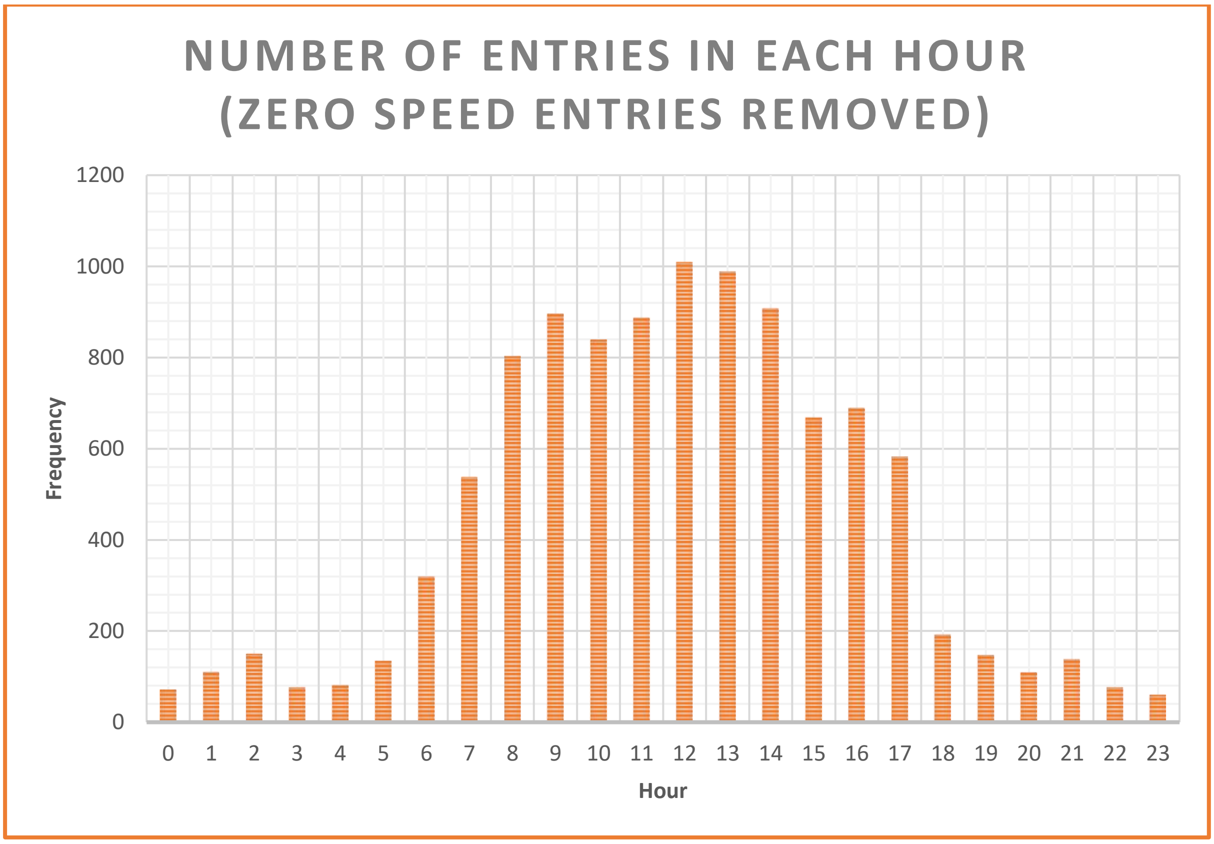

Figure A2.6. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 25 October 2017.*

Thursday, 26 October 2017

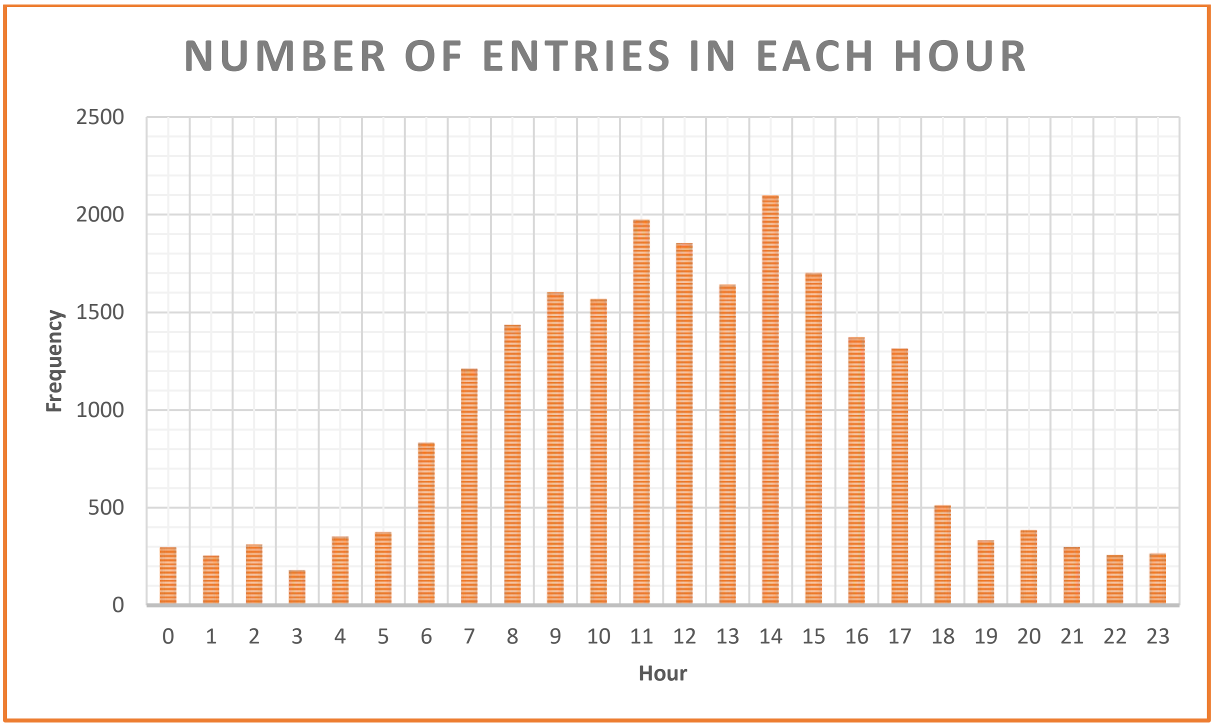

Figure A2.7. *Number of entries recorded in the study area during each hour of 26 October 2017.*

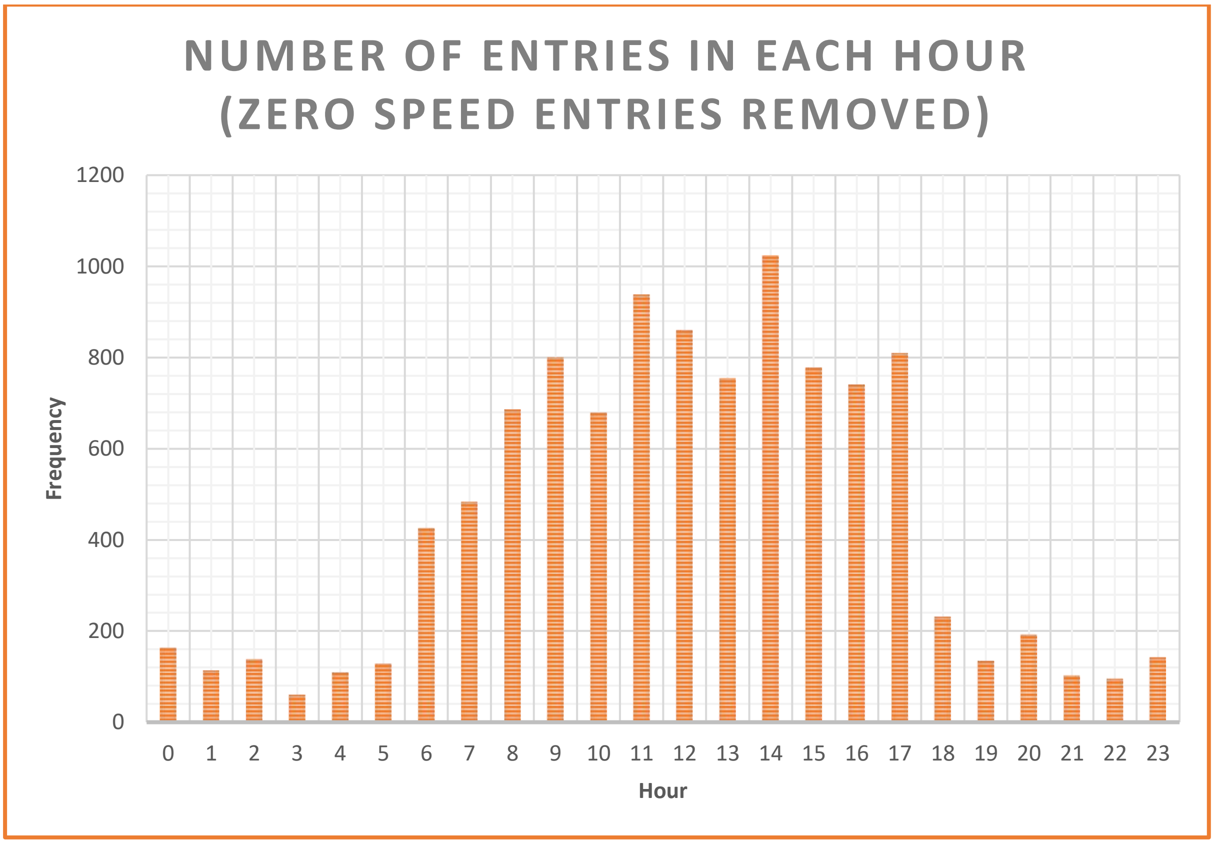

Figure A2.8. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 26 October 2017.*

<u>*Sunday, 29 October 2017*</u>

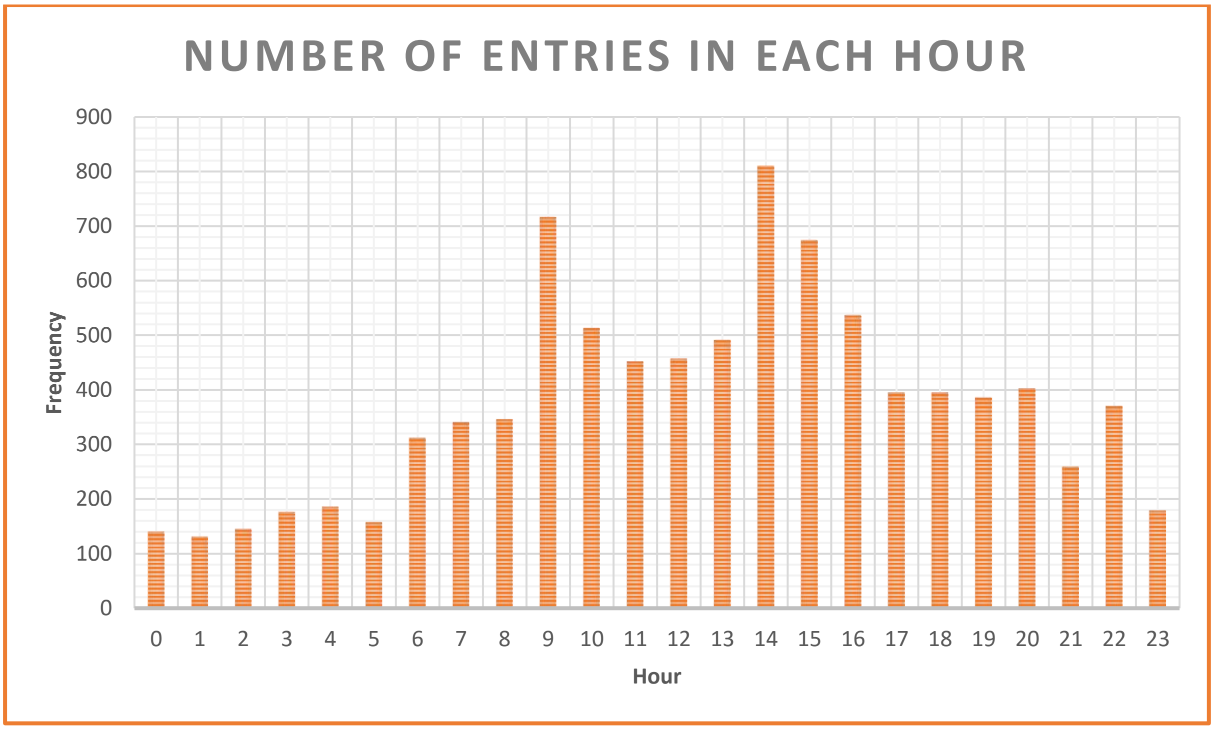

Figure A2.9. *Number of entries recorded in the study area during each hour of 29 October 2017.*

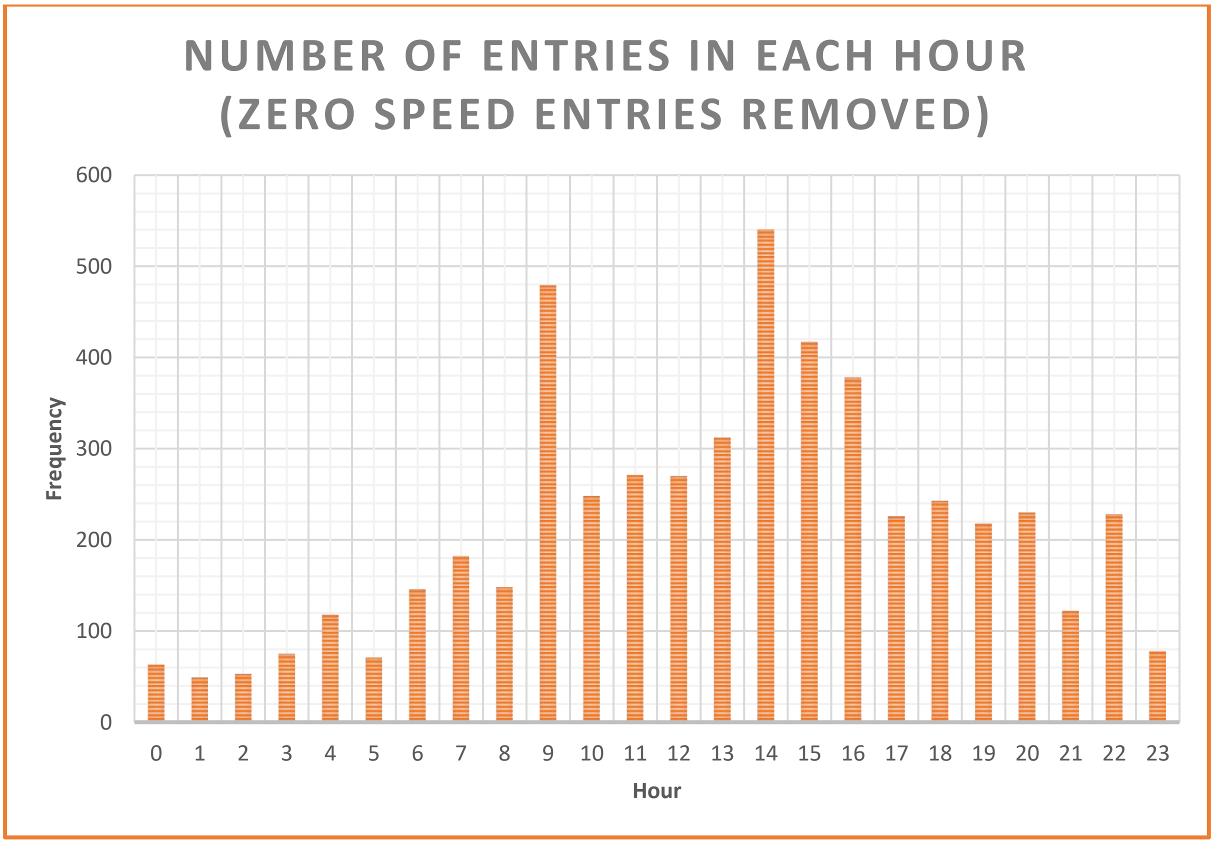

Figure A2.10. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 29 October 2017.*

Tuesday, 31 October 2017

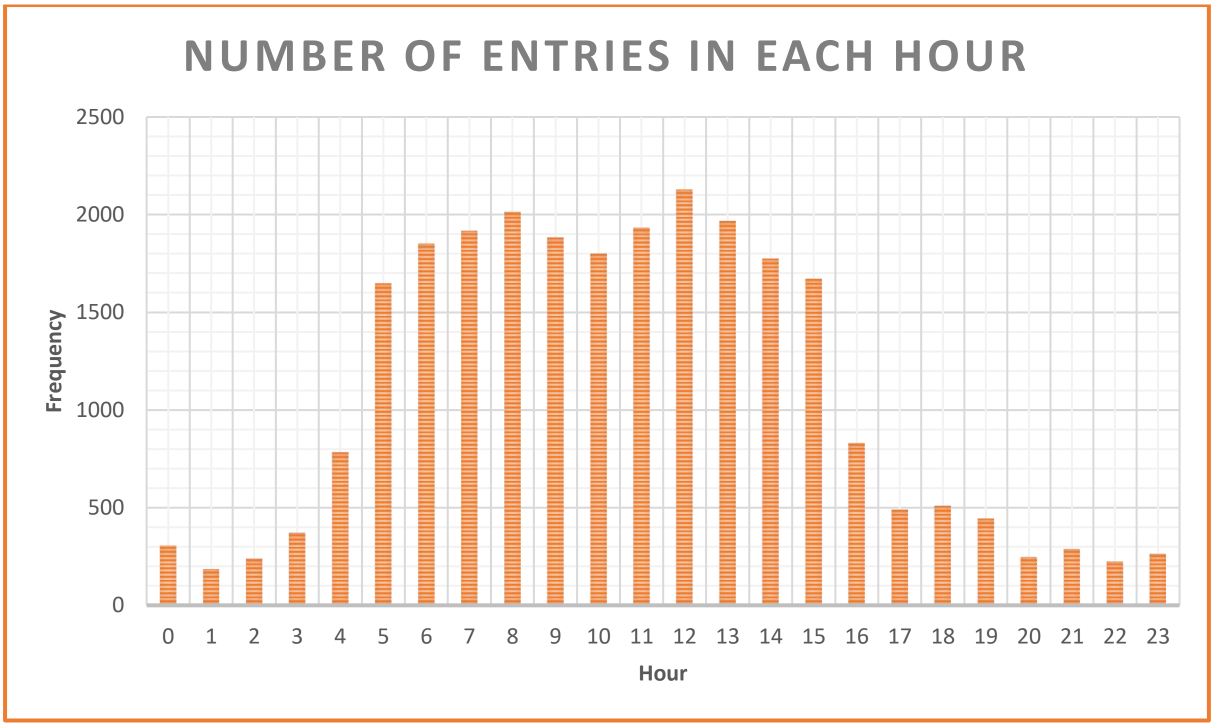

Figure A2.11. *Number of entries recorded in the study area during each hour of 31 October 2017.*

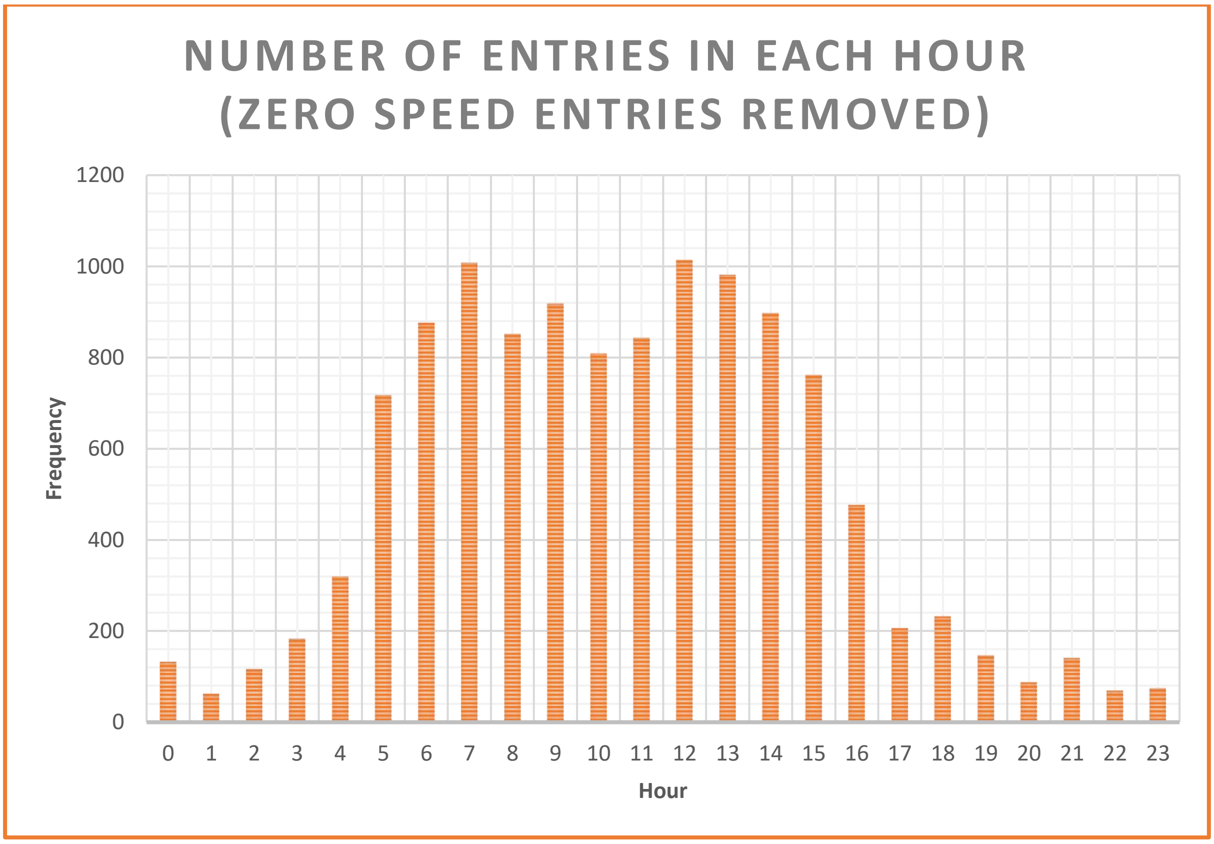

Figure A2.12. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 31 October 2017.*

Wednesday, 1 November 2017

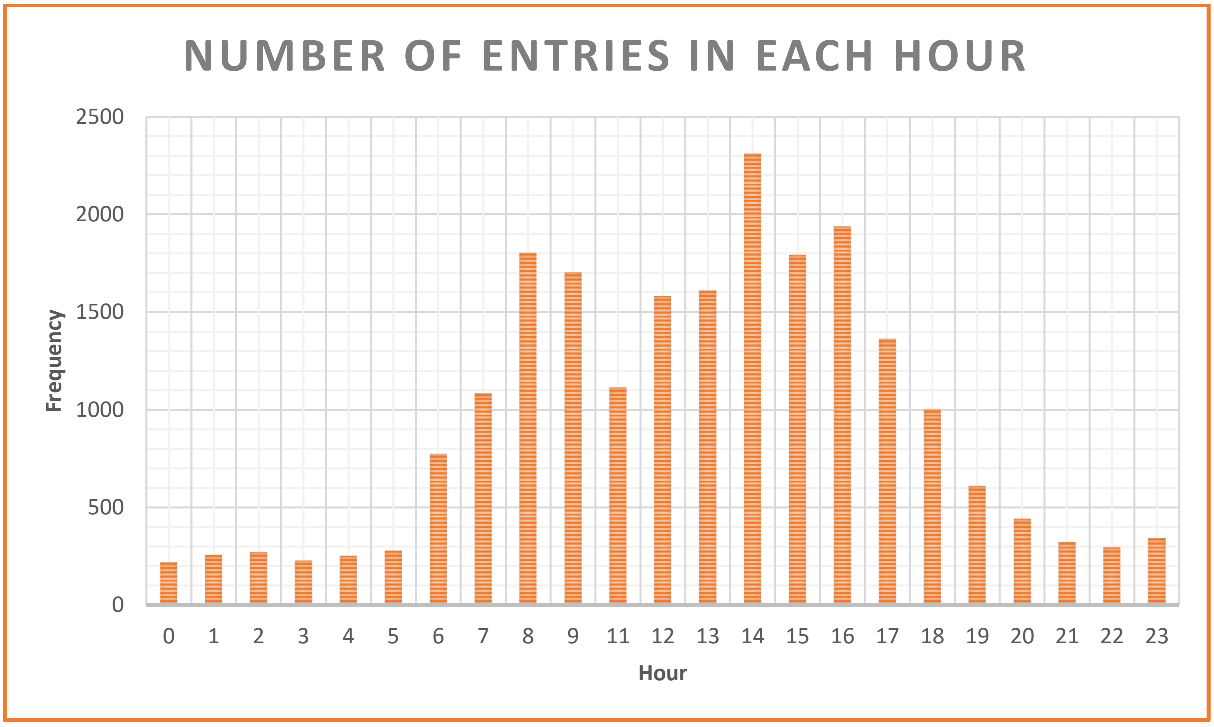

Figure A2.13. *Number of entries recorded in the study area during each hour of 1 November 2017.*

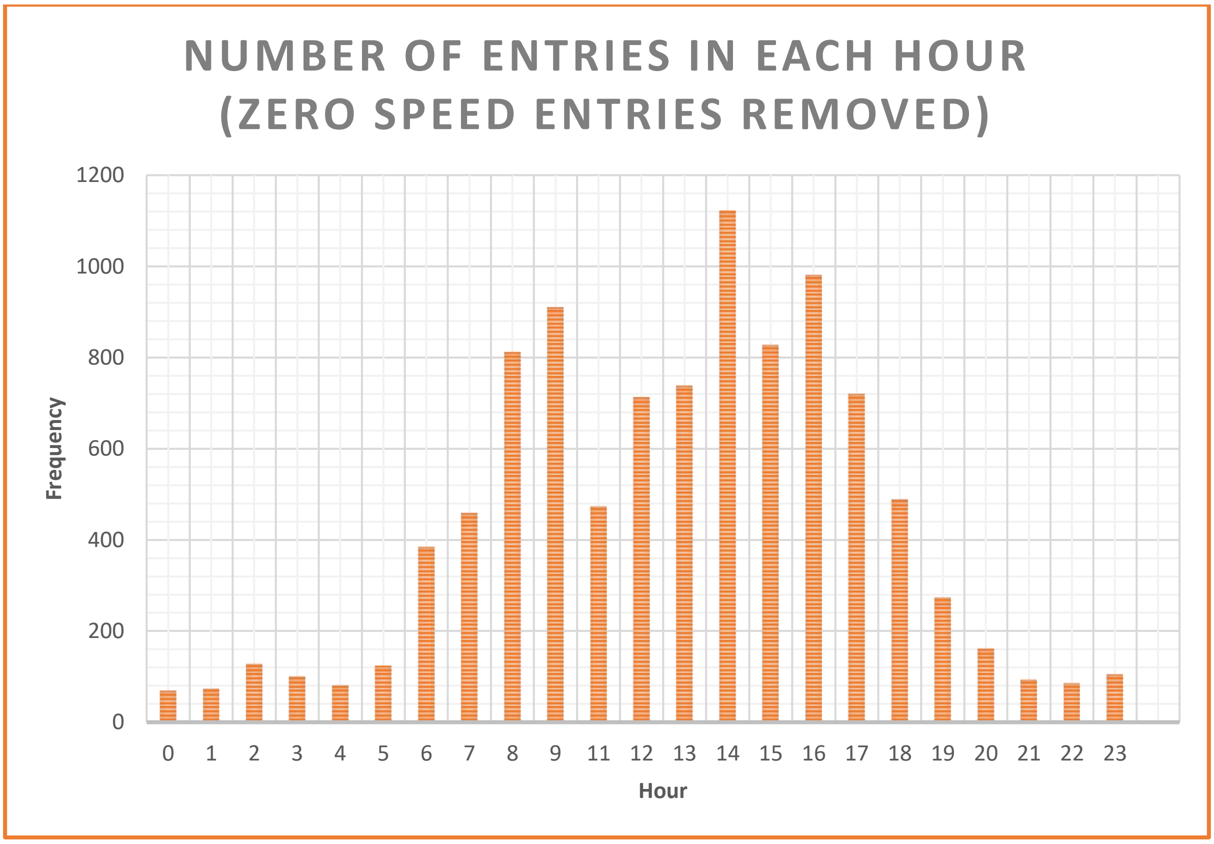

Figure A2.14. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 1 November 2017.*

Thursday, 2 November 2017

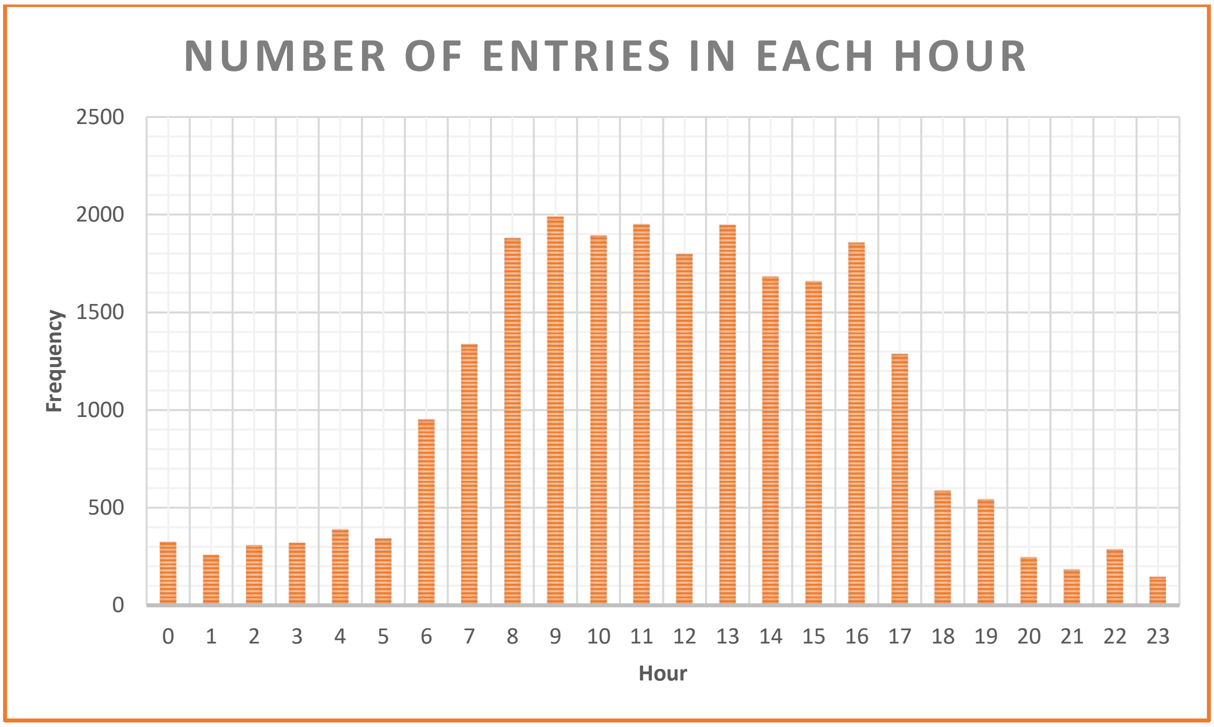

Figure A2.15. *Number of entries recorded in the study area during each hour of 2 November 2017.*

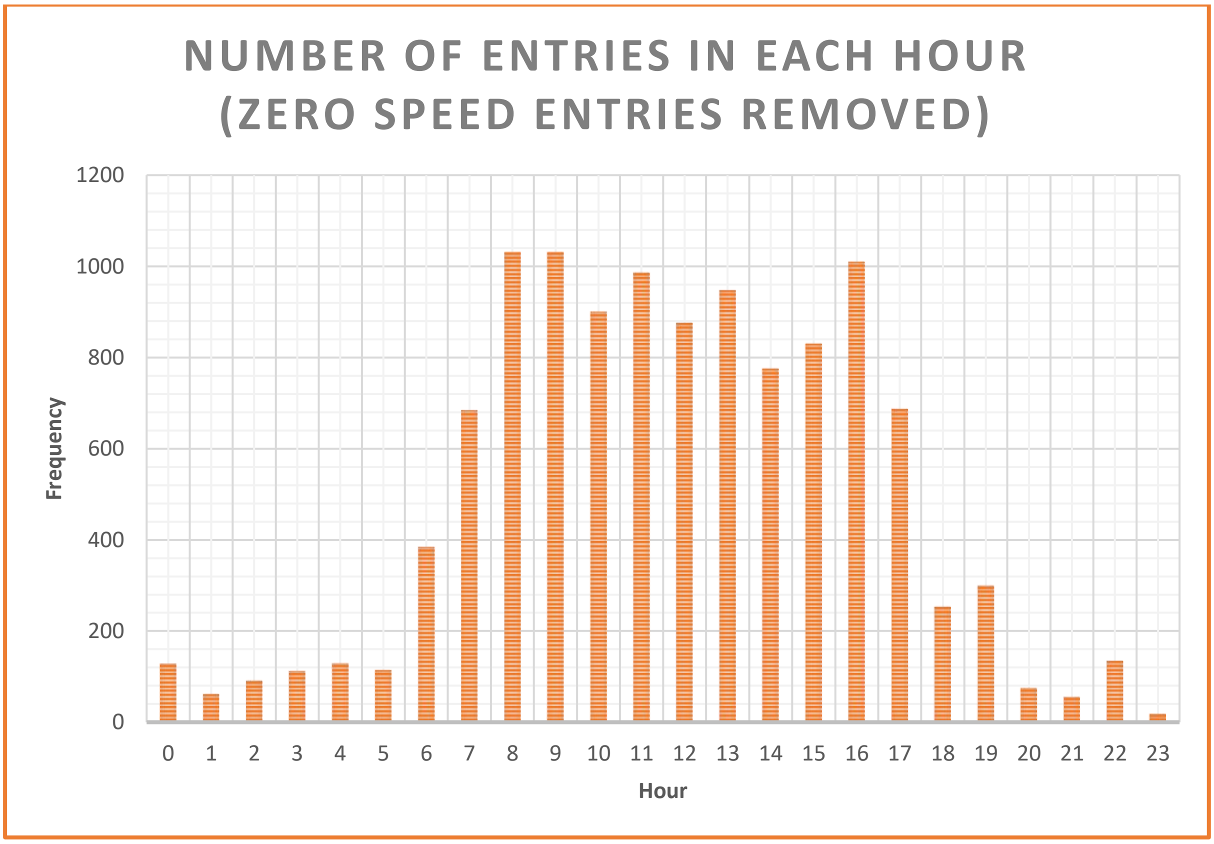

Figure A2.16. *Number of entries (with speeds not equal to zero) recorded in the study area during each hour of 2 November 2017.*

A2.2. Temporal distribution of trucks

Sunday, 22 October 2017

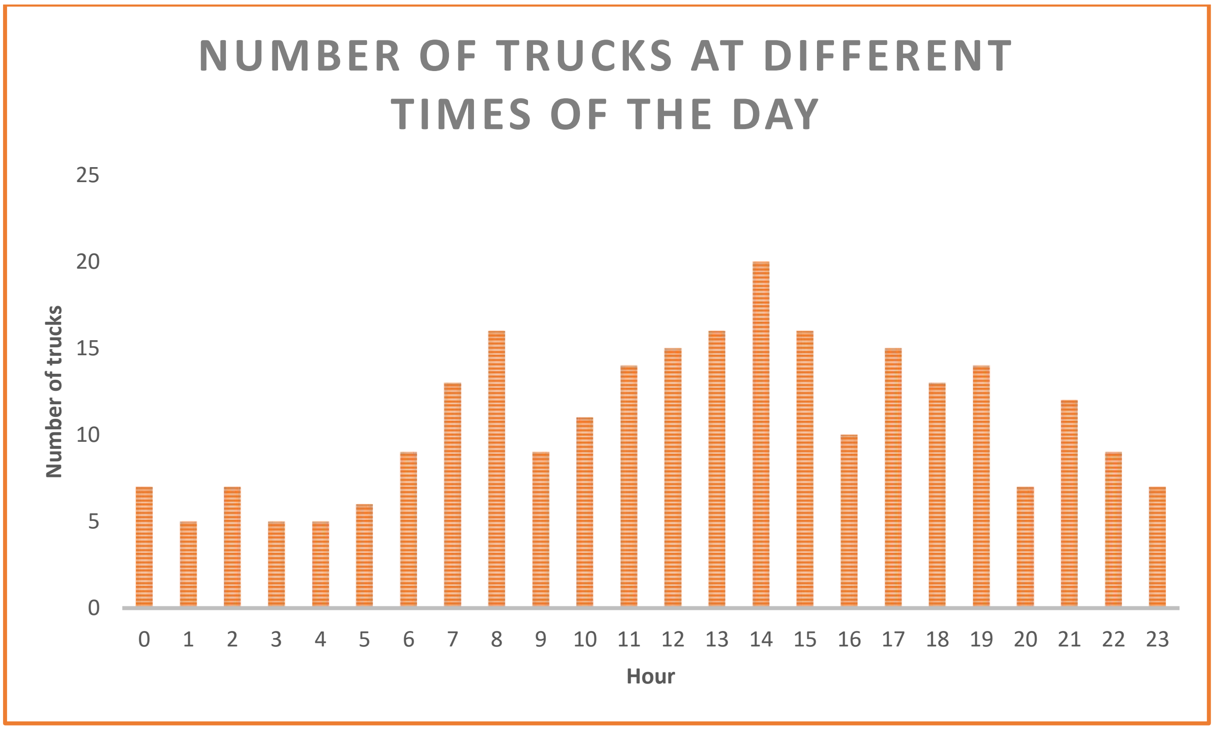

Figure A2.17. *Number of trucks present in the study area during each hour of 22 October 2017.*

Tuesday, 24 October 2017

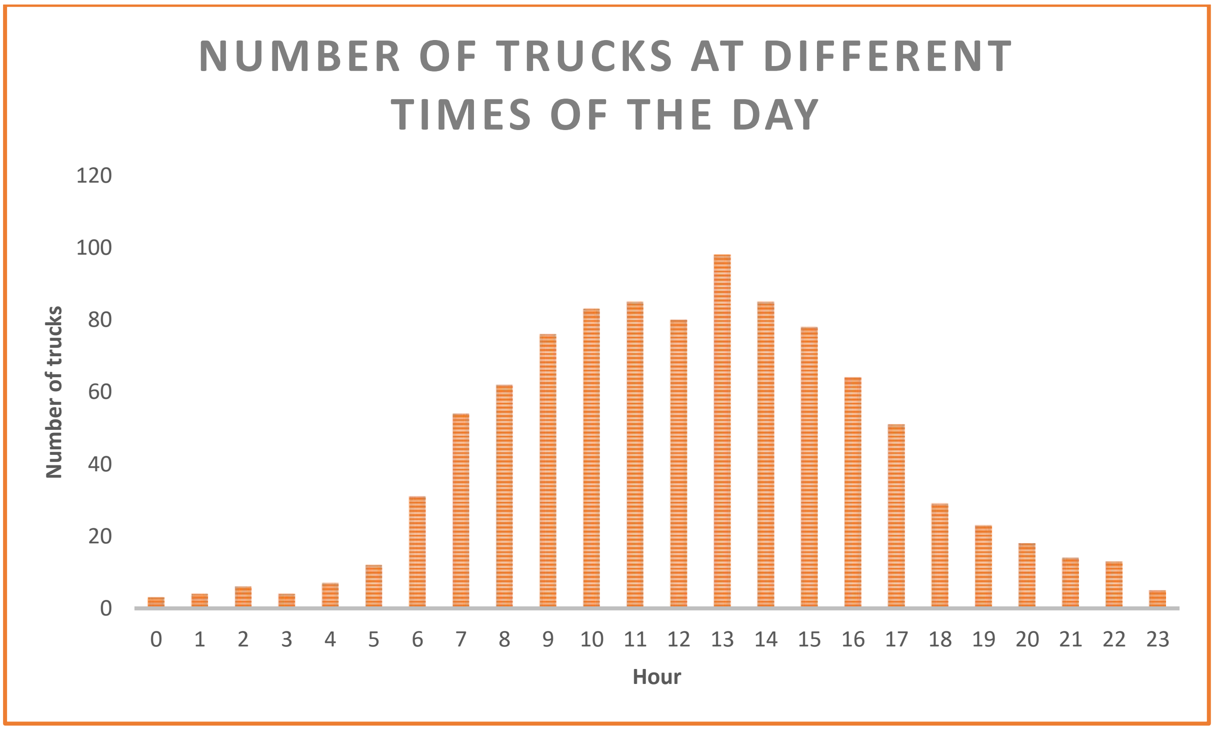

Figure A2.18. *Number of trucks present in the study area during each hour of 24 October 2017.*

Wednesday, 25 October 2017

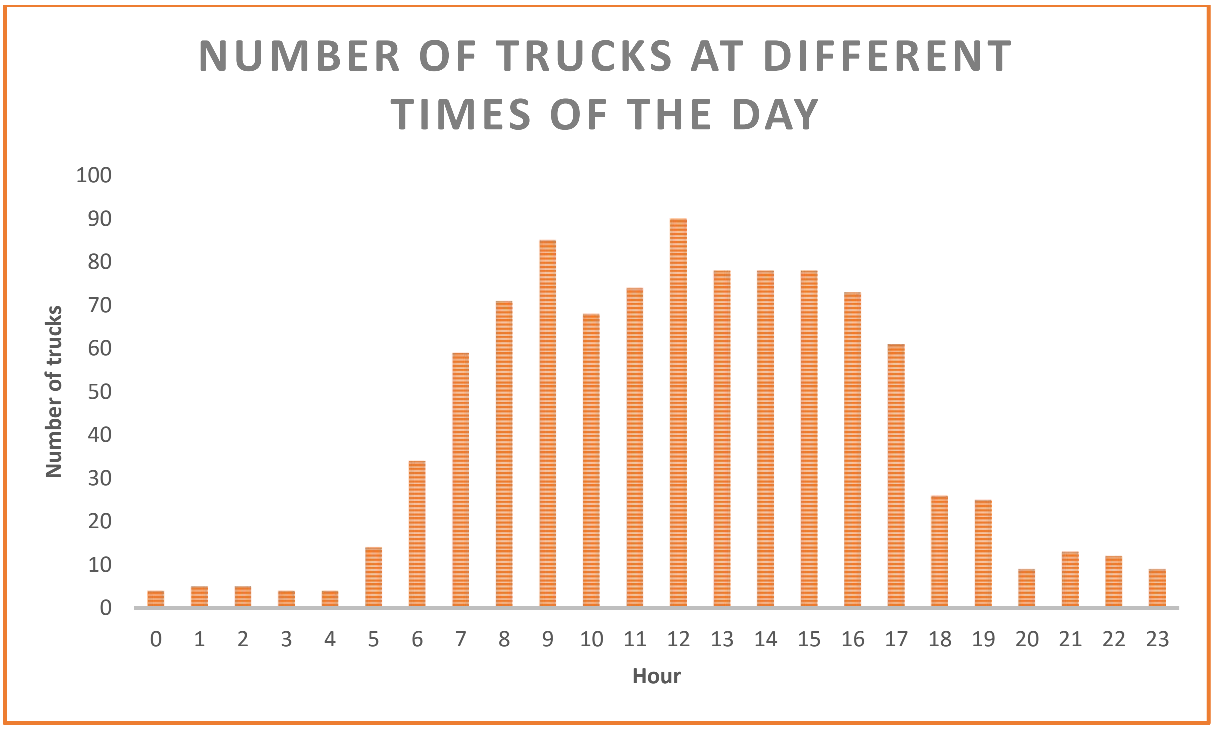

Figure A2.19. *Number of trucks present in the study area during each hour of 25 October 2017.*

Thursday, 26 October 2017

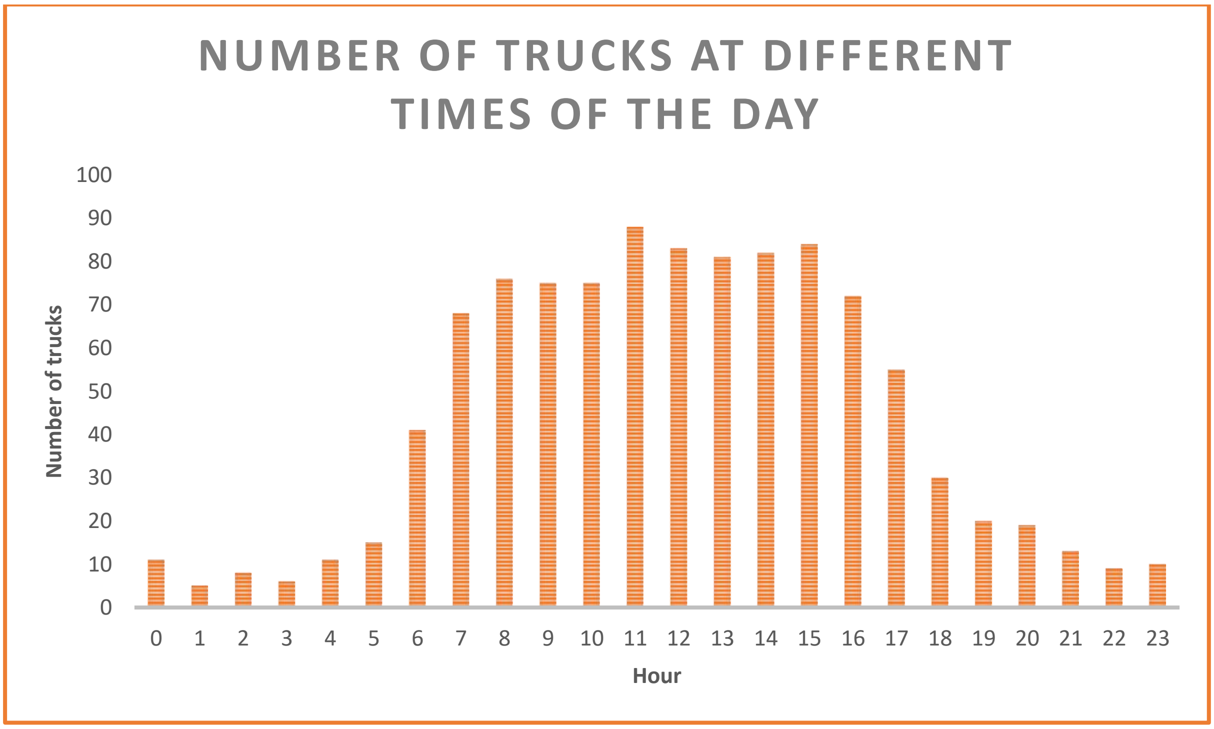

Figure A2.20. *Number of trucks present in the study area during each hour of 26 October 2017.*

Sunday, 29 October 2017

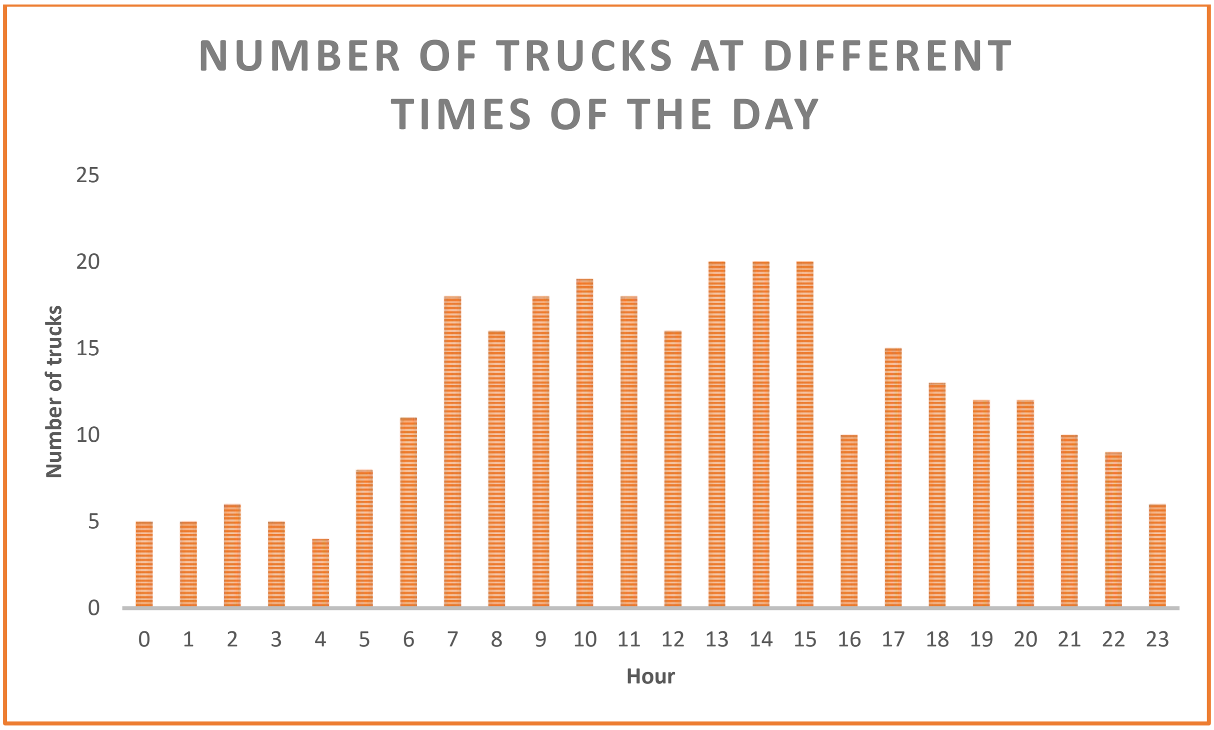

Figure A2.21. *Number of trucks present in the study area during each hour of 29 October 2017.*

Tuesday, 31 October 2017

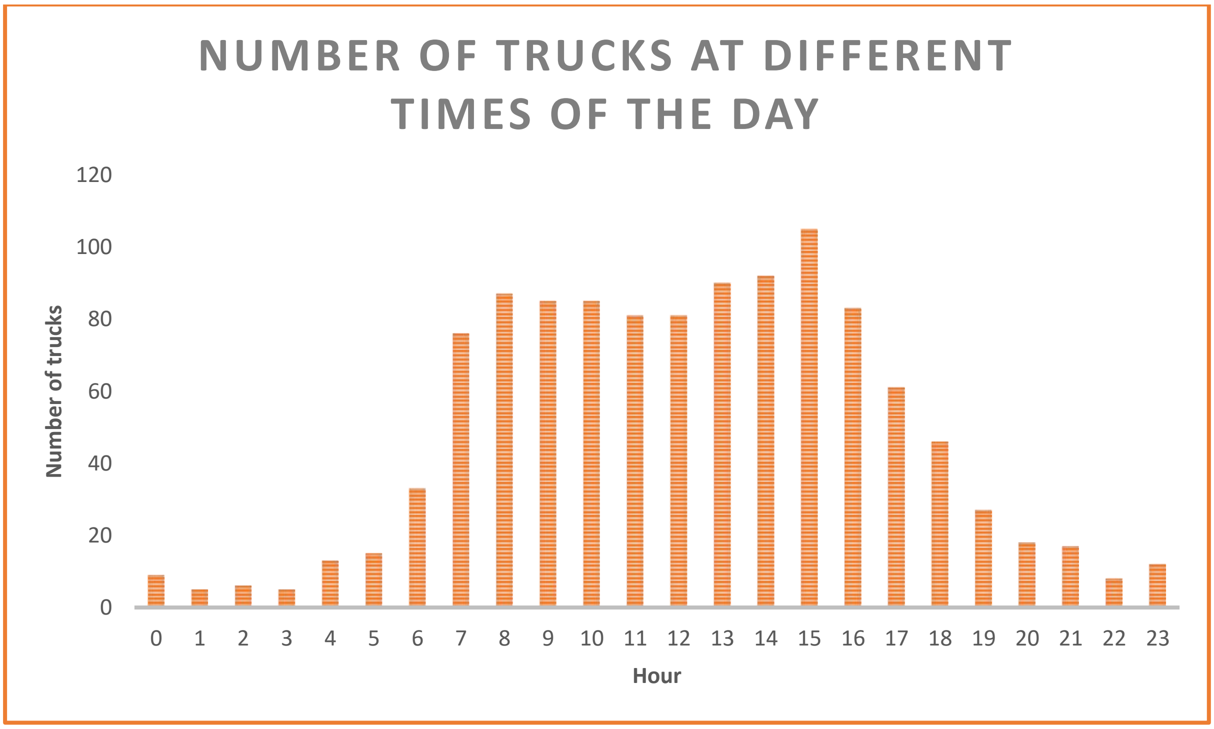

Figure A2.22. *Number of trucks present in the study area during each hour of 31 October 2017.*

Wednesday, 1 November 2017

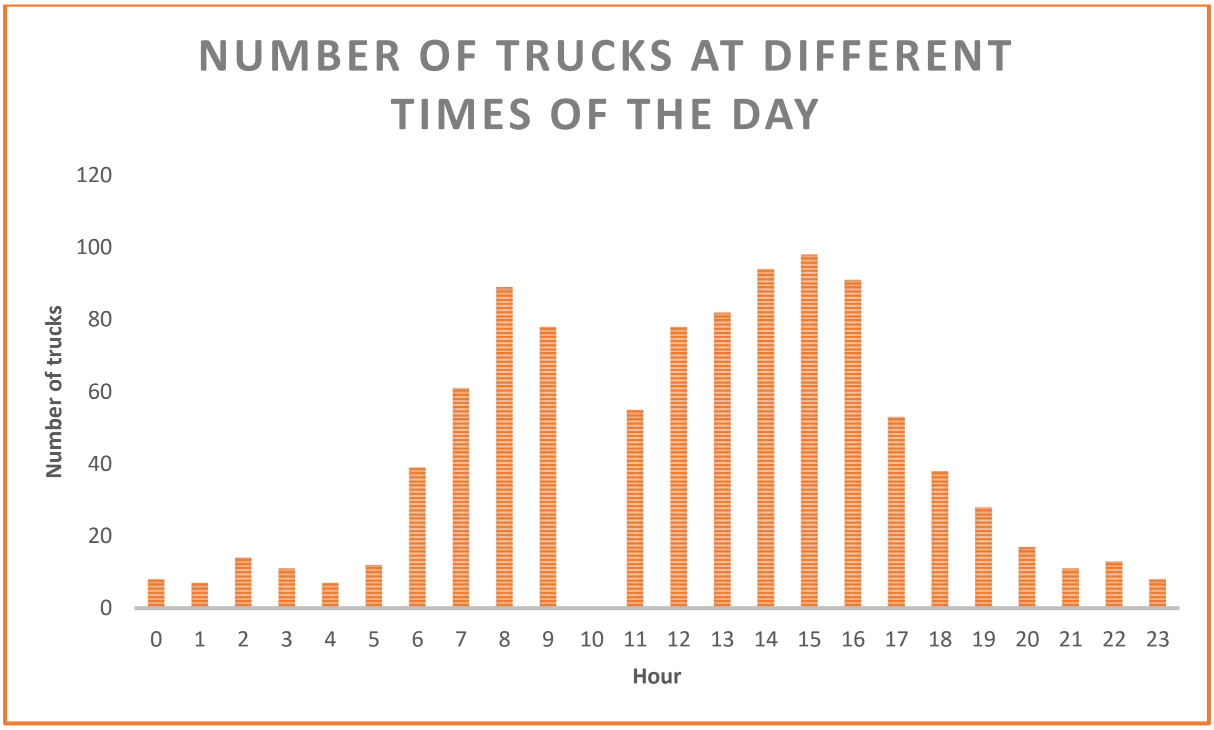

Figure A2.23. *Number of trucks present in the study area during each hour of 1 November 2017.*

Thursday, 2 November 2017

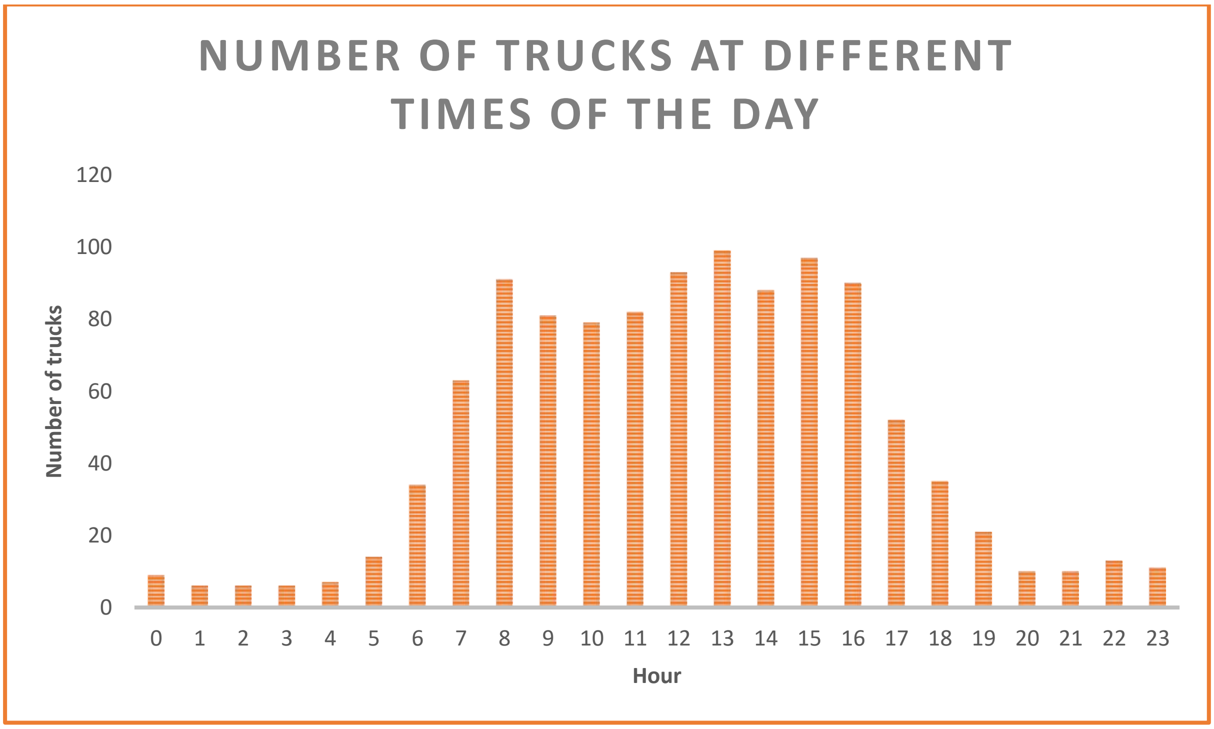

Figure A2.24. *Number of trucks present in the study area during each hour of 2 November 2017.*

A2.3. Spatial distribution of trucks

Sunday, 22 October 2017

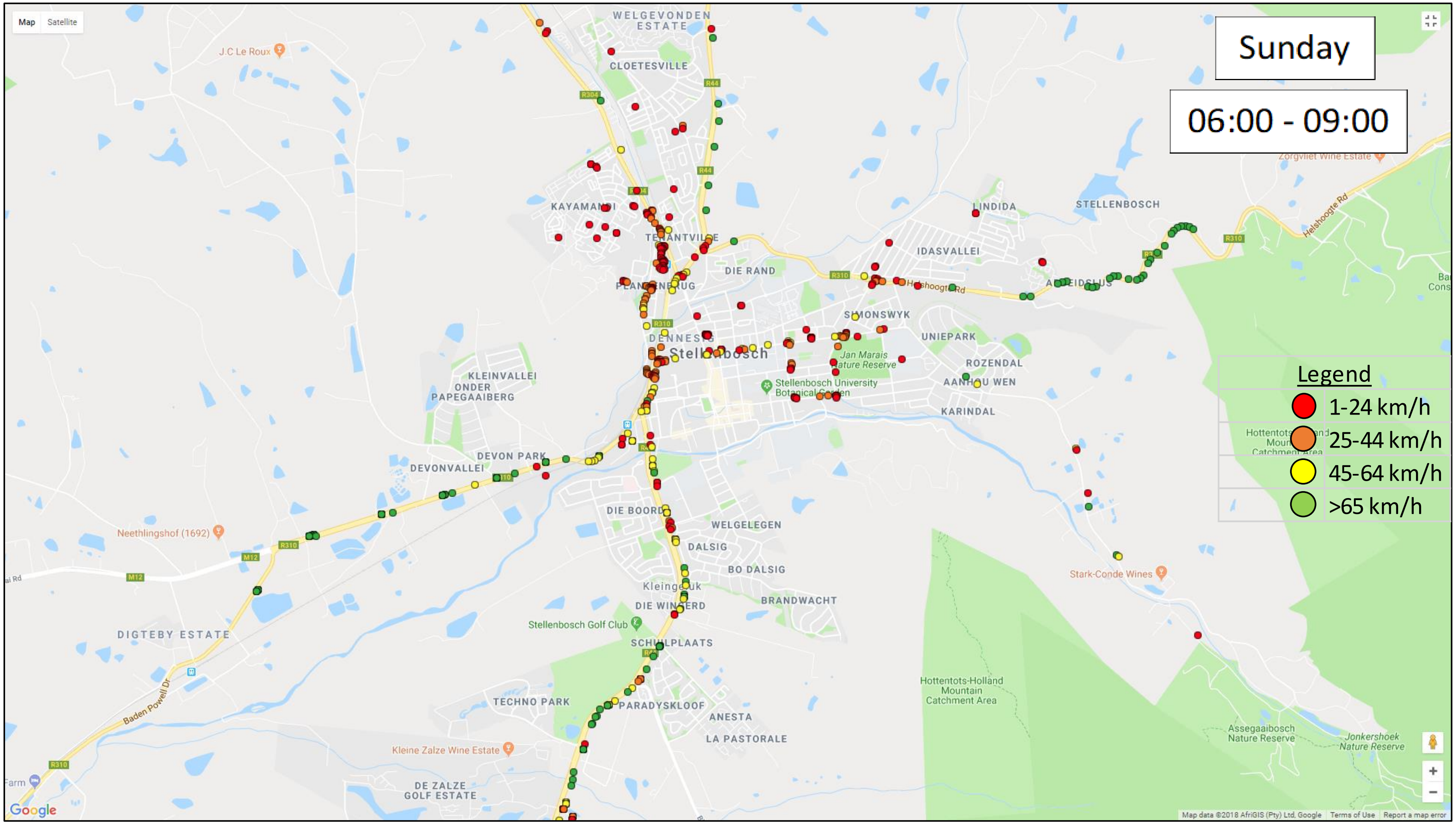

Figure A2.25. *Truck locations recorded between 06:00 and 09:00 on 22 October 2017 (HamsterMap, no date).*

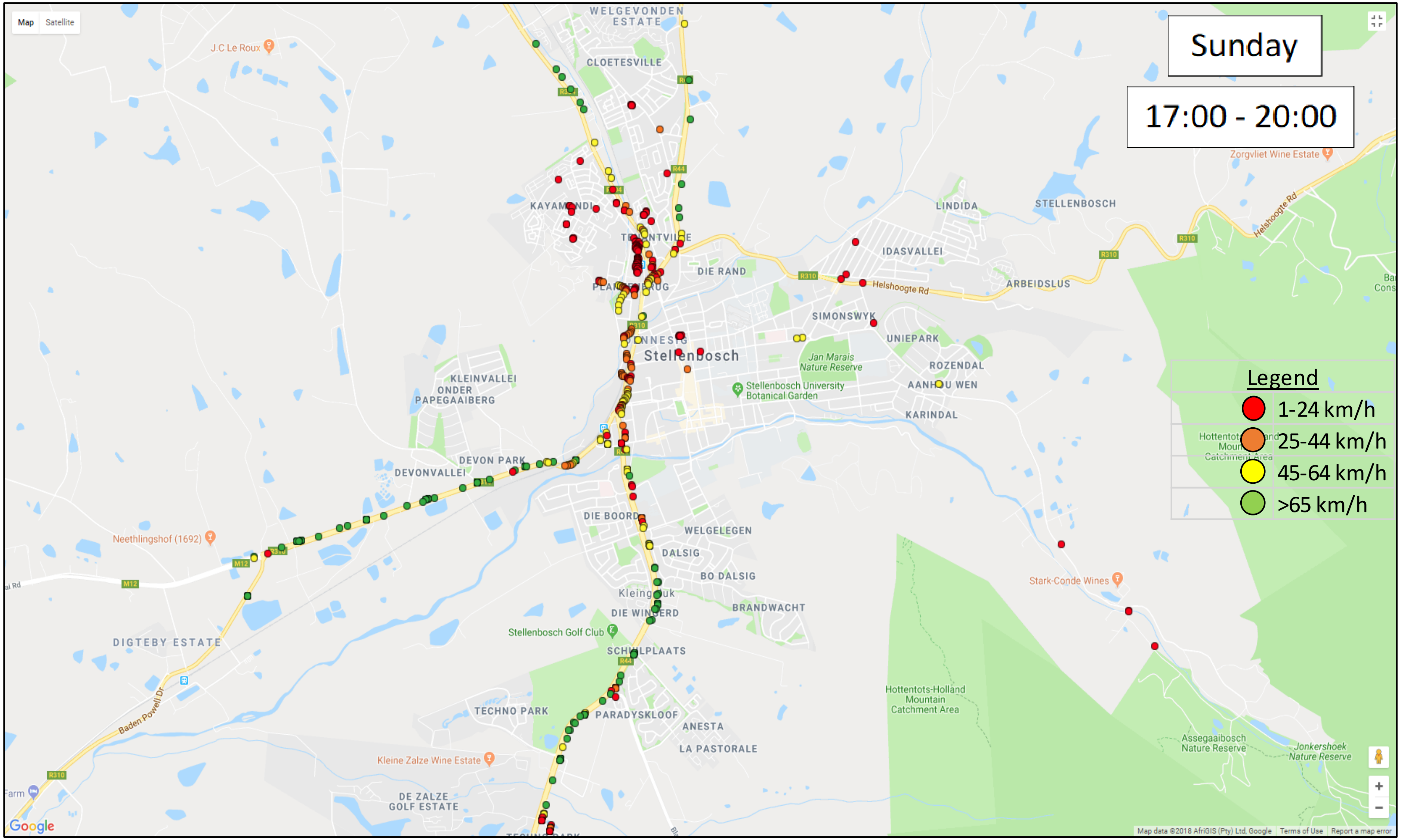

Figure A2.26. *Truck locations recorded between 17:00 and 20:00 on 22 October 2017 (HamsterMap, no date).*

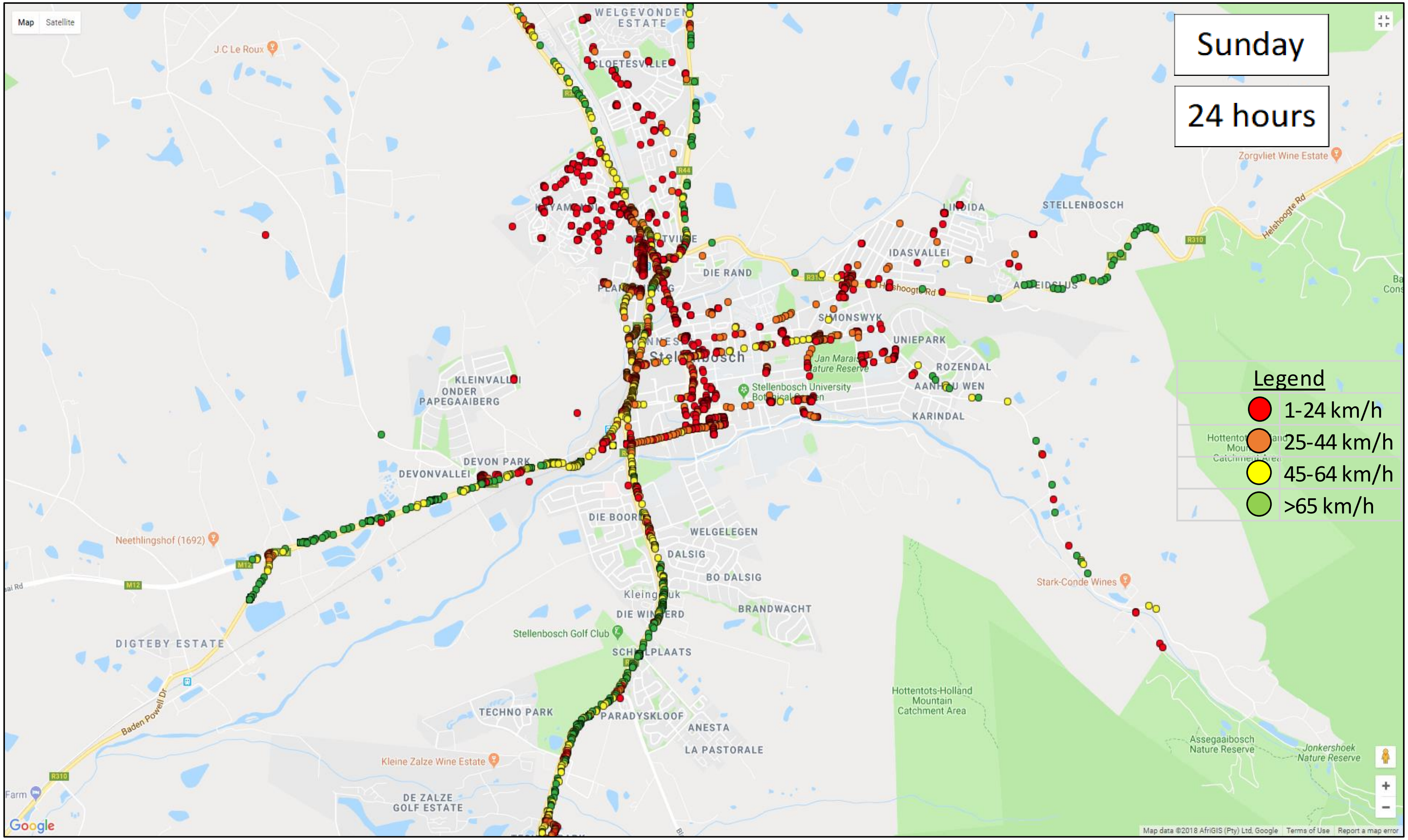

Figure A2.27. *All truck locations recorded on 22 October 2017 (HamsterMap, no date).*

Tuesday, 24 October 2017

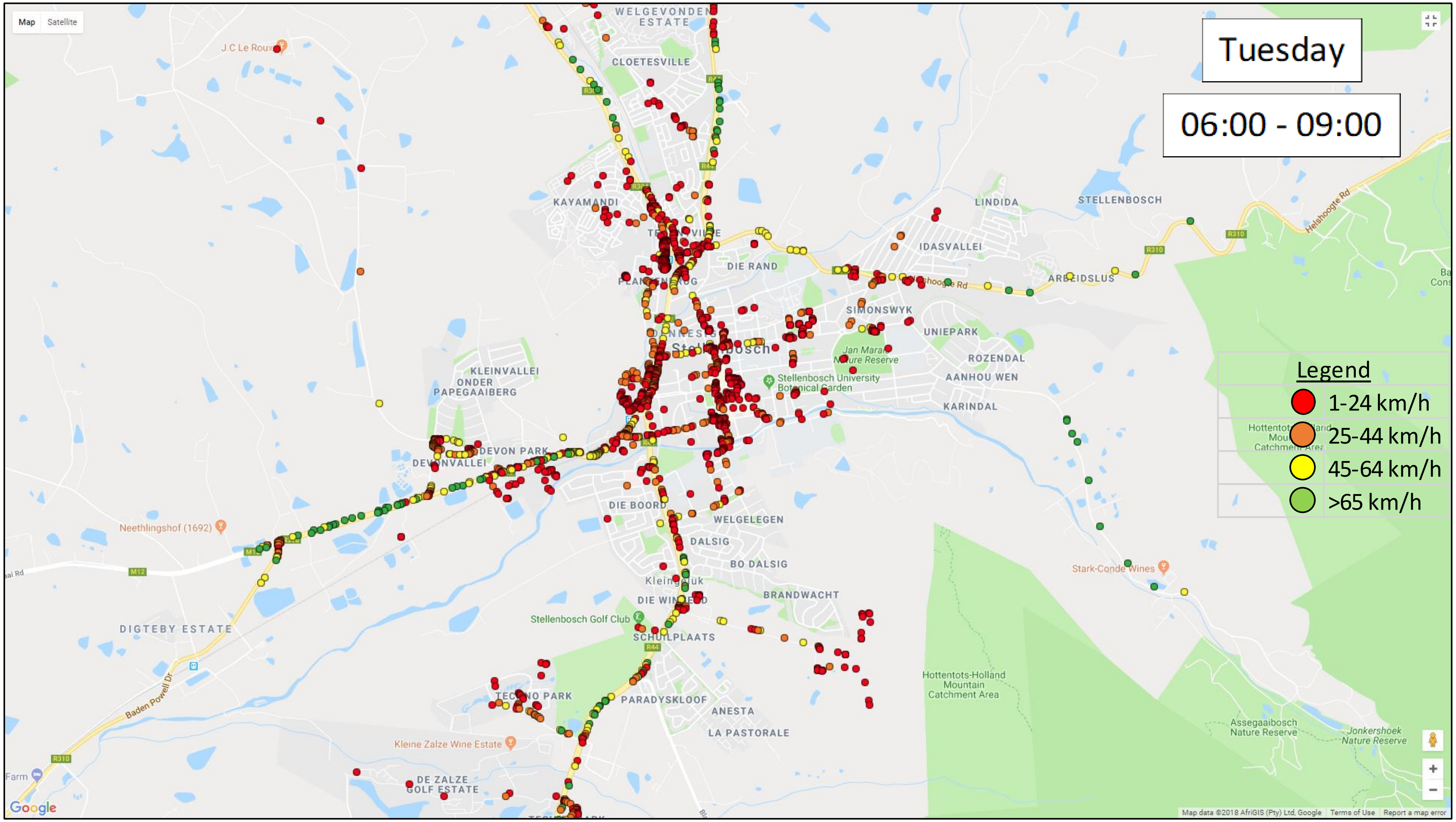

Figure A2.28. *Truck locations recorded between 06:00 and 09:00 on 24 October 2017 (HamsterMap, no date).*

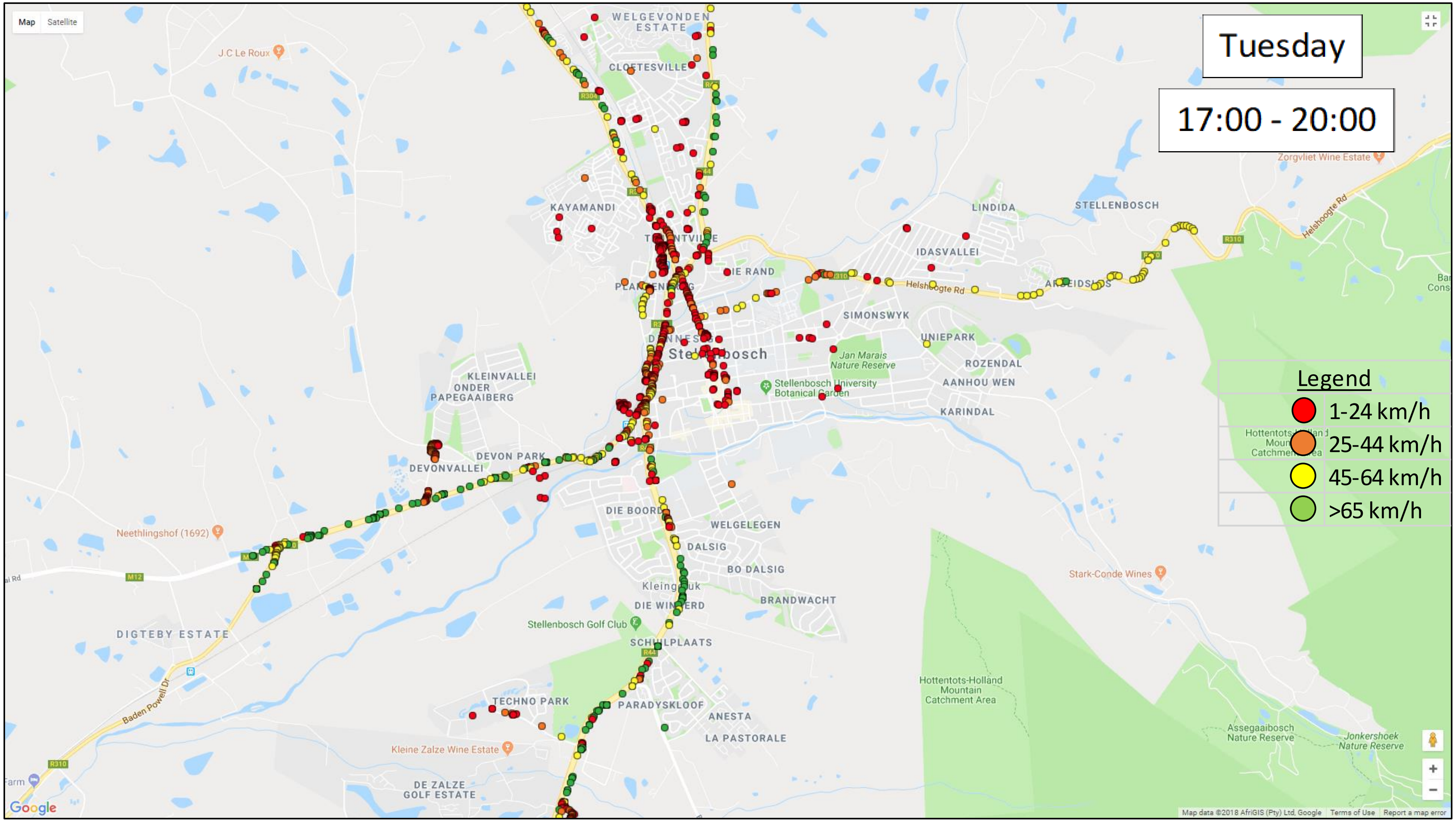

Figure A2.29. *Truck locations recorded between 17:00 and 20:00 on 24 October 2017 (HamsterMap, no date).*

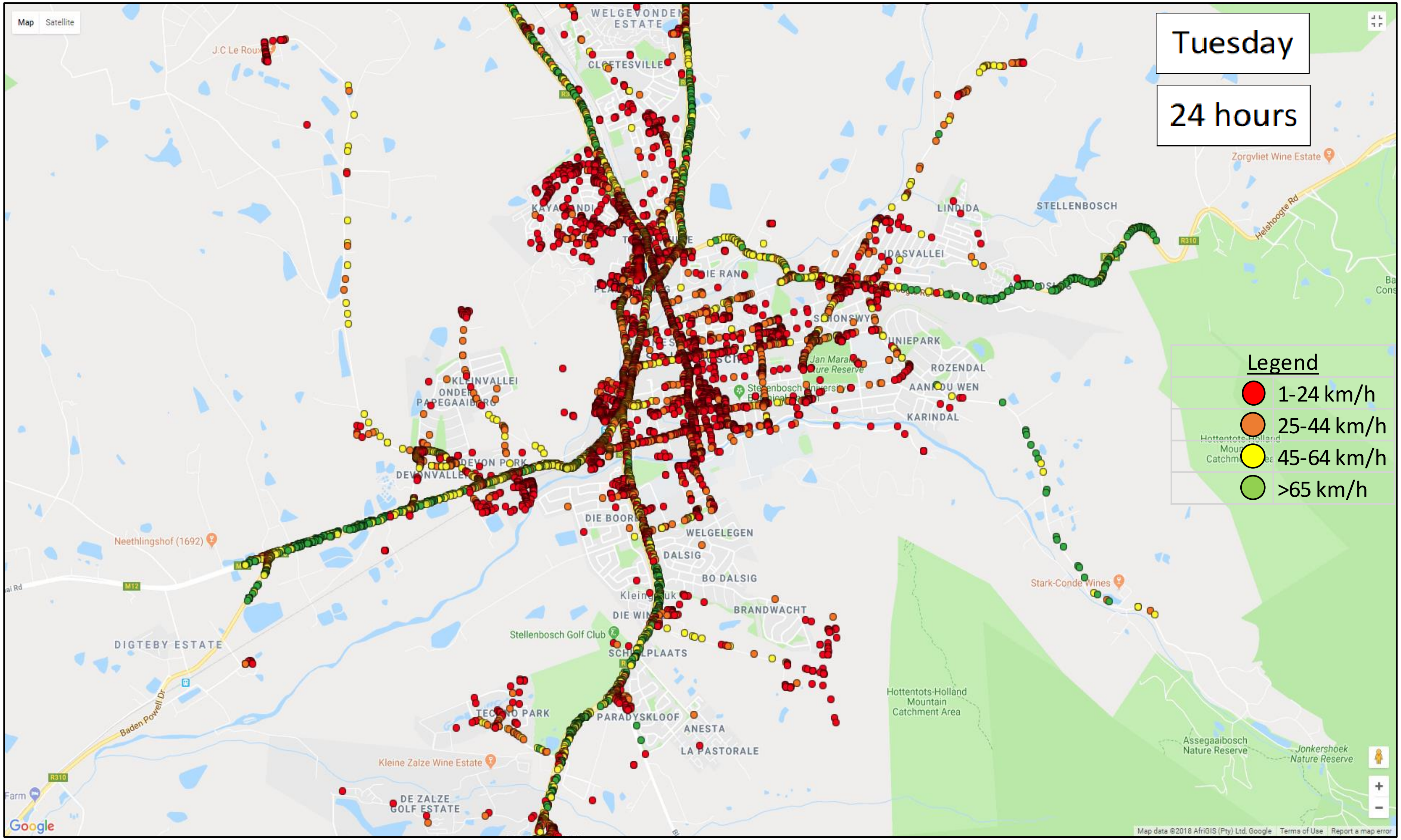

Figure A2.30. All truck locations recorded on 24 October 2017 (HamsterMap, no date).

Wednesday, 25 October 2017

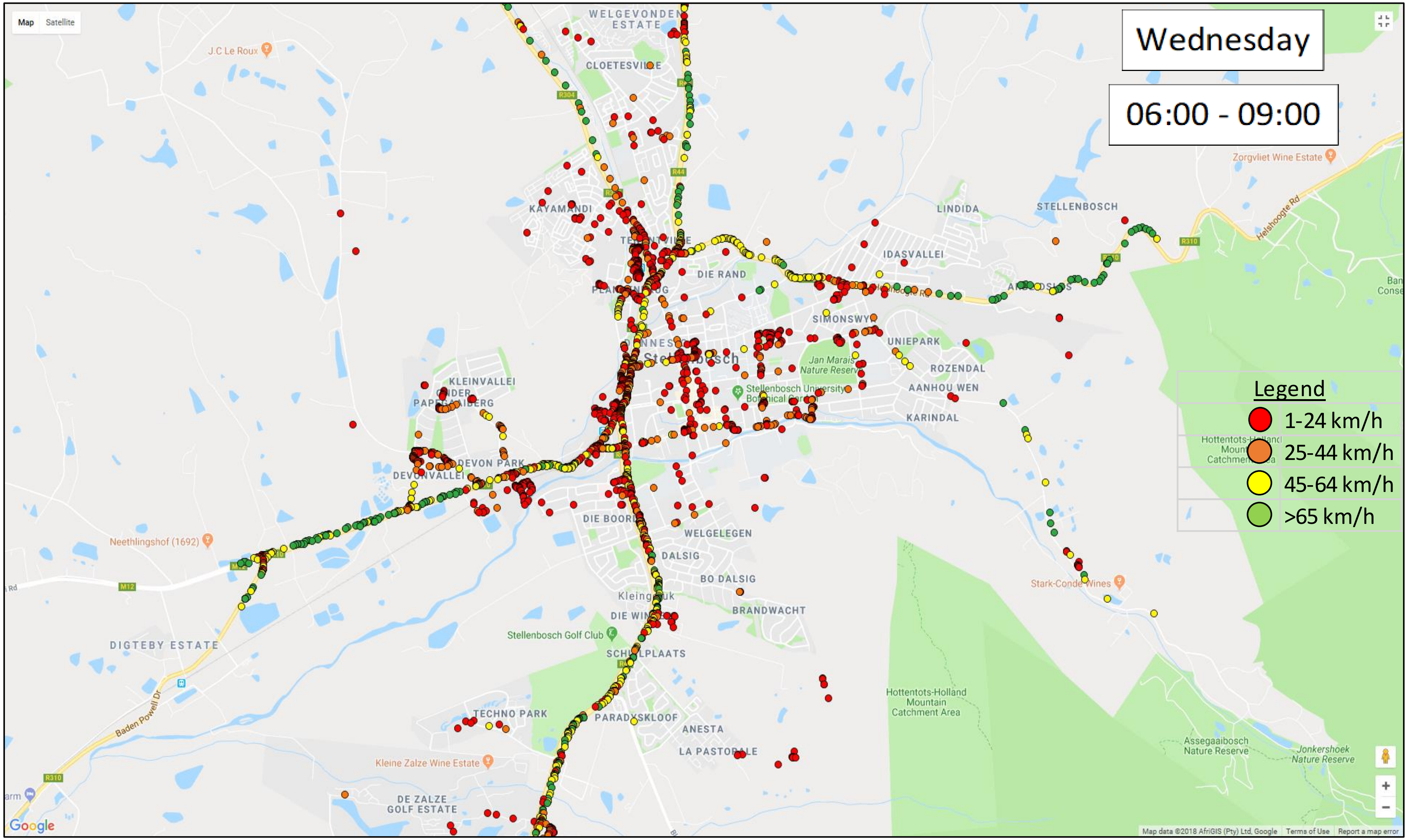

Figure A2.31. *Truck locations recorded between 06:00 and 09:00 on 25 October 2017 (HamsterMap, no date).*

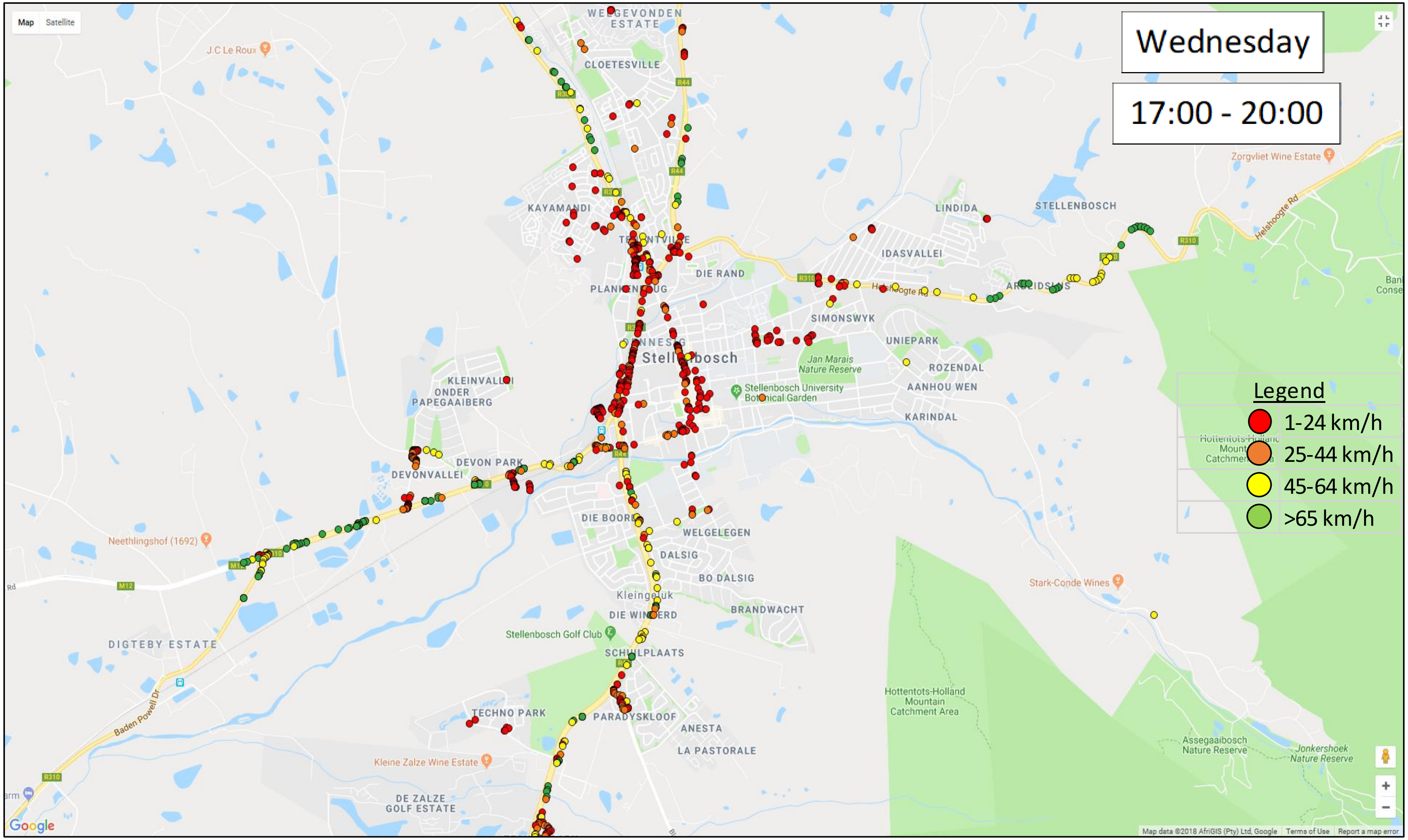

Figure A2.32. *Truck locations recorded between 17:00 and 20:00 on 25 October 2017 (HamsterMap, no date).*

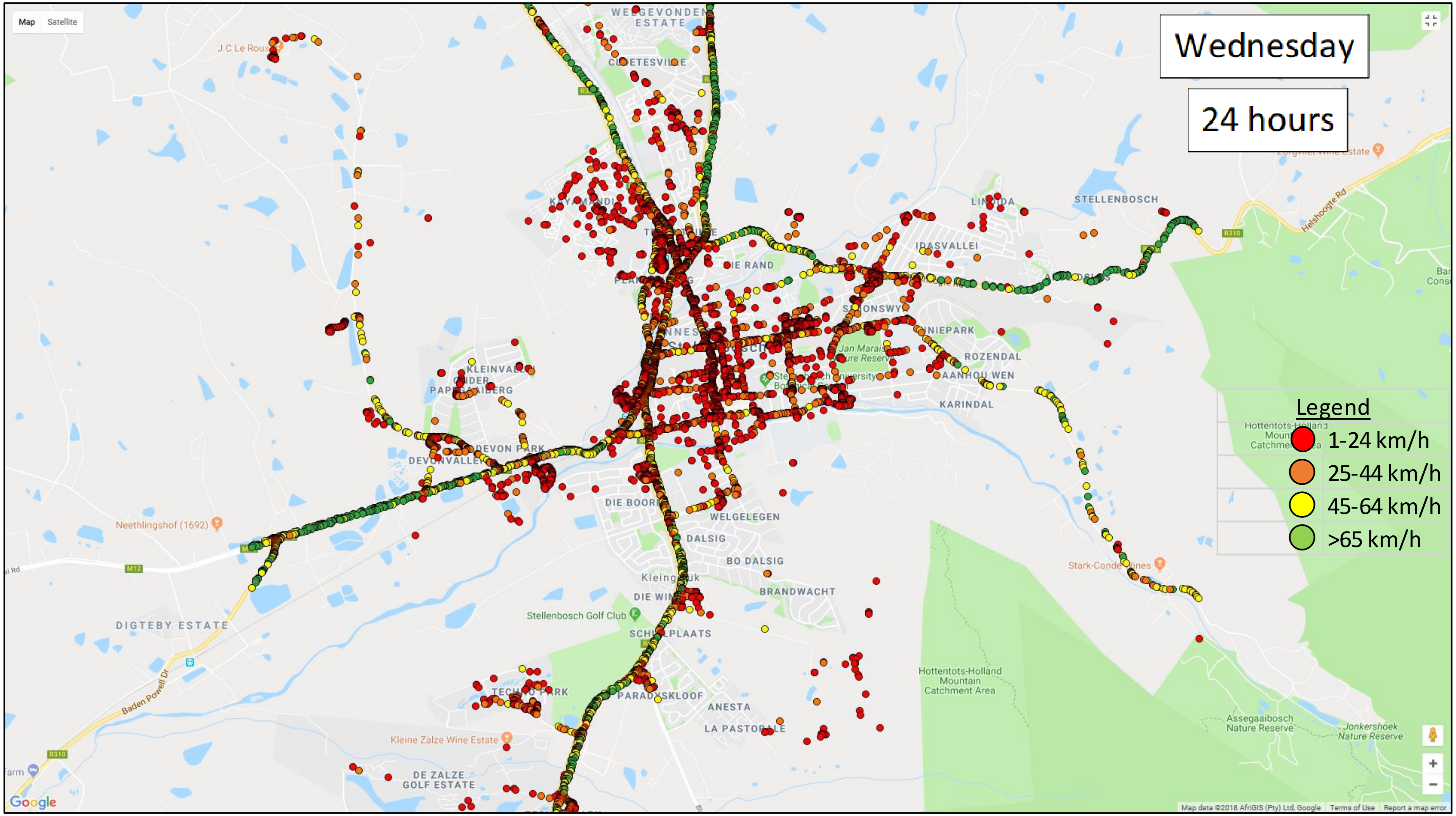

Figure A2.33. All truck locations recorded on 25 October 2017 (HamsterMap, no date).

Thursday, 26 October 2017

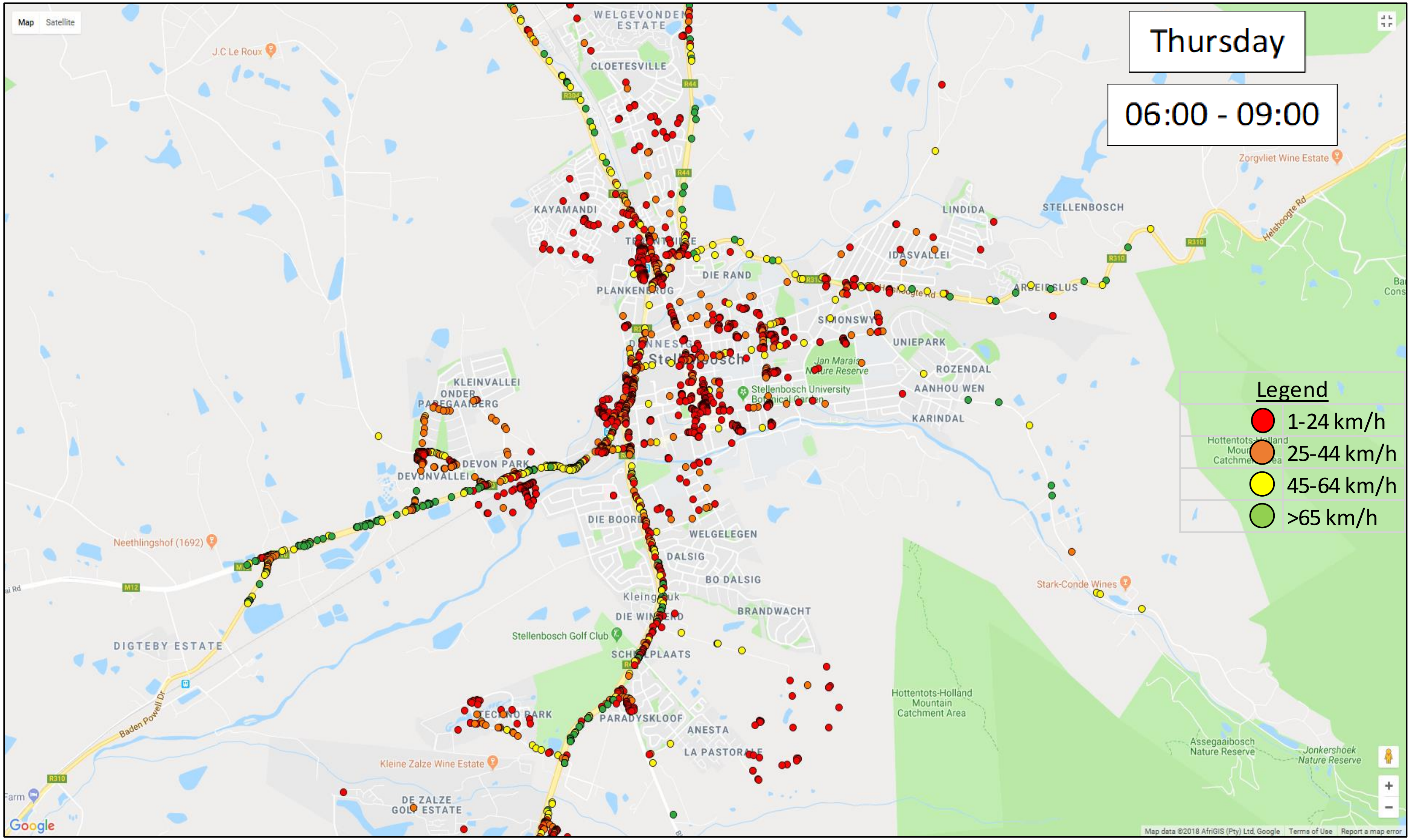

Figure A2.34. *Truck locations recorded between 06:00 and 09:00 on 26 October 2017 (HamsterMap, no date).*

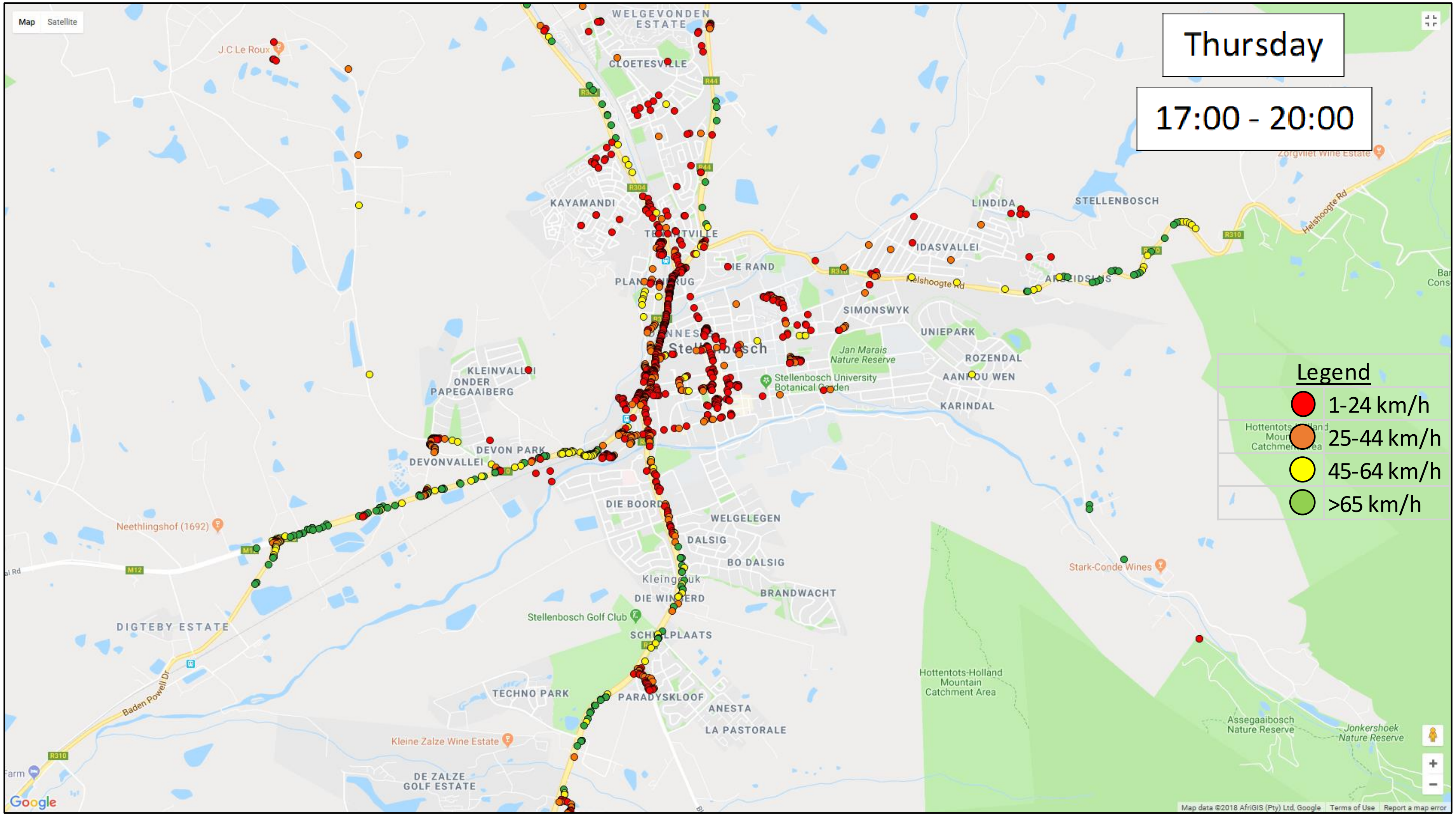

Figure A2.35. *Truck locations recorded between 17:00 and 20:00 on 26 October 2017 (HamsterMap, no date).*

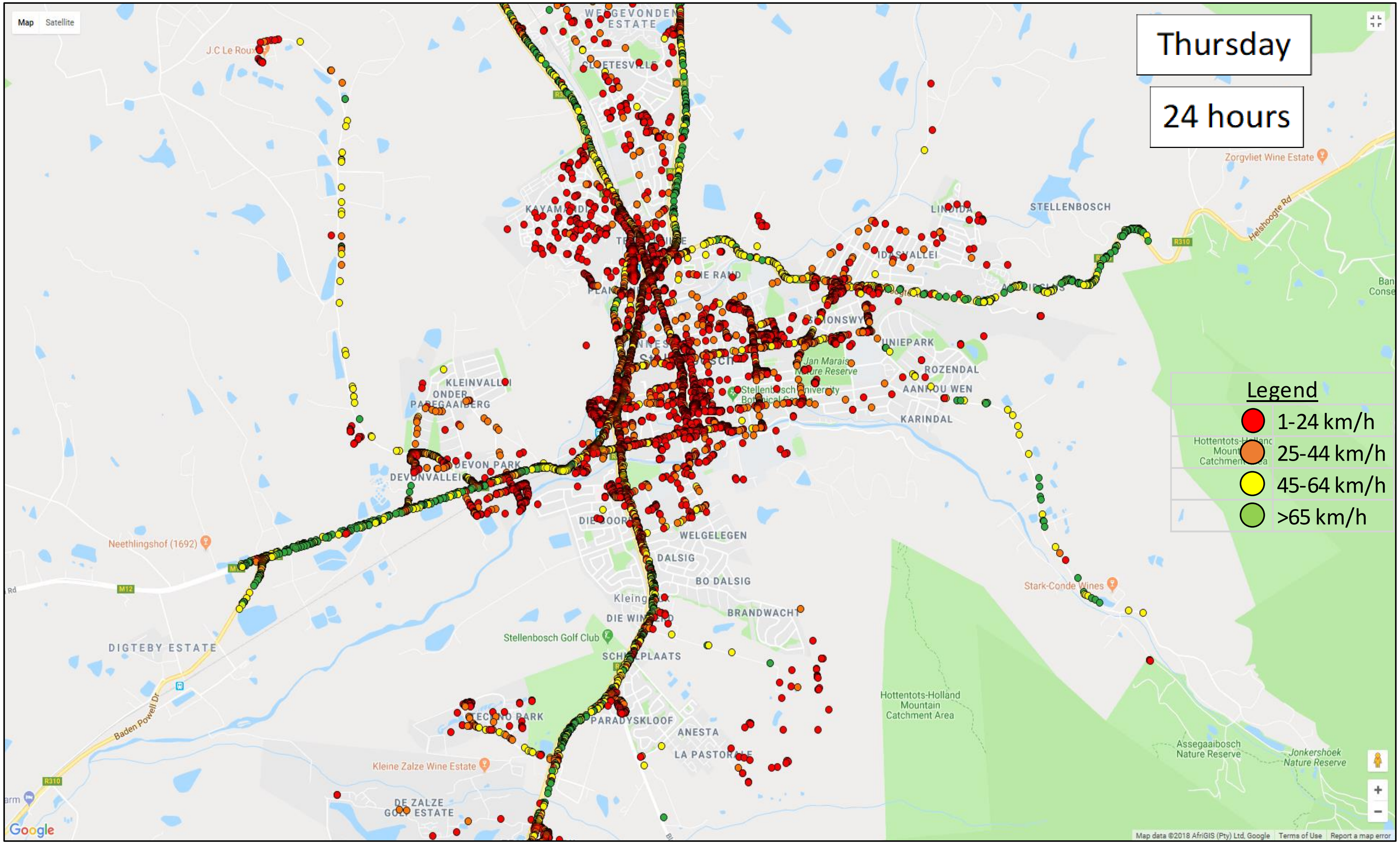

Figure A2.36. *All truck locations recorded on 26 October 2017 (HamsterMap, no date).*

Sunday, 29 October 2017

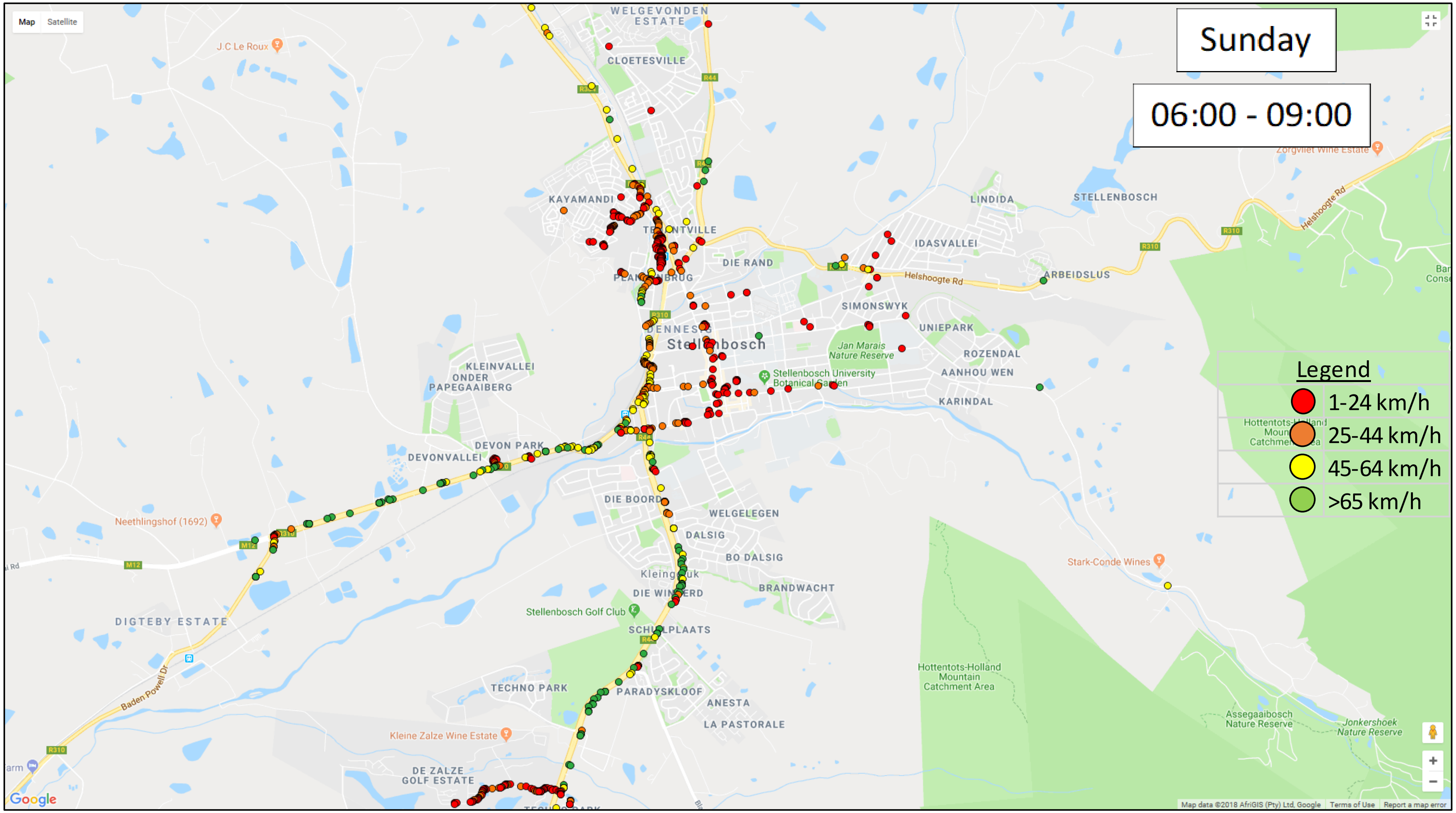

Figure A2.37. *Truck locations recorded between 06:00 and 09:00 on 29 October 2017 (HamsterMap, no date).*

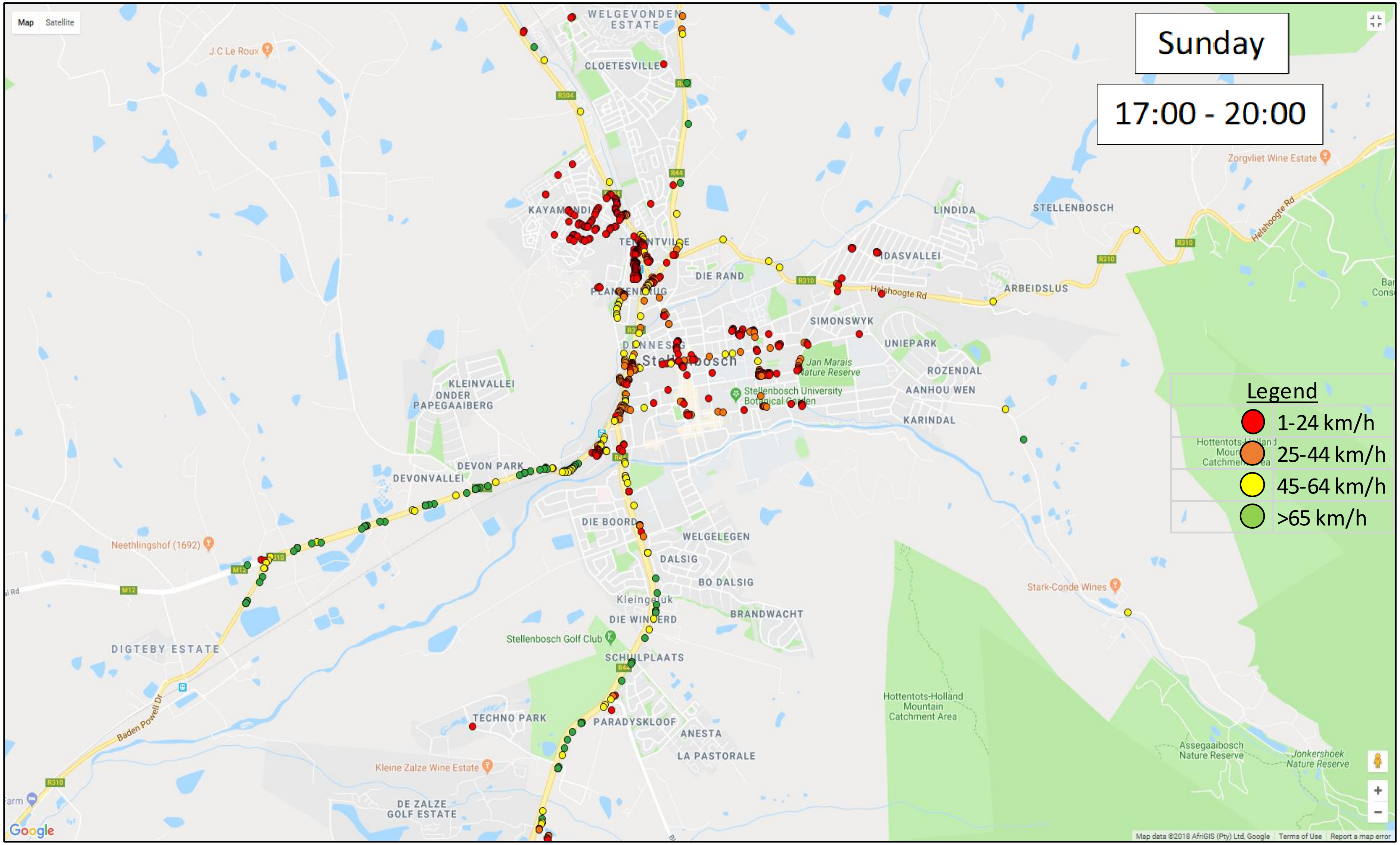

Figure A2.38. *Truck locations recorded between 17:00 and 20:00 on 29 October 2017 (HamsterMap, no date).*

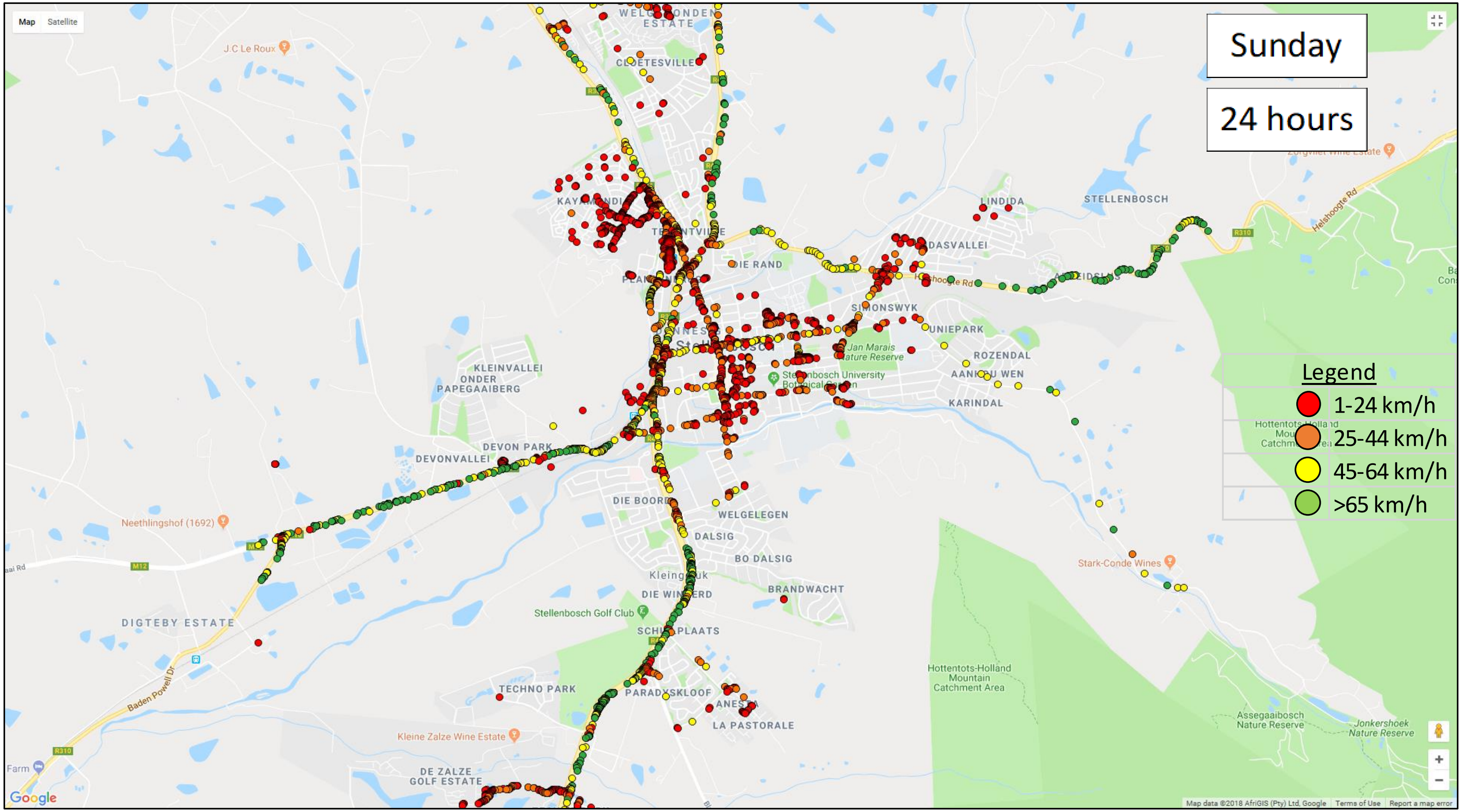

__Figure A2.39.__ All truck locations recorded on 29 October 2017 (HamsterMap, no date).

Tuesday, 31 October 2017

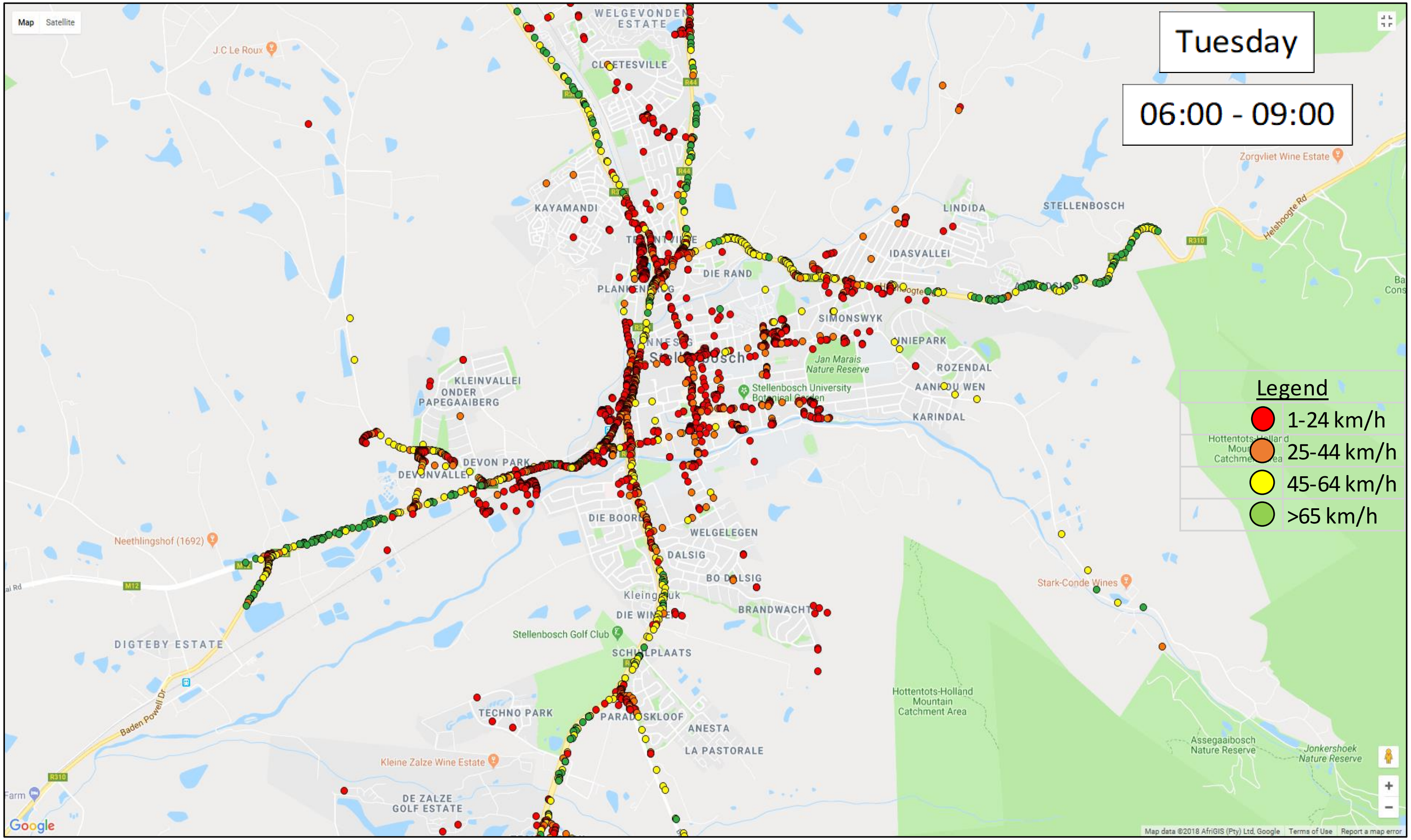

Figure A2.40. *Truck locations recorded between 06:00 and 09:00 on 31 October 2017 (HamsterMap, no date).*

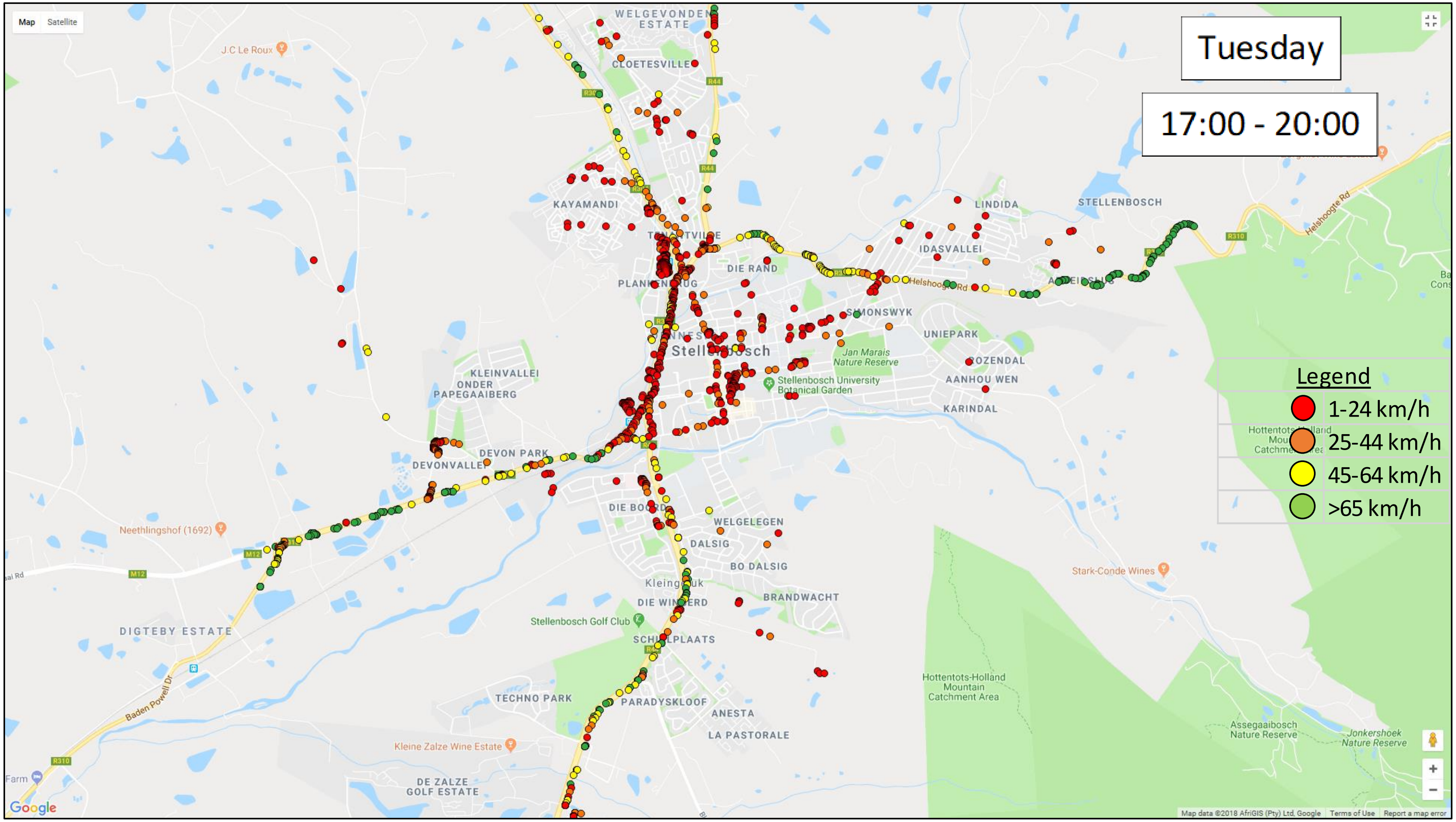

Figure A2.41. *Truck locations recorded between 17:00 and 20:00 on 31 October 2017 (HamsterMap, no date).*

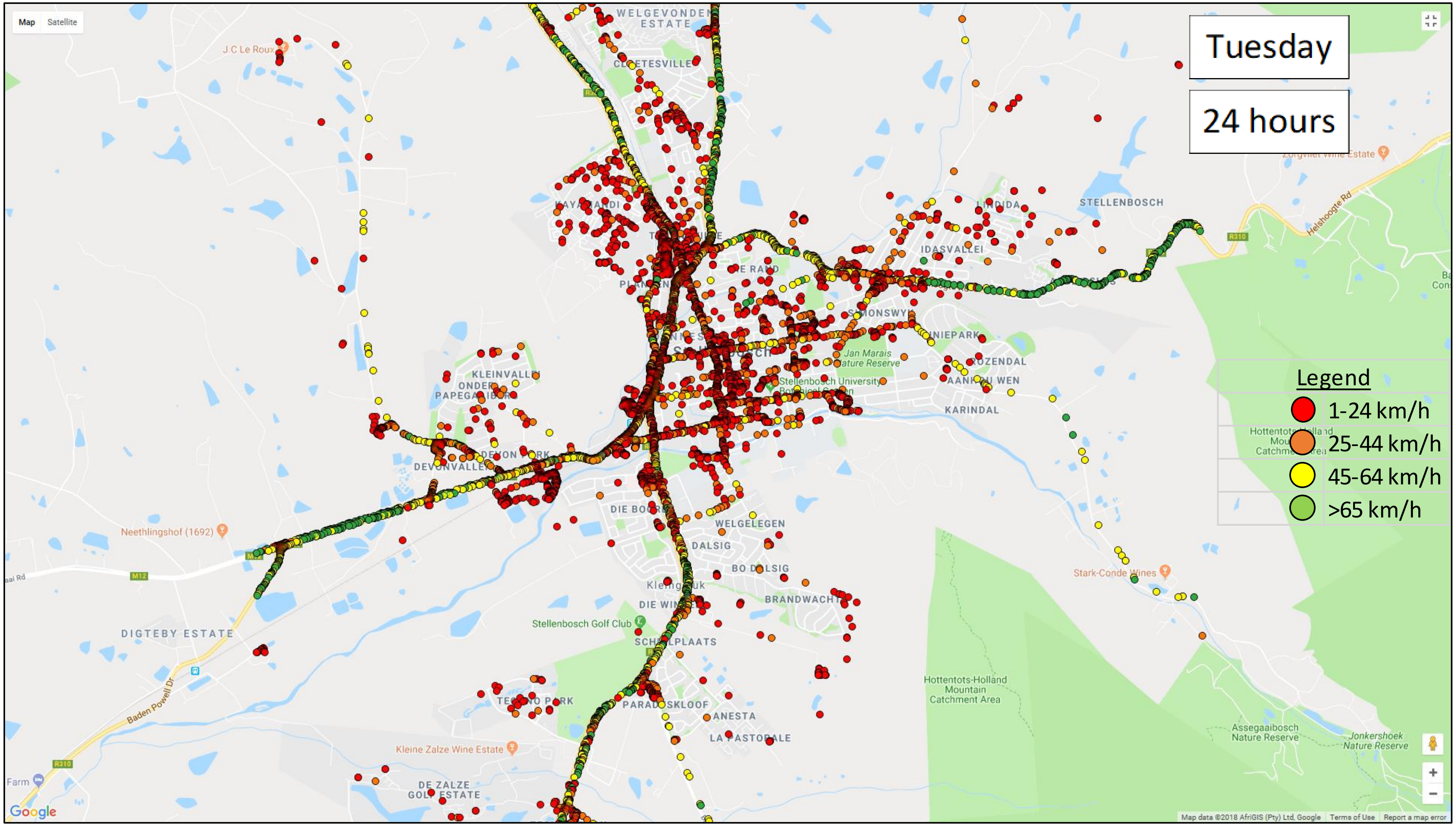

Figure A2.42. All truck locations recorded on 31 October 2017 (HamsterMap, no date).

Wednesday, 1 November 2017

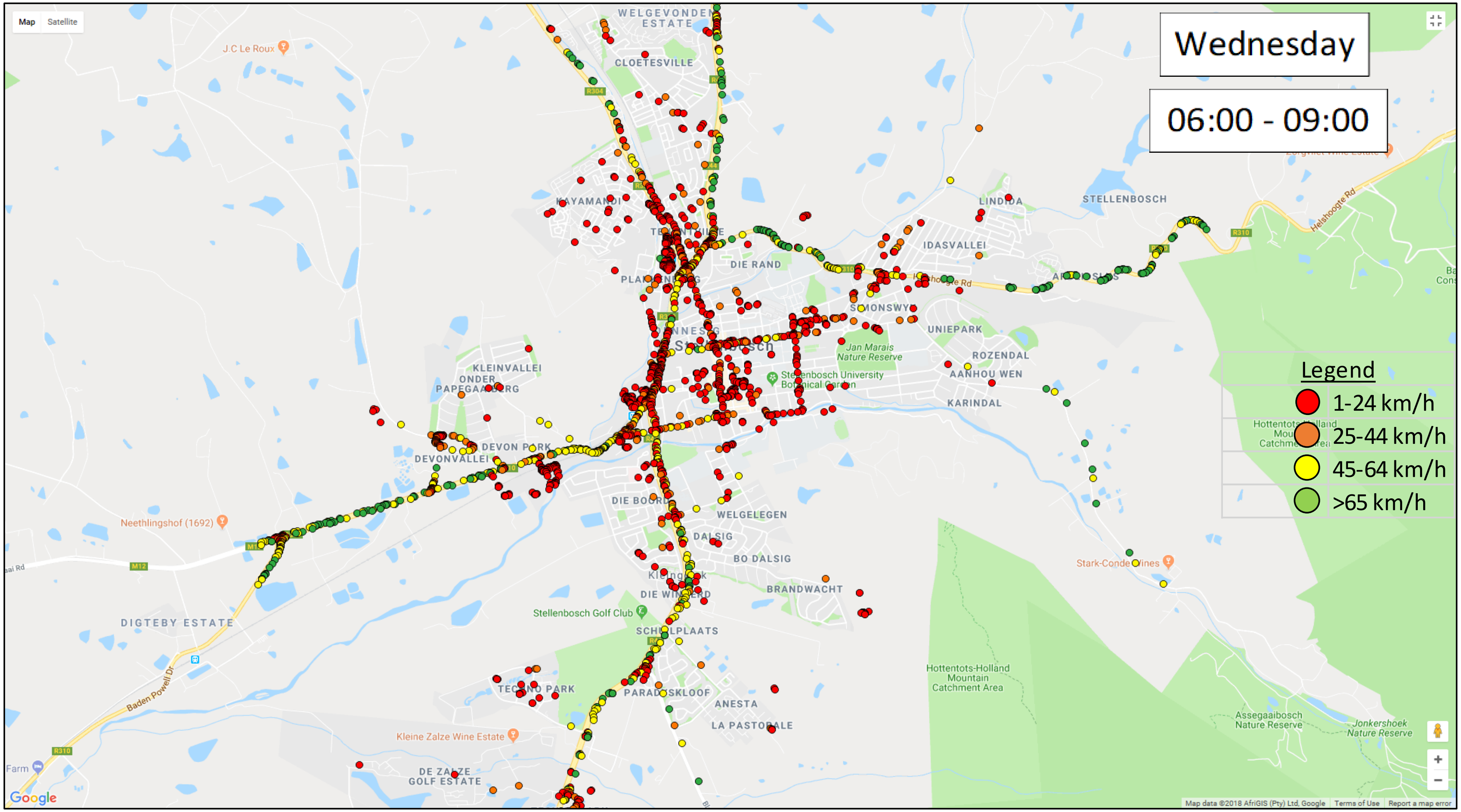

Figure A2.43. *Truck locations recorded between 06:00 and 09:00 on 1 November 2017 (HamsterMap, no date).*

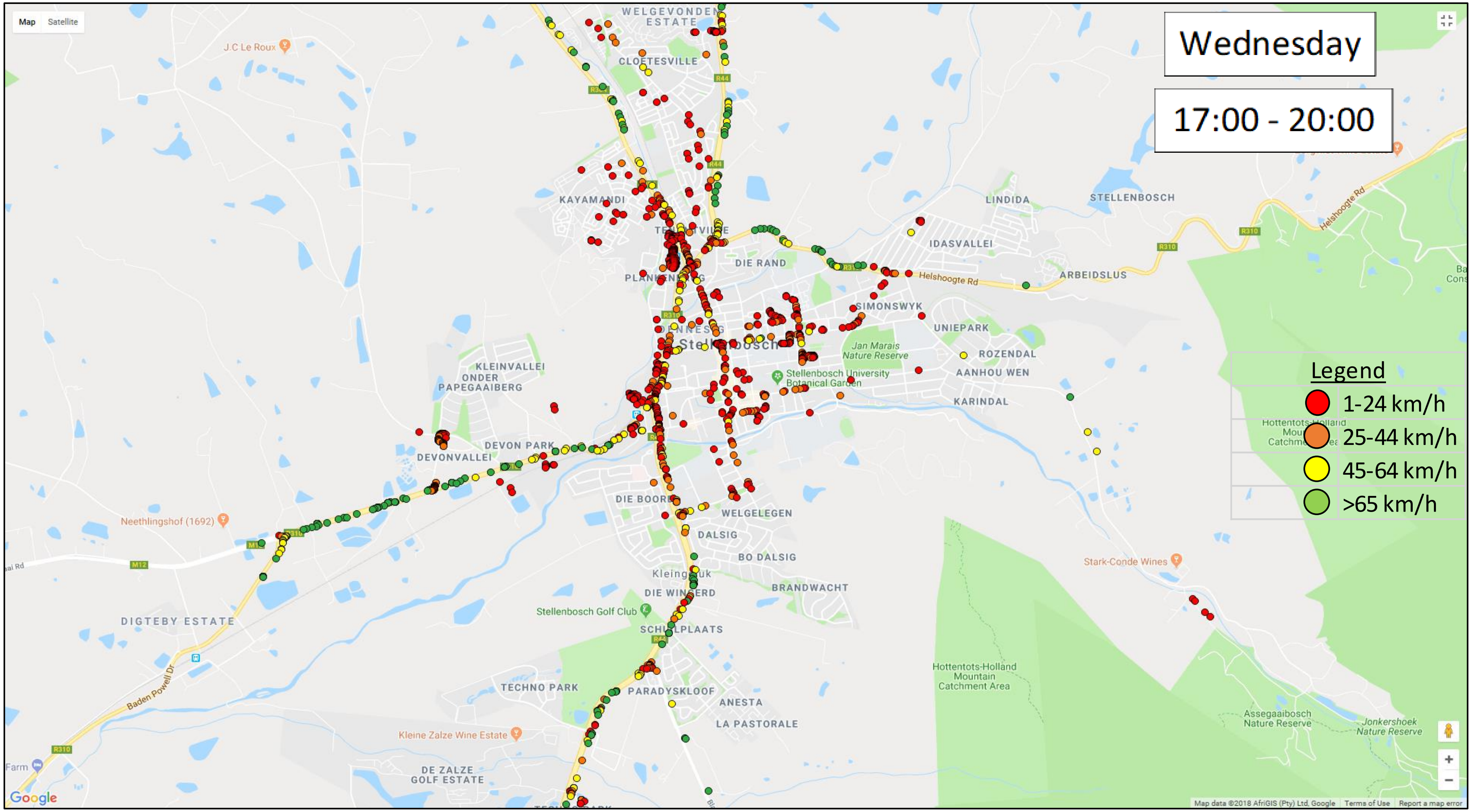

Figure A2.44. *Truck locations recorded between 17:00 and 20:00 on 1 November 2017 (HamsterMap, no date).*

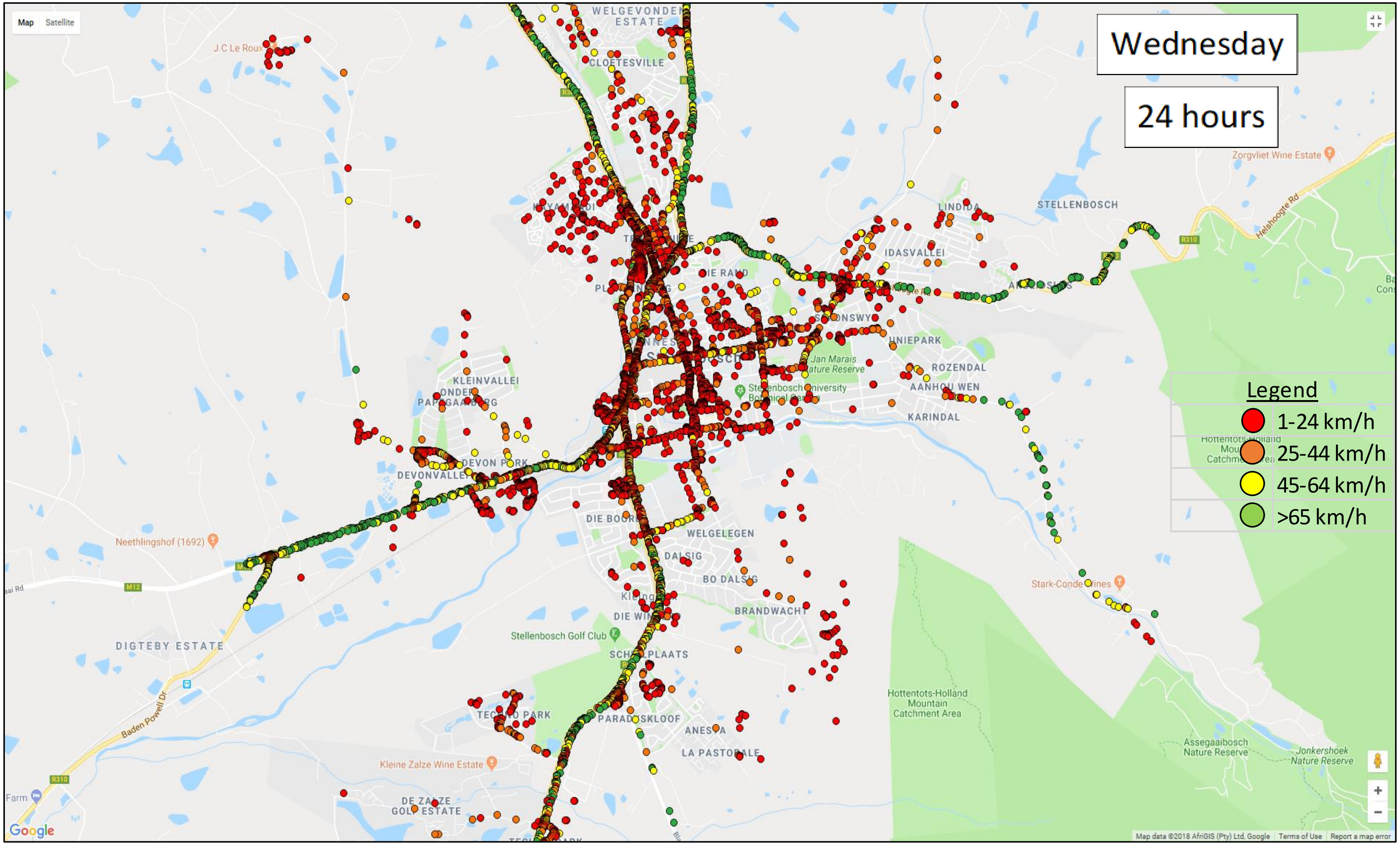

Figure A2.45. *All truck locations recorded on 1 November 2017 (HamsterMap, no date).*

Thursday, 2 November 2017

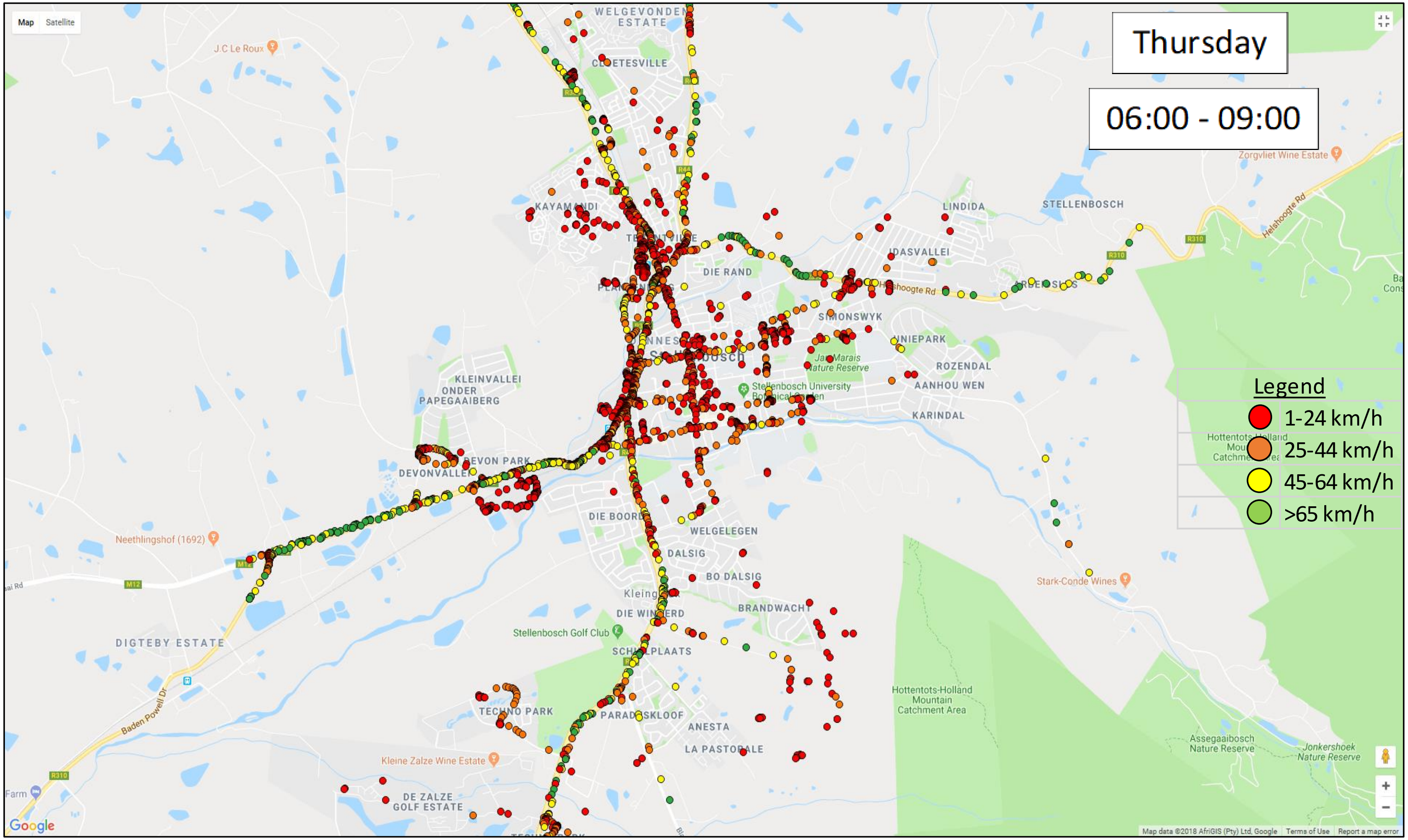

Figure A2.46. *Truck locations recorded between 06:00 and 09:00 on 2 November 2017 (HamsterMap, no date).*

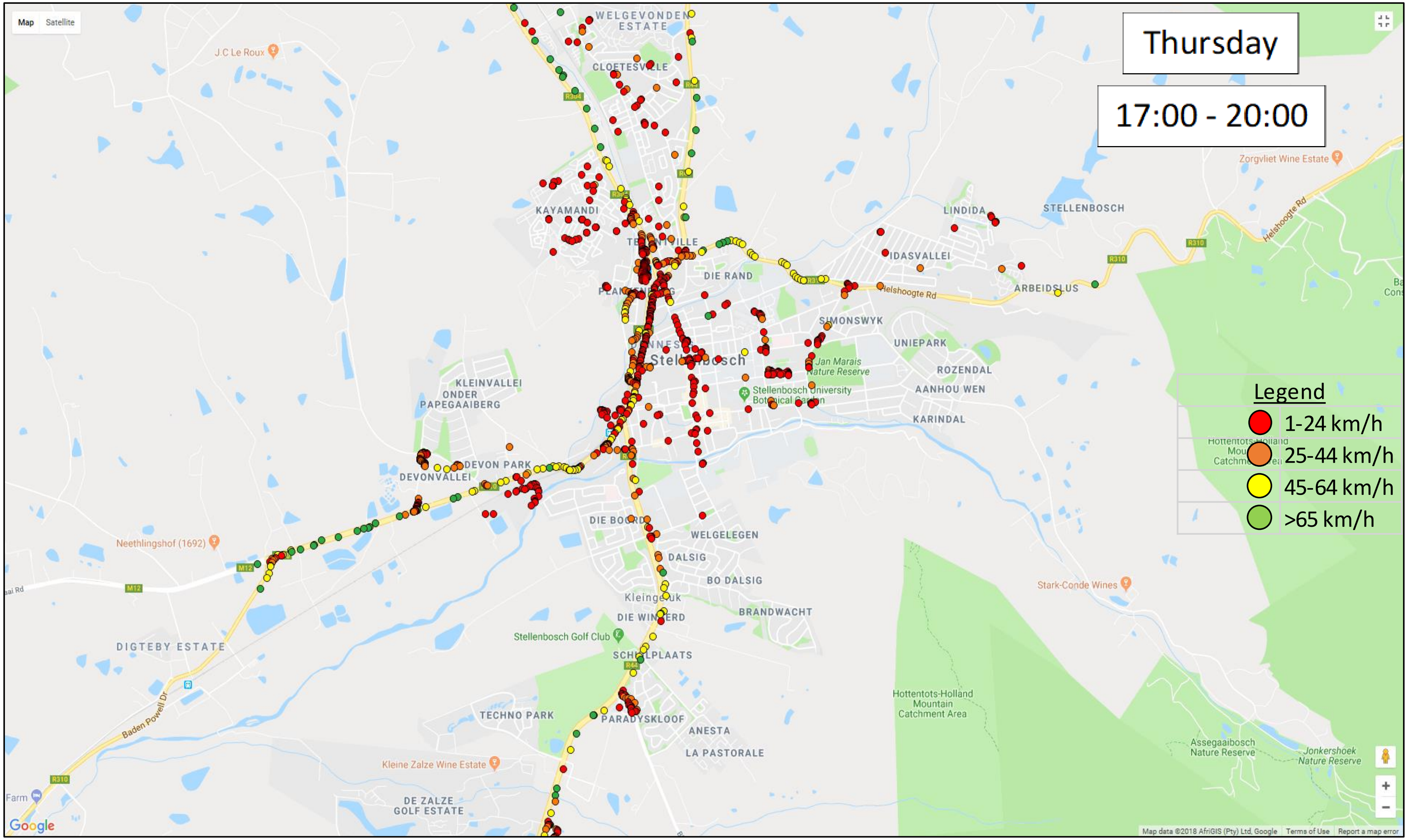

Figure A2.47. *Truck locations recorded between 17:00 and 20:00 on 2 November 2017 (HamsterMap, no date).*

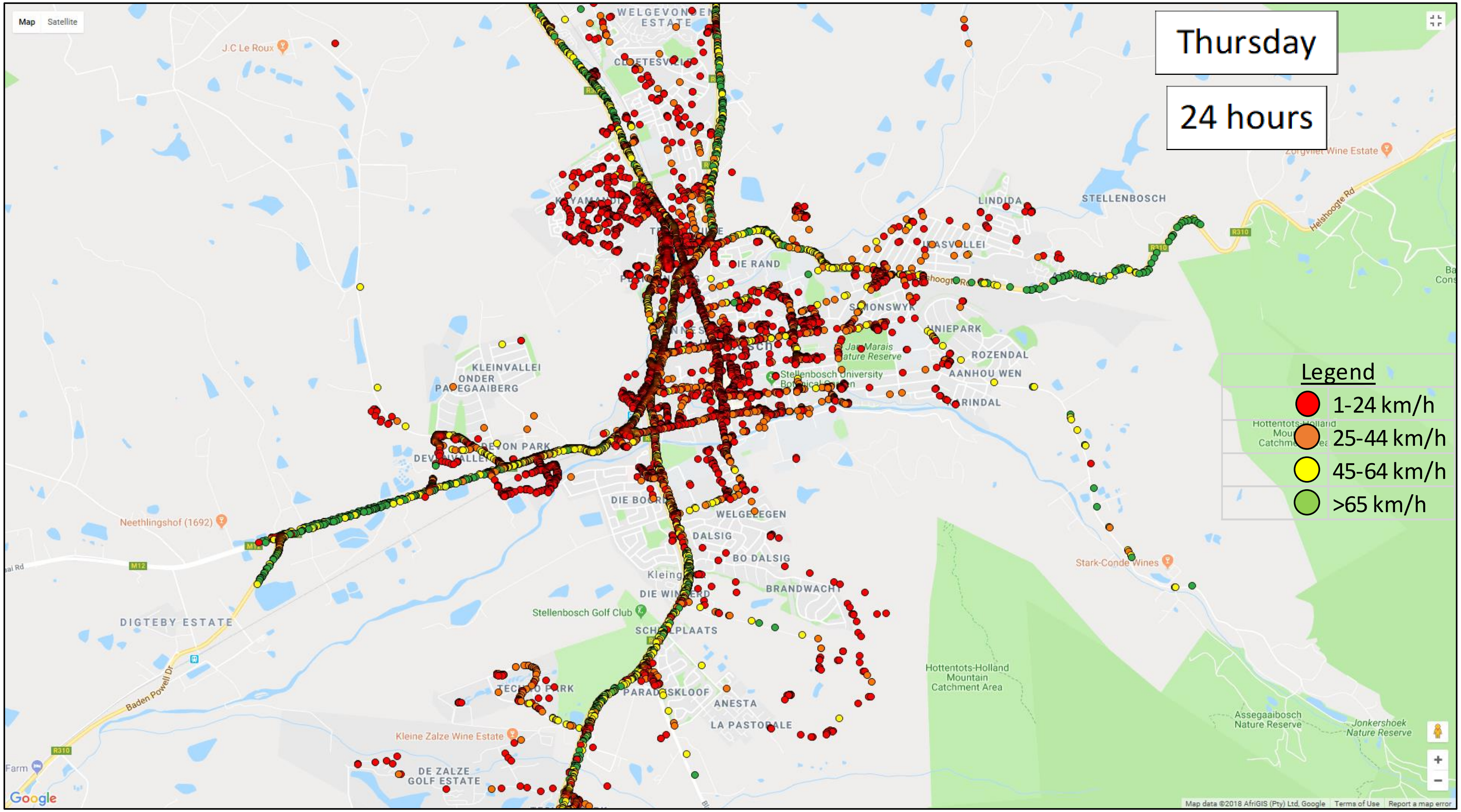

Figure A2.48. *All truck locations recorded on 2 November 2017 (HamsterMap, no date).*

A2.4. Speed reasonability tests

<u>*Sunday, 22 October 2017*</u>

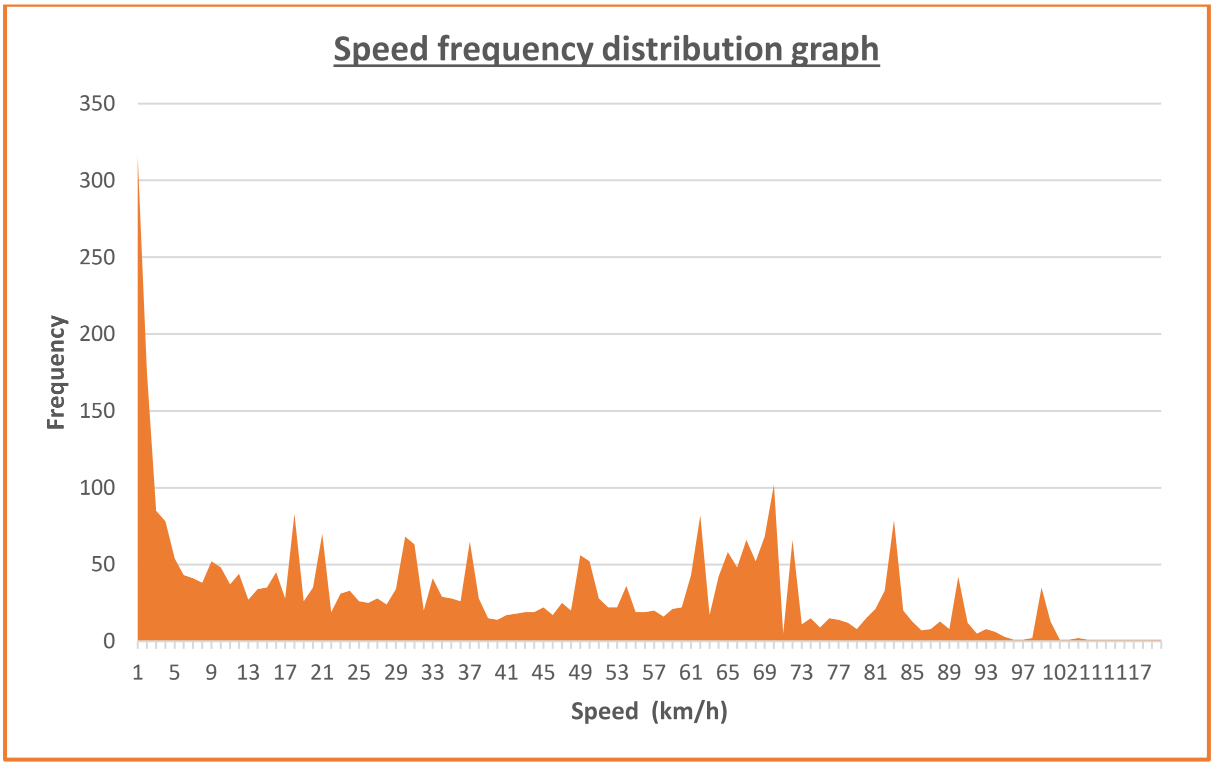

Figure A2.49. *Speed frequency distribution graph of 22 October 2017.*

<u>*Tuesday, 24 October 2017*</u>

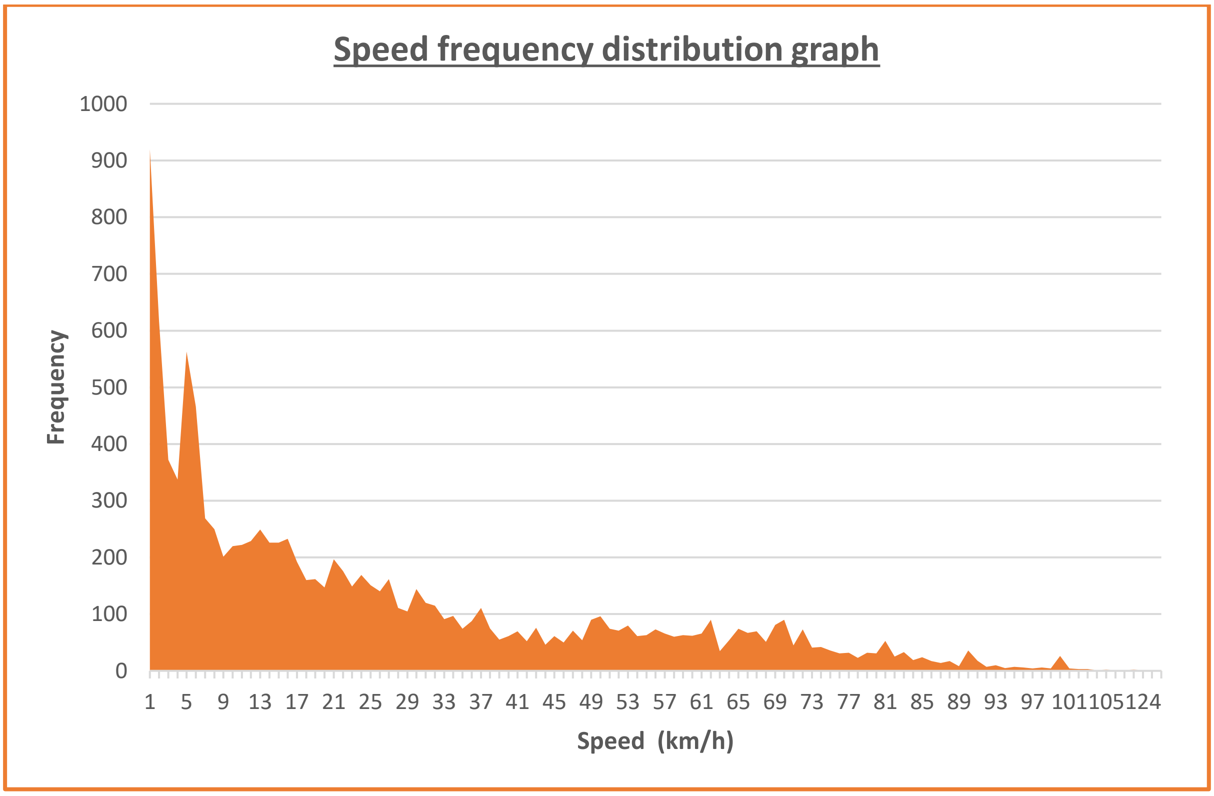

Figure A2.50 *Speed frequency distribution graph of 24 October 2017.*

Wednesday, 25 October 2017

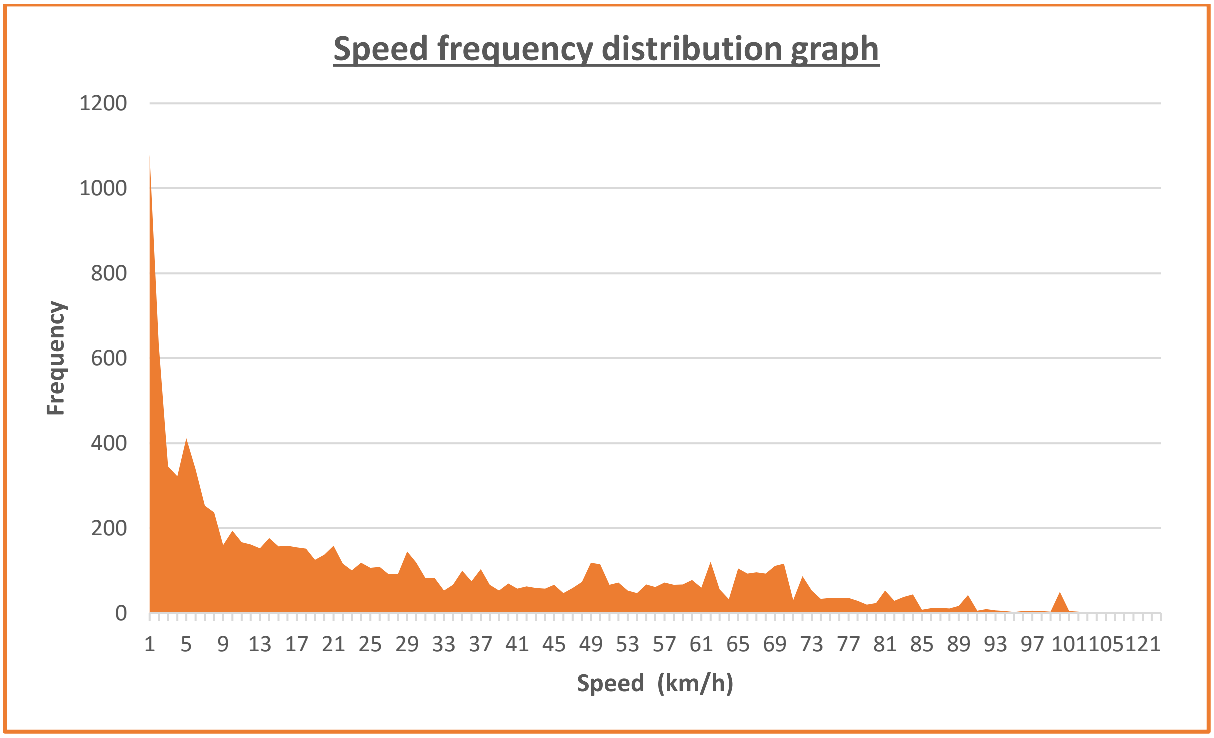

Figure A2.51. *Speed frequency distribution graph of 25 October 2017.*

Thursday, 26 October 2017

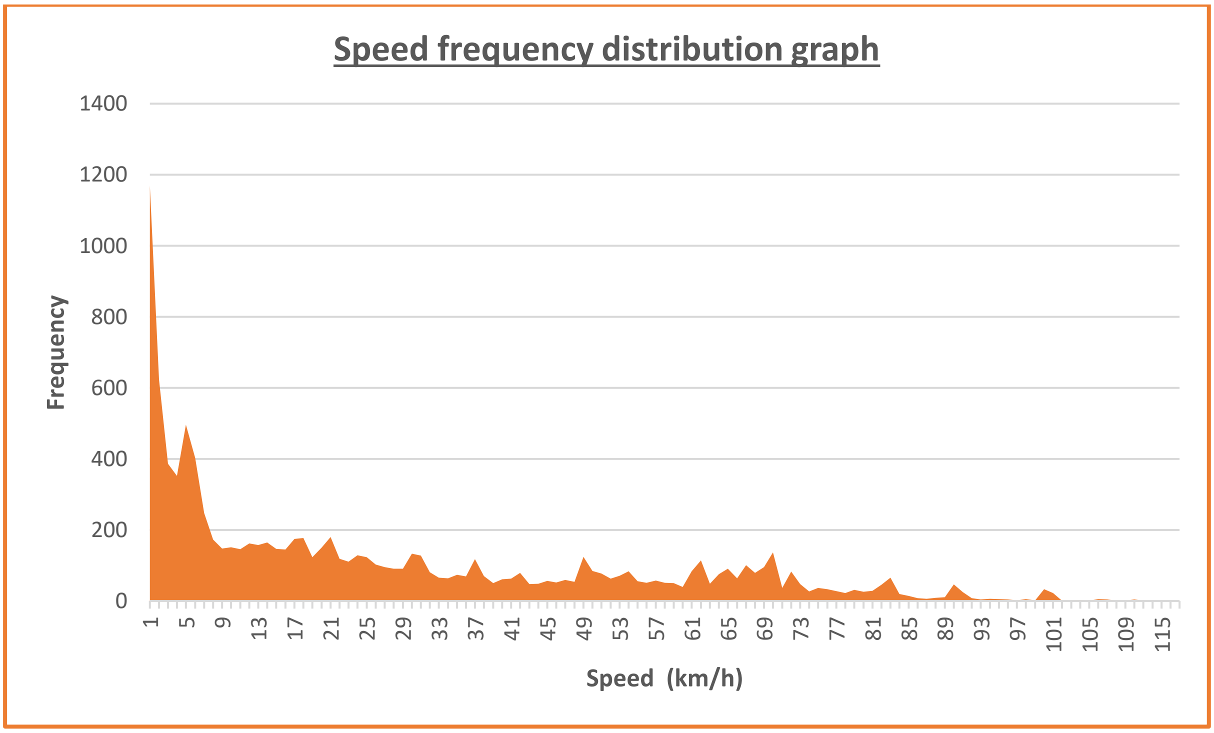

Figure A2.52. *Speed frequency distribution graph of 26 October 2017.*

Sunday, 29 October 2017

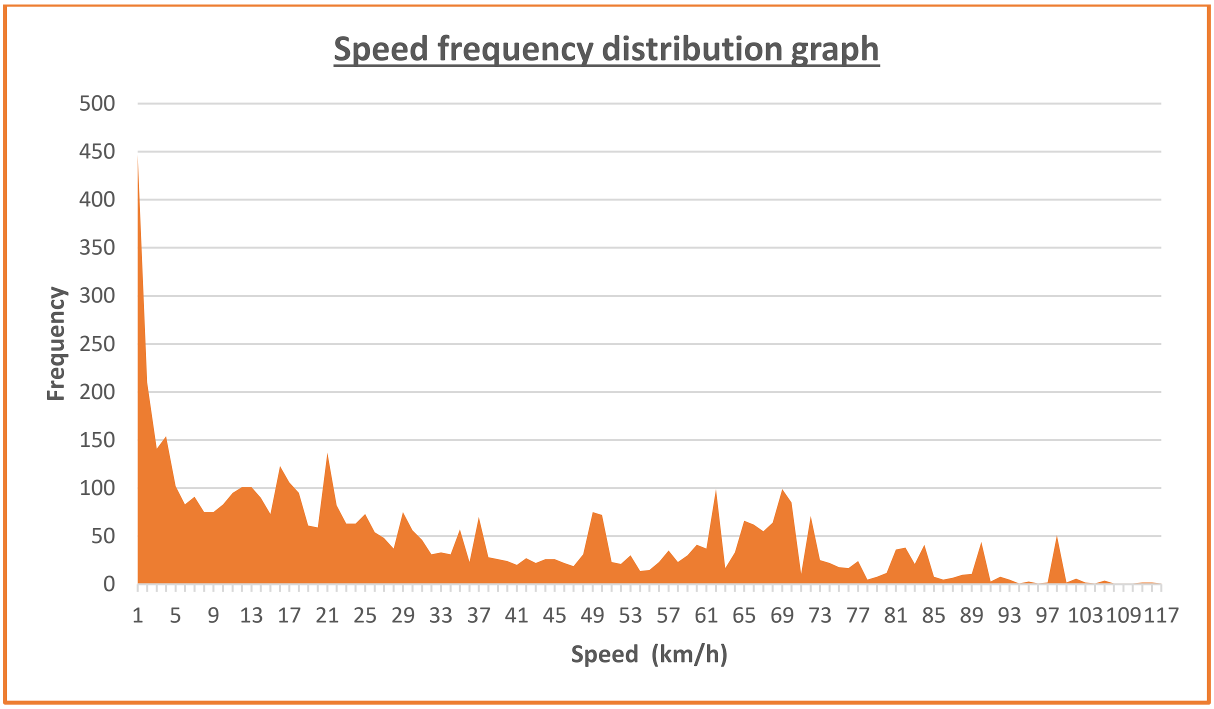

Figure A2.53. *Speed frequency distribution graph of 29 October 2017.*

Tuesday, 31 October 2017

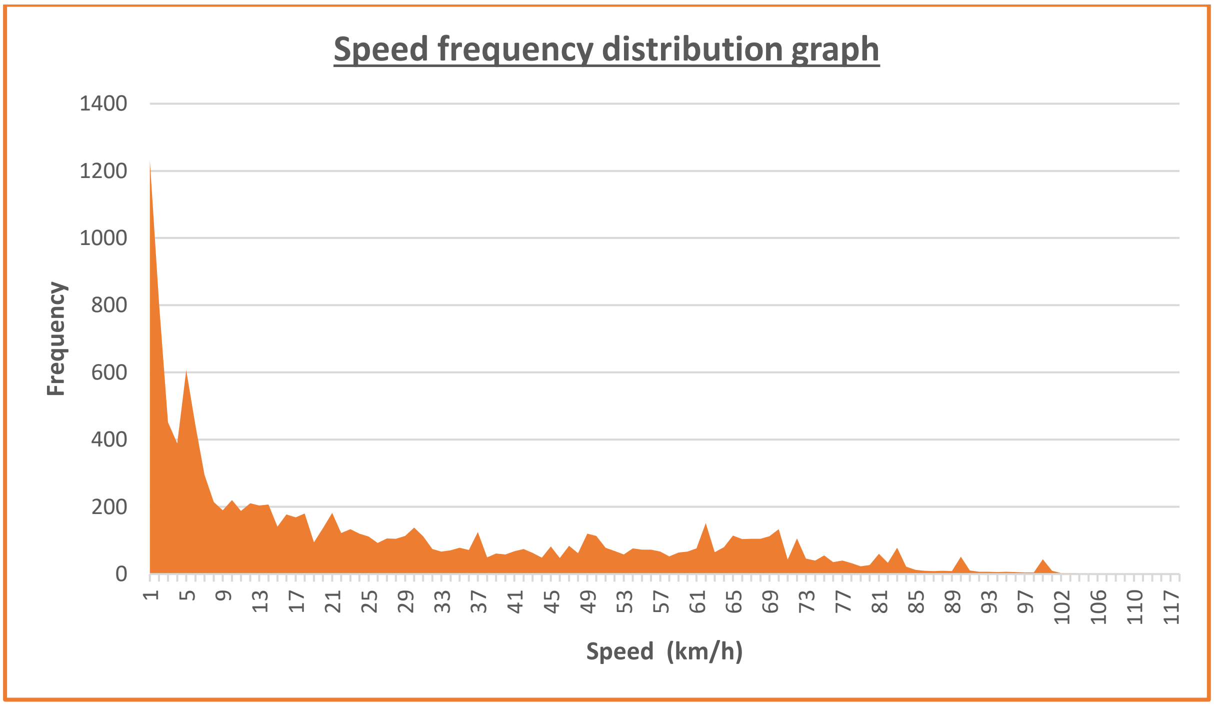

Figure A2.54. *Speed frequency distribution graph of 31 October 2017.*

Wednesday, 1 November 2017

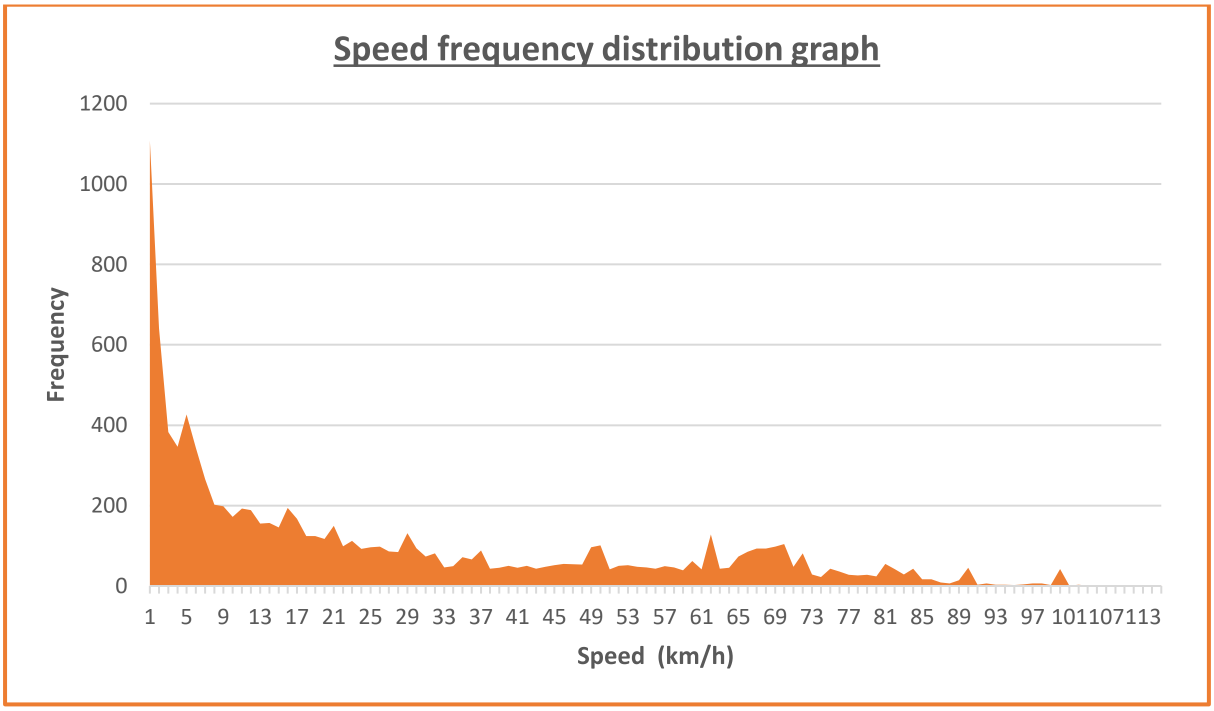

Figure A2.55. *Speed frequency distribution graph of 1 November 2017.*

Thursday, 2 November 2017

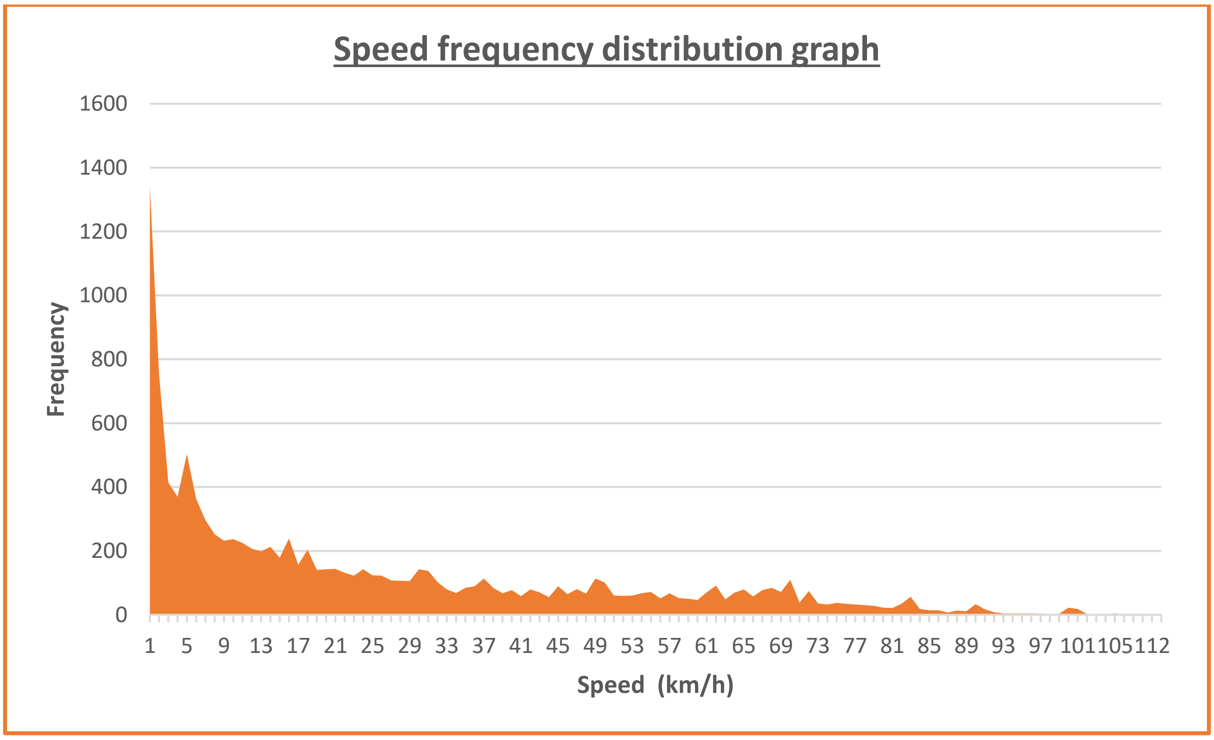

Figure A2.56. *Speed frequency distribution graph of 2 November 2017.*

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HamsterMap (no date) *Create a MAP pasting data data from Excel!* Available at: http://www.hamstermap.com/custommap.html (Accessed: 15 November 2017).