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Intelligent Transport Systems for South Africa:  
Contextual Investigation of the Application of Non-Motorised Transport Intelligent Transport Measures

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## Summary

The transition towards "smart" environments utilising technology has given rise to Intelligent Transport Systems (ITS) to enhance transport system efficiency and safety. Often overlooked Non-Motorised Transport (NMT) has not received sufficient attention, despite its importance in making cities sustainable. The development of ITS has been focused on motorised vehicles, with little attention paid to NMT. This study aims to bridge the gap where it will investigate different advancements in ITS specifically targeted towards NMT and analyse their applicability in South Africa, using a few case studies within the City of Cape Town. The objective is to evaluate the effectiveness of such measures and provide recommendations for further testing or implementation of identified measures.

This dissertation examines the impact, types, and advantages of Intelligent Transport System (ITS) measures, focusing on Non-Motorised Transport (NMT), and identifies significant applicable lessons for specific contexts. Several studies suggest that ITS measures have multiple benefits, including reducing traffic congestion, improving road safety, lowering fuel consumption, and enhancing public transport reliability. Vanderschuren (2006) identified six key objectives of ITS measures: safety, mobility, efficiency, productivity, sustainability, and environmental impact. This dissertation explores some of the ITS measures and how they intend on achieving their objectives.

This dissertation focuses on exploring the benefits of a few established Intelligent Transportation Systems (ITS) measures globally and identifying key improvements and benefits. The purpose of studying the literature is to determine the success of implementing these ITS measures internationally and the benefits yielded. This study presents three international case studies and results. The first study conducted by the United States of America's Department of Transportation Federal Highway Administration where they evaluated the safety effectiveness of Pedestrian Countdown Signals (PCSs) in Charlotte (North Carolina), and Philadelphia (Pennsylvania). The study results showed that after the implementation of PCSs, pedestrian crashes decreased by 9%, total crashes decreased by 8%, and rear-end crashes decreased by 12%. The second case study conducted in Rome, Italy, evaluated the safety improvements obtained with a LED lighting system positioned at the crosswalk section. The study showed that the LED lighting system reduced cars' mean speed by 19.3% at the crosswalk section in illuminated conditions and even by 16.4% in the absence of pedestrians. The third case study from Haarlemmermeer, Netherlands, discussed the use of thermal detection sensors to improve the efficiency of pedestrian push buttons at signalised intersections for smoother traffic, less vehicle idling, and fewer frustrated motorists. By implementing these sensors, the city officials reduced vehicle idling time, air pollution and interruptions in vehicle flow caused by jaywalkers and needless pedestrian green calls. The dissertation concludes that studying the benefits and effectiveness of NMT based ITS measures can provide greater insight into pedestrian safety and can help decide which interventions could work in a local contexts.

This dissertation discusses the challenges facing NMT, such as walking and cycling in African cities. Despite the fact that walking is the dominant mode of transport in African cities, neither walking nor cycling has received the attention they deserve in terms of policy development and implementation. The legacy of colonialism and contemporary focus on automobile-dependent planning are cited as reasons for the lack of attention given to NMT (Vanderschuren and Galaria, 2003). South Africa's complex history, including apartheid, has resulted in unsustainable urban areas with a lack of accessibility. The end of apartheid has led to freedom of movement but has also resulted in an increased demand for transport. Majority of South African commuters are required to travel long distances for job opportunities. Commuters use public transport as long travel distances make walking or cycling infeasible modes. To address this problem, South African cities are adopting a "Corridor City" with Transit Orientated Development, where nodes across the urban area are identified for densification with mixed-use developments and corridors linking them through strong public transport corridors. This strategy will reduce travel time to job opportunities making NMT a more feasible mode of transport. If this proves successful demand for

NMT will significantly, increase thus will require to carefully planning infrastructure to accommodate future demand.

The dissertation explored various ITS measures for NMT globally, but local contextual constraints may affect their effectiveness. Further, the dissertation explains how non-compliant pedestrian behaviour in South Africa presents a challenge for ITS measures that rely on traffic rules compliance. This also highlights the different groups of ITS measures and their applicability in the South African context.

This dissertation explored two local case studies in Cape Town namely a combination of a traffic signal countdown timer and LED lane lights and the second case study of thermal sensors installed at a pedestrian crossing.

Based on this dataset it appears that compliance have not improved by implementation of traffic signal countdown timer, hence, in this case study the countdown pedestrian signal appears to be ineffective in influencing pedestrian behaviour.

To determine how effective the implementation of the LED lane lights are a comparison between the numbers of drivers adhering to the solid-white stop line (during the vehicle-red signal phase) pre-and-post lane lights were installed.

It is evident from the case study that there is a clear reduction (from 26% to 6%) in the average number of stop line violations, specifically on weekends. Due to the fact that driver behaviour during the week is expected to be relatively more aggressive compared to weekends the data reflected higher violations than in comparison to weekdays.

The next case study explored was recent implementation of pedestrian thermal sensors installed in the City of Cape Town as a pilot project. The thermal sensor since installation resulted in no more cases of signal vandalism reported and it appears that pedestrian crossing efficiency has been improved. Unfortunately, limited data pre-installation was available hence all analysis done was post installation in comparison to design norms. Early indications shows a 40% improvement however longer trails are required to be tested for conclusive evidence.

In summary, the literature and case studies support the idea that ITS measures that requires high levels of traffic compliance are likely to be ineffective in the South African context but ITS measures that do not require high levels of traffic compliance is applicable to South African context. The challenge is prioritisation and lack of infrastructure, as road safety is such a prominent problem in South Africa funding and focus are geared towards making road environments safe before funding is spent in optimisation. The secondary challenge is that the NMT network within South Africa is not at the level of developed counties thus before implementation of ITS measures for optimisation NMT infrastructure networks required to fully established.

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# 1. Introduction

## 1.1. Thesis Background

Transport systems are fundamental in the functioning of any society. Transport systems play a vital role in increased productivity and increase in economic growth however there are many associated negative externalities that stem from transport systems such as (Santos, G. et al, 2010):

- Accidents
- Infrastructure impacts
- Environmental impacts
- Congestion
- Oil Dependence
- Social Impacts and
- Economic impacts

One of the latest trends globally in the past few decades has been the transition towards ‘smart’ environments, utilising advancements in technology and the ‘internet of things’ to improve society. The transport sector has not been left behind, with technology being integrated into transportation systems. This integration has given rise to its own field, known as Intelligent Transport Systems (ITS), which is applied across various elements of transport engineering. The primary objective of ITS is to enhance transport system efficiency and safety through monitoring, evaluation, and management. Some examples of ITS applications in transport include autonomous vehicles, connected vehicles, smart intersections, and Mobility as a Service (MaaS). ITS measures if applied correctly can play an important role in mitigating many of the negative externalities that transport systems cause.

Non-Motorised Transport (NMT) is an aspect that is often overlooked in relation to ITS implementations and has not received sufficient attention, despite its importance in making the future of cities sustainable. Creating mixed land-use environments where the majority of trip requirements can be met through NMT is a significant element of achieving sustainability in cities. Therefore, it is crucial to explore the use of ITS measures for NMT, as NMT is expected to become even more critical in future cities.

While time constraints will not permit to conduct an in-depth analysis on all the various types of NMT based ITS measures this dissertation will focus on existing application of ITS measures within South Africa. NMT based ITS measures in South Africa are mostly focused on improving road safety as it is one of leading problems in South Africa therefore a central theme of this dissertation will centre around road safety.

Despite the progress made in transport technology, the number of road traffic deaths worldwide remains unacceptably high, with road traffic injuries being the leading cause of death for children and young adults. Pedestrians, cyclists, and motorcyclists account for over half of the global road traffic deaths (WHO, 2018).

## 1.2. Problem to be investigated

In the field of ITS, several challenges arise in dealing with NMT. Over the past 50 years, the global trend has shifted from non-motorised modes of transport towards automobile-centric cities and towns. This has led to the spatial expansion of urban areas, resulting in reduced population and land density, and inadvertently increasing the distances for daily trips, such as work, school, and shopping. Consequently, government budgets shifted away from investment in NMT infrastructure and towards road-based transportation systems, which are more suited for longer distance trips. However, it soon became apparent that such a city pattern and car-oriented development is

not sustainable, as noted by Hall (1964). As a result, public transport, mixed development strategies, such as Transit Oriented Developments, and investment in NMT have been reintroduced.

### **1.2.1. Available NMT based ITS internationally**

Prior to analysing which ITS measures are suitable for implementation in South African conditions, it is imperative to conduct market research of the existing solutions. This investigation will ensure that efforts are not duplicated by attempting to create something that may already exist. Subsequently, a detailed analysis can be undertaken to determine the applicability of each intervention, if any, in the context of South Africa.

### **1.2.2. Applicability in South Africa?**

Improving NMT safety presents a significant challenge that must be tackled in South Africa. However, this is not a unique challenge to South Africa, as it is faced by both developed and developing countries alike (Baufeldt, 2016). Owing to a variety of contributing factors, the challenges confronting NMT as a mode of transportation are typically much greater in developing countries, where NMT trips are often not acknowledged as a vital mode of transport and, hence, are not adequately planned, designed, or implemented. This issue is evident in South Africa, where many parts of the country lack adequate NMT facilities, and the country has one of the highest road fatality and injury rates in the world (International Transport Forum, 2019).

Pedestrian behaviour is a key factor in developing countries like South Africa. It is observed that there is a low tolerance for traffic rules, and a limited level of traffic rules education. The prevalence of illegal jaywalking is a common feature at pedestrian crossings along roads (Behrens, and Makajuma, 2017). Thus, for any ITS measure to be effective in South Africa, it is crucial to consider local pedestrian behaviour. It is also vital to take into account the socio-economic context of each developing country, as this plays a significant role in determining which measures can be deemed viable. In South Africa, the country faces major service delivery challenges, such as energy supply, housing, basic services, etc. Therefore, to develop effective solutions, lower maintenance interventions that can be universally accessible must be explored.

## **1.3. Purpose of Study**

The objective of this dissertation is to examine different advancements in the field of ITS that are specifically targeted towards NMT. The study will investigate NMT based ITS measures internationally, with a focus on analysing their applicability in a developing country like South Africa. In this research, a few case studies focussed on road safety improvements will be examined to evaluate the effectiveness of such measures. Based on the findings of the study, recommendations will be provided for further testing or implementation of the identified measures.

## **1.4. Research Methodology**

Research methodology requires two stages, firstly market research to explore what technologies are currently available in terms of NMT based ITS measures. In order to understand this, an in-depth literature review is required to unpack the purpose and types of NMT focused ITS measures. Thereafter local literature is used to find trends to evaluate applicability of specific ITS interventions within the South African context. Further, to enhance evaluation case studies of ITS measures applied within South Africa will be expanded on in this dissertation.

## 1.5. Scope and Limitations

The focus of this dissertation is to explore NMT based ITS measures in urban areas, specifically in South Africa, using the City of Cape Town as a case study. Although Cape Town may not represent all the urban characteristics in South Africa, it is considered a suitable area for research as it is one of the main cities in the country and has been influenced by policies and frameworks that affect other major cities. Due to resource constraints, investigations could not be extended to other urban areas in South Africa.

While the literature review of this dissertation will be exploring a wide range of NMT based ITS measures the latter part of this dissertation will be focused on existing case studies found in South Africa, more specifically Cape Town. While implementation of ITS measures have started around South Africa it is still relatively new concept and sufficient data has not yet been collected. The noticeable trend is that most cities are opting for measures geared towards influencing road safety improvements as this is one of the most critical issues facing the country currently. As a result this road safety is a central theme throughout this dissertation.

In 2010, subsequent to the conference in Moscow, the United Nations General Assembly (UNGA) A/64/255, unanimously adopted a resolution calling for a Decade of Action for Road Safety 2011–2020 (United Nations Decade of Action – UNDA). UNDA set out 5 pillars of road safety to achieve global objects for improvement in road safety all of which are aligned to traffic engineering and road safety (Road Traffic Management Cooperation, 2016).

In order to achieve overall road safety, all 5 pillars need to be met. The 5 pillars are similar to universal traffic engineering safety principles (also commonly known as ‘4 E’s of road safety’) which are *Education, Enforcement, Engineering and Evaluation*. The 5 pillars are as follows (Road Traffic Management Cooperation, 2016):

- i. Pillar 1: Road Safety Management
- ii. Pillar 2: Safer Roads and Mobility
- iii. Pillar 3: Safer Vehicles
- iv. Pillar 4: Safer Road Users
- v. Pillar 5: Post-Crash Response

In this dissertation the role of ITS measures in all 4 traffic engineering safety principles will be explored. Objective and priorities need to be understood before any ITS implementation. To ensure the correct ITS measure is used the problem that is required to be solved (or system being enhanced) need to be matched with benefits of the relevant ITS measures. ITS measures that are commonly used internationally may not be the priority in South African environments hence careful consideration is required with alignment to strategic goals.

While other regulatory, policy, and educational strategies are also important in positively influencing pedestrian behaviour, the focus of this research is solely on ITS measures. To ensure contextual understanding, a mixture of local and international literature is required. The main limitations of the quantitative investigations were the type of available data for Cape Town and the predetermined time frame. Infrastructure assessments had limitations regarding the rigour of the investigation, and future measures can be added to improve assessments' significance.

A pilot study should be tested on infrastructure in a suitable South African city to truly understand the effectiveness of a proposed ITS measure. However, due to approval processes and timelines, it is not viable for this dissertation's requirements. ITS interventions are mutually inclusive of NMT, and some general ITS measures that influence NMT are included in this study.

## 1.6. Thesis Structure

The opening chapter of this dissertation introduces the research topic and the problems under investigation. Chapter 2 provides an extensive review of literature on the advantages of ITS, specifically for NMT, to lay a foundation for the benefits that the use of ITS within transport systems can bring. The chapter will examine the effectiveness of ITS internationally and investigate successful case studies where ITS measures have been implemented for NMT.

Chapter 3 presents a more focused local literature review to gain contextual understanding of local policies, guidelines and standards pertaining to NMT and investigate whether ITS has been identified as a tool to improve the efficiency and safety of NMT in South Africa. Once an understanding of the effectiveness of ITS measures and available technology for NMT users has been established, Chapter 4 sets out the research methodology by reflecting on key lessons learnt from literature and summarising objectives of various ITS measures reviewed. Chapter 5 expands on this work and explores local case studies in Cape Town at pedestrian crossings. Data collected before and after the implementation of ITS measures is analysed at the first pedestrian crossing located at Buitengracht Street and Walter Sisulu Avenue. The second case study examines recently installed thermal sensors along the West Coast in the City of Cape Town at pedestrian crossings.

Finally, in Chapter 6, the research findings will be summarised and conclusions presented along with recommendations for further research based on the findings established in this dissertation.

## 2. International Literature Review regarding NMT based ITS

One advantage of residing in a ‘developing nation’ is the opportunity to learn from the experiences of research institutions worldwide, who have tested and developed ‘proof of concept’ for various innovative ideas. Several systems or ideas have already been developed, providing possibilities to learn from their shortcomings and improve upon them, resulting in saved time and costs.

This chapter aims to examine the impact, types, and advantages of a range of NMT focused ITS measures and identify significant lessons that can be applied to our specific context. The study will be conducted through the examination of case studies and international policies, with a focus on road safety implications.

### 2.1. Global NMT trends

“The number of road traffic deaths on the world’s roads remain unacceptably high. Road traffic injuries are the leading killer of children and young adults. More than half the global road traffic deaths are amongst pedestrians, cyclists and motorcyclists. Pedestrians accounting for 23% of road fatalities with an additional 3% of fatalities to cyclists” (WHO, 2018).

Figure 1, depicted below, illustrates the global distribution of road fatalities by road user type. It is noteworthy that 4 wheeled vehicle drivers’ account for the highest fatalities (29%) globally whereas compared to Africa pedestrians and 4 wheeled drivers’ both account for fatalities equally (40%).

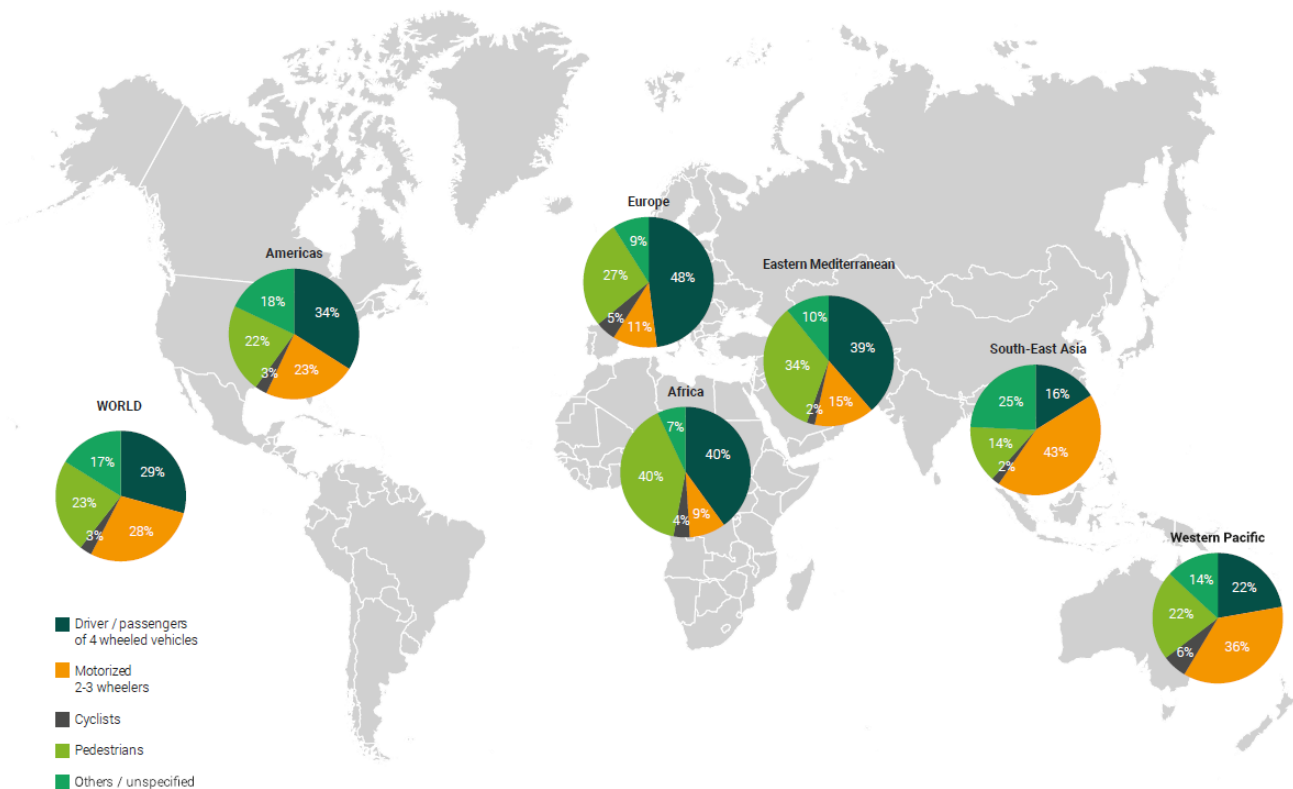


Figure 1: Distribution of deaths by road user type by WHO region (WHO, 2018)

## 2.2. Objectives of ITS Measures

“Several studies suggest that Intelligent Transport System (ITS) measures have multiple benefits. They are believed to help reduce traffic congestion, improve road safety, lower fuel consumption and enhance public transport reliability” (Vanderschuren, 2006).

This chapter will utilise Vanderschuren's (2006) assessment of the objectives of ITS measures as a basis, with a specific focus on NMT. Vanderschuren (2006) identified six key objectives that ITS aims to achieve, as outlined below:

### 2.2.1. Safety

According to the World Health Organization (WHO, 2018), road fatalities contribute to 1.35 million deaths annually, resulting in 3,700 fatalities on the world's roads every day. Furthermore, tens of millions more are injured or disabled each year, causing life-altering effects not only for the injured but also for their families, friends, and colleagues. The reasons for these fatalities are attributed to rapid urbanisation, poor safety standards, lack of enforcement, driving distracted or fatigued, driving under the influence of drugs or alcohol, failure to wear seatbelts, and speeding. The most notable statistic reported by the WHO is that the leading cause of deaths for people between the ages of 5-29 is road fatalities (WHO, 2018). In South Africa, similar trends are observed, with a recorded rate of 22.4 per 100,000 inhabitants or 12,945 fatalities (International Transport Forum, 2019).

Human error is cited as the main reason for road fatalities. The use of Intelligent Transport Systems (ITS) measures in road safety can eliminate the majority of human error, which will inevitably minimise accidents. The use of ITS measures should reduce the probability of a fatality in the event of a crash and lower the overall number of crashes. The total crash rate, fatality crash rate, and injury crash rate are common effectiveness metrics used to assess safety performance. Additionally, ITS services have to work to lower a facility or system's accident rate (Vanderschuren, 2006).

### 2.2.2. Mobility

One of the fundamental understandings in Transport Engineering is that travel is a disutility. In planning and designing transport systems, ensuring reasonable levels of mobility by reducing delay and improving travel time is one of the key objectives. Depending on the sort of transport system being studied, there are numerous approaches to assess delay. A system's delay is often expressed in seconds or minutes per vehicle. Additionally, the length of the delay for system users can be expressed in person-hours. The term "travel time variability" refers to the range of the system's total journey time, taking into account any modal transfers or detours. Reducing travel time variability increases the accuracy of arrival time predictions that customers or businesses use to make planning and scheduling decisions. ITS services can lessen the variance of journey time in transportation networks by enhancing operations, incident response, and giving information on delays. If commercial vehicles are rerouted away from busy locations during trip planning, for instance, there will be less variation in journey time. (Vanderschuren, 2006).

### 2.2.3. Efficiency

Several components of ITS aim to optimise the efficiency of existing facilities and rights-of-way usage. This is done to fulfil mobility and commerce needs while minimising the necessity of constructing or expanding facilities. The primary approach to achieve this is by enhancing the effective capacity of the transportation system. Effective capacity refers to the maximum potential rate at which persons or vehicles can traverse a link, node, or network considering various roadway conditions such as weather, incidents, and traffic demand variations.

Capacity, on the other hand, is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a particular point or uniform section of a lane or roadway under typical roadway, traffic, and control conditions, according to the Highway Capacity Manual (TRB, 2010). The primary distinction between effective capacity and capacity is that capacity is measured under normal facility conditions, such as good pavement and weather conditions, without any incidents affecting the system. In contrast, effective capacity may vary based on the aforementioned factors and the utilisation of management and operational strategies.

Throughput is the number of individuals, goods, or vehicles that traverse a roadway section or network per unit time. Increases in throughput may sometimes indicate an increase in effective capacity. Under specific conditions, it may also represent the maximum number of travellers that a transportation system can accommodate. As compared to effective capacity, throughput is easier to measure and, as a result, can be used as a replacement measure when assessing the performance of an ITS project. However, it is essential to note that local circumstances affect both local capacities and measured throughputs (Vanderschuren, 2006).

#### **2.2.4. Productivity**

The implementation of ITS often leads to a reduction in operating costs and productivity gains. Furthermore, ITS options may have lower acquisition and lifecycle expenses when compared to conventional transportation improvement methods. The yardstick for evaluating the success of this objective is the cost savings obtained through the implementation of ITS. Another way to evaluate cost savings is to calculate the difference between the expenses of traditional solutions and ITS in resolving issues (Vanderschuren, 2006).

#### **2.2.5. Energy and Environment**

In the context of ITS services, the consideration of air quality and energy impacts is of paramount importance, particularly for non-attainment areas. In most instances, the estimation of environmental benefits can only be achieved through analysis and simulation. Problems related to regional measurement include the limited impact of individual projects and a significant number of exogenous variables, including weather, contributions from non-mobile sources or other regions, and the time-evolving nature of ozone pollution. Small-scale studies indicate positive environmental impacts resulting from smoother and more efficient flows within the transportation system. However, the long-term environmental effects of large-scale deployment and the reactions of travellers to these systems are not yet well understood. Decreases in emission levels and energy consumption represent measures of effectiveness for this objective (Vanderschuren, 2006).

#### **2.2.6. Customer Satisfaction**

Given that many ITS projects and programmes were specifically developed to serve the public, it is important to ensure that user (i.e., customer) expectations are being met or surpassed. Customer satisfaction measures and characterises the distance between users' expectations and experiences in relation to a service or product. The central question in a customer satisfaction evaluation is, "Does the product deliver sufficient value (or benefits) in exchange for the customer's investment, whether the investment is measured in money or time?" Typical results reported in evaluating the impact of customer satisfaction with a product or service include product awareness, expectations of product benefit(s), product use, response (decision-making or behaviour change), realisation of benefits and assessment of value. Although satisfaction is difficult to measure directly, measures related to satisfaction can be observed including the amount of travel in various modes, and the quality of service, as well as the volume of complaints and/or compliments received by the service provider (Vanderschuren, 2006).

In addition to user or customer satisfaction, it is necessary to evaluate the satisfaction of the transportation system provider or manager. For example, many ITS projects are implemented to improve co-ordination between various stakeholders in the transportation arena. In such projects, it is important to measure the satisfaction of the transportation provider to ensure the best use of limited funding. One way to measure the performance of such a project is to survey transportation providers before and after a project was implemented to see if co-ordination was improved. It may also be possible to bring together providers from each of the stakeholder groups to evaluate their satisfaction with the system before and after the implementation of an ITS project (Vanderschuren, 2006).

### 2.2.7. Universal Accessibility

‘The South African Constitution stipulates that all people have to be treated equitably in transport situations. There is always conflict between NMT and vehicular traffic and this conflict needs to be minimised through good design and transport management’ (NDoT, 2014).

In addition to considering the functional classification of roads based on motor vehicle speeds and the need for separation from non-motorised transport users, it is important to also take into account the functional needs of people and their ability to move around their environments. Universal design aims to ensure that all individuals can easily access transport-related activities. This involves both mobility, which refers to movement, and access, which refers to the ease of using infrastructure (NDoT, 2014).

While ITS implementations aim to enhance safety, efficiency, and mobility of transport systems, it is crucial not to overlook the importance of equitable access to the system. ITS measures must be utilised to enhance the universal accessibility of transport systems.

## 2.3. Description of ITS Measures

ITS is a very broad fast-moving field with various new interventions being introduced in the market in different countries around the world. This varies between intersection control, data collection technology, self-learning and artificial intelligence built into technological systems, driver assistance to autonomous vehicles with many more.

In 2006 Vanderschuren identified categorisation of types of ITS measures however at the time NMT based ITS measures were not developed and categorisation will be required to be reviewed. Categorising ITS measures presents quite a unique challenge as many ITS measures have mutually inclusive objectives and are not transport mode specific but rather relates to the transport system as a whole. For example, an ITS measure whose primary function is road safety may have an indirect side effect of improving travel time (due to improved driver behaviour) therefore to clearly distinguish measures category ITS measure is categorised based on its primary objective. Following on the work presented by Vanderschuren (2006) ITS categories can be defined within the following types:

- **Mobility Intelligent Transport Systems** – These measures aim to optimise the use of Non-motorised facilities and reduce unnecessary and inefficient delay with primary objective of mobility, efficiency and productivity.
- **Safety Intelligent Transport Systems** – Safety related ITS measures which aim to reduce accidents and dangerous situations with primary objective of safety.
- **Communication Intelligent Transport Systems** - The provision of information, guidance, education and security and all measures to ensure a more satisfying experience with primary objective of customer satisfaction and universal accessibility.

### 2.3.1. Mobility Transport Management Systems

Government and road agencies are responsible for the provision of infrastructure and infrastructure related (ITS) systems enhancing road safety, mobility etc. In section 2.1. above the type of Non-Motorised Transport infrastructure use to travel is either through dedicated separated facilities, separated facilities adjacent to roadways or within the road shoulder. In the road environment, ITS development in transport management systems have largely being concentrated on the interface of different modes i.e. pedestrian and vehicular traffic or cyclist and pedestrian etc. The interface in the road network occurs most frequently at intersections or pedestrian crossings, hence, most ITS measures are focussed around improving safety, mobility and efficiency and accessibility at the interface.

It is noted that a lack of investment into NMT infrastructure has delayed the opportunity to enhance the efficiency of NMT mobility. The NMT network can only be optimised once the basic NMT infrastructure is built (Baufeldt, J. 2016). Despite lacking the basic NMT infrastructure there are road based ITS measures which benefits are mutually inclusive of NMT. This can be used as opportunity to proactively use ITS measures for enhanced efficiency of NMT.

The majority of travel can be seen as a disutility as it is merely a means to an end. This is, generally, measured in cost or time. However, time in travel is not linear for example waiting time and walking time can be taken as twice the value of in-vehicle time (Ortuzar, 2011).

Some of the ITS measures are focused on innovative solutions to reduce the perceived waiting time. Examples of infrastructure NMT based ITS systems are:

- *People Movers*: Also known as moving walkway is a slow moving conveyer mechanism that transport people horizontally or on inclined plane over a short distance. These are typically found in mass transit stations, shopping malls and high pedestrian volume areas (Kusumaningtyas, I. and Lodewijks, G., 2008).
- *Escalators and Lifts*: While not developed or intended as an ITS measure falls into the category of NMT based ITS measures. Despite this technology being available for many years it still plays a crucial role in Mobility ITS measures for NMT.
- *Smart Intersection*: A typical intersection that is fully connected to internet via Lidar scanners, CCTV cameras, traffic signal control and backend artificial intelligence real time optimisation. Using a combination of a various ITS measures is what is deemed as a 'Smart Intersection' where each cycle is optimised for the current live traffic conditions (Yang, S et al, 2020).
- *Traffic Signals*: Traffic signals or traffic lights are intersection control signalling devices positioned at intersections or pedestrian crossings in order to control traffic flow. One of the oldest forms of technology introduced into transport systems first being used in 1868. Traffic signals while primarily aims to control and manage traffic flow of motor vehicles, they also facilitate safe crossing of pedestrians. Garder (1989) has shown that traffic signals reduce pedestrian risk by half. As technology developed further modifications to traffic signal have been made improving efficiency and safety. Below are some of the modifications made in recent years focused on NMT:
  - *Scramble signal phase* – a scramble signal phase is an all red signal phase for all vehicular traffic on all intersection legs and all green for pedestrian crossing with no conflict movements. Dependant on vehicle and pedestrian intersection demand a scramble phase can significantly reduce pedestrian conflict, without significantly impacting intersection delay (Garder, 1989).
  - *Push button* – To more effectively accommodate non-motorised transport traffic signals incorporate a push button which on demand will bring up the pedestrian signal phase. This minimises unnecessary scramble pedestrian phase if there are no pedestrians waiting to cross. It

also ensure better level of accessibility to all using sound and tactile paving will is universally accessible (Meder M et al., 2016). Figure 2 below displays push button configuration used in Cape Town.

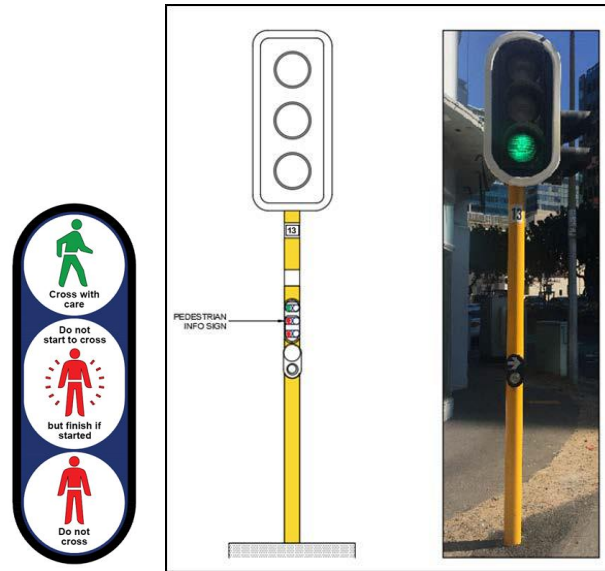


Figure 2: Push button placement on Traffic Signal in Cape Town (Meder M et al., 2016)

- *SCOOT* – SCOOT is a real time responsive computer model that receives live traffic signal green times and vehicle presence measurement data from detectors on street on a second by second basis from the traffic control system. The SCOOT model then, automatically, adjusts the traffic signal timings to maximise the junction capacity by minimising exit blocking. While this system was initially aimed at vehicular traffic using pedestrian detection measures, as will be discussed later in this section this is then extended to ensure pedestrian crossing is as efficient as possible.
- *Dancing traffic signal*: The Dancing traffic signal is an innovation where individuals enter a booth and select a song. When red phase of traffic signal phase is active the music in the booth begins, while the individual is instructed to begin dancing. A video feed of the individual dancing is relayed in real time to the pedestrian lights with the resulting red figure dancing entertaining waiting pedestrians encouraging them to wait for a safe crossing opportunity. Initial results had shown an improvement of 81% more pedestrians waiting for the green light than previously (SMART, 2014). Figure 3, Figure 4, Figure 5 and Figure 6 below showing various stages of dancing traffic signal.



Figure 3: Smart dancing traffic light (SMART, 2014)



Figure 4: Dancing booth with live feed (SMART, 2014)



Figure 5: Song Selection for dancing traffic signal (SMART, 2014)



Figure 6: Live feed to traffic signal (SMART 2014)

- *Signal Countdown timer* – Another measure to attempt to reduce perceived waiting time are signal countdown timers. This is installed and has a countdown to show how much more time left to cross (Srinivasan, R. et al. 2019).



*Figure 7: Pedestrian Signal Countdown timer (Cape Town)*

### **2.3.2. Safety Intelligent Transport Systems**

As discussed in numerous sections in this dissertation, road safety is one of the greatest concerns within Africa as indicated on Figure 1 showing that 40% of road fatalities within Africa are pedestrians. In order to influence and improve road safety this section will present various developments in NMT associated ITS measures to improve road safety.

- *LED pedestrian crossing* – LED pedestrian crossings are LED lights installed along walkways or pedestrian crossings (synced with traffic signals) to enhance safety. Studies have shown that with LED lighting approaching vehicles lower their approach speed by 19.3% (Patella, et al, 2020). Figure 8 below illustrates LED lighting for a pedestrian crossing in Cape Town CBD.

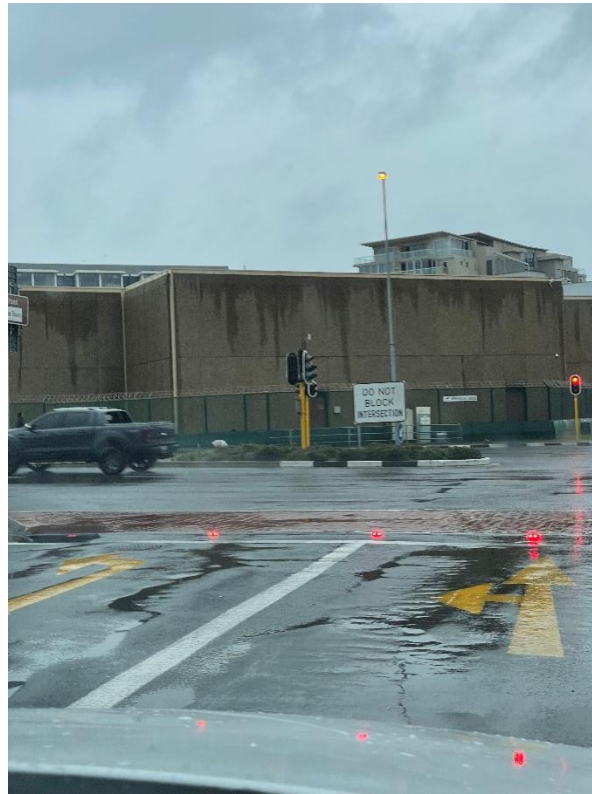


Figure 8: LED Lighting along Pedestrian crossing synced with traffic signals (Cape Town)

- *High-Intensity Activated Crosswalk (HAWK)*: HAWK offers a unique beacon configuration with two red lights and a single yellow light. The light cycle begins with the activation of the signal by a pedestrian, through automated or manual procedures, followed by a flashing yellow indication that turns into a solid yellow indication, informing drivers to prepare to stop. The solid yellow indication is then followed by a solid red indication during the walk period and finishes with a flashing red indication, which encourages drivers to stop and then proceed with caution if there are no pedestrians crossing (Fayyaz et al., 2019).



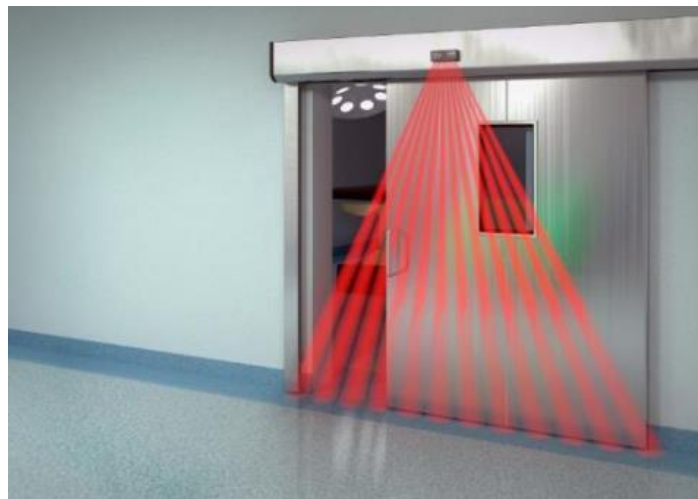
Figure 9: HAWK Crossing in UTAH, USA (Fayyaz K., Galvez de Leon P. & Schultz G.G., 2019)

- *Pedestrian Detection Technology*: There are several technologies that use one or more types of detection technology at intersections. These aim to detect pedestrian at intersections or crossings in order to activate the pedestrian signal phase (FDoT, 2019). Some of the technology used currently include but are not limited to:
  - *Laser Scanner* – uses infrared laser pulses and detection of reflection pulses (FDoT, 2019). See Figure 10 below:



*Figure 10: BEA LZR-I30 Laser Scanner (FDoT, 2019)*

- *Infrared technology (Active and Passive sensors)* – This uses similar technology that is used in motion sensors which are commonly used in shopping mall for automatic doors etc. While it can detect pedestrians or movement it cannot detect volume (FDoT, 2019). See Figure 11 below:



*Figure 11: Active infrared sensor - automatic door opening (FDoT, 2019)*

- *SmartWalk XP* – The SmartWalk XP sensor uses microwave radar technology that works similar to an ultrasonic sensor (FDoT, 2019). In ultrasonic sensors, a transmitter generates electromagnetic waves that are sent via antennae. A beam of energy is produced by a microwave detector at a specific frequency, and the difference between the beam of energy emitted by the device and the beam that was reflected helps to detect the object. For smaller, slower-moving items like walkers the device can provide more accurate findings than for larger faster-moving objects like cars See Figure 12 below:



Figure 12: MS Sedco SmartWalk XP pedestrian presence sensor (FDoT, 2019)

- *Computer Visioning (Automated Video Image Processing)* - is a broad term that refers to all video-based approaches used for automated detection and counting via computer models or algorithms as opposed to manual detection or counting. To detect the pedestrian presence and/or count pedestrian volume, video image processing is based on the intelligent analysis of digital images from video cameras (FDoT, 2019). See Figure 13 below:



Figure 13: AGD 640 Stereo vision pedestrian detector (FDoT, 2019)

- *Thermal Technology* - Passive infrared and automatic image processing technologies are combined to create thermal technology. Similar to passive infrared sensors, thermal cameras monitor body temperature to produce infrared images. They are positioned above the detecting area, allowing for both movement tracking and detection functions. The fact that heat sensors are unaffected by changes in ambient light is a significant advantage. (FDoT, 2019). See Figure 14 below:



Figure 14: FLIR TrafiOne Thermal Imaging sensor for pedestrian detection (FDoT, 2019)

- *Radio Beam Sensors* - There are two categories of radio beam sensors: those that can detect metal objects and those that are solely reflecting. Reflective sensors can be applied for both pedestrian and bicycle detection, while metal-detection sensors are typically employed for bicycle detection. In pedestrian detection and counting, radio beams function similarly to active infrared sensors, except that they generate radio signals as opposed to infrared beams. This function makes it possible to safely put radio beam sensors behind covers or other obstructions, preventing theft or vandalism. (FDoT, 2019). See Figure 15 below:



*Figure 15: RBX-EB in recycled plastic post (FDoT, 2019)*

- *Piezoelectric Sensor or Strip* - By transforming changes in pressure, acceleration, strain, etc. into an electrical charge, piezoelectric sensors use the piezoelectric effect to quantify these changes. The sensors and wires are typically "disguised" in a road mat, commonly referred to as a "pressure mat," and they are simple pedestrian and cyclist detection applications that can detect the presence and absence of an individual within a detection zone. (FDoT, 2019). See Figure 16 below:



*Figure 16: RidePod + Piezoelectric counter (FDoT, 2019)*

- *Pressure, Acoustic or Seismic Sensors* – Based on the force exerted to the sensor, pressure sensors are capable of detecting bicycles and pedestrians. One kind of pressure sensor is the piezoelectric sensor or strip. While seismic sensors recognize energy waves through the earth, acoustic sensors detect sound waves created by the passage of feet, bicycle tires, and other wheels. Just below paved or natural surface walkways, pressure and acoustic/seismic sensors are installed; the cost of installation is often minimal, and they are largely vandal-proof. (FDoT, 2019). See Figure 17 below:



Figure 17: Eco-Counter SLAB Pedestrian counter (FDoT, 2019)

- *Inductive loops* - Inductive loops are a ‘traditional’ method of traffic detection, they have been used as traffic detection sensors since the 1950s (FDoT, 2019). These loops, which are hidden in the pavement beneath the road, are mostly used for traffic counts. These loops are designed to find and count only metal things, such as cars and bicycles. See Figure 18 below:



Figure 18: Inductive loop detector for bicycle detection (FDoT, 2019)

- *Pneumatic tubes* Pneumatic tubes are another common detection technique, although they are only useful for counting and detecting bicycles, not pedestrians (FDoT, 2019). An air switch is used by pneumatic tubes to detect short airbursts from passing motorised or non-motorised vehicles, and a data logger uses specified parameters (such as axle spacing) to validate the vehicle type. See Figure 19 below:



Figure 19: Pneumatic tubes stretched across road (FDoT, 2019)

- *Magnetometers* - Magnetometers detect vehicle actions based on fluctuations in the usual magnetic field when metal parts pass, much like inductive loop detectors. Magnetometers are often used in vehicle detection to locate and track moving vehicles. Since the detection of bicycles was not initially thought to be a function of magnetometers, it may be possible to count cyclists using motorised traffic magnetometers currently in use, but the installation and configuration may not be ideal for accurate cyclist counting, especially when used on roads with the mixed vehicle and bicycle traffic. (FDoT, 2019). See Figure 20 below:



Figure 20: Sensys FLexMag magnetometer Sensor (FDoT, 2019)

- *Fibre Optic Pressure sensors* - Fibre optic pressure sensors have been extensively used throughout Europe as the foundation for "bicycle barometers," permanent bicycle counting stations that display bicycle counts. Fibre optic pressure sensors are suited for difficult pressure-monitoring applications in submerged and hostile settings. (FDoT, 2019). See Figure 21 below:



Figure 21: OPP-C Fibre optic pressure sensor (FDoT, 2019)

### 2.3.3. Communication Intelligent Transport Systems

Communication of Intelligent Transport Systems aims to provide the traveller with pre-trip and on-trip information to inform their trip to widely achieve efficiency, mobility, accessibility, safety and customer satisfaction. Due to the volume of information systems present today it is not the purpose of this dissertation to have a complete list of systems, however, a look at the more widely used and that are adaptable to South African conditions with a focus on systems catering to Non-motorised Transport. Examples of Communication Intelligent Transport Systems are:

- *Navigation Systems:* Navigation systems are the most common and widely used information system used. Navigation systems are electronic systems that provide real time information to users which includes routing options, distance, elevation and travel time from origin to destination (with options of mode choice). Currently there is an estimated 6.567 billion smartphones in use today (Statista, 2022). The majority of the world's population has direct access to internet and navigation systems through large variety of applications created for navigation. Figure 22 and Figure 23 below show examples of how Google has presented navigation systems and infused with augmented reality which is the basis of many further technological advancements in future. The most popular used applications are:
  - Google Maps,
  - Apple Maps,
  - Waze Navigation, and
  - TomTom Go.

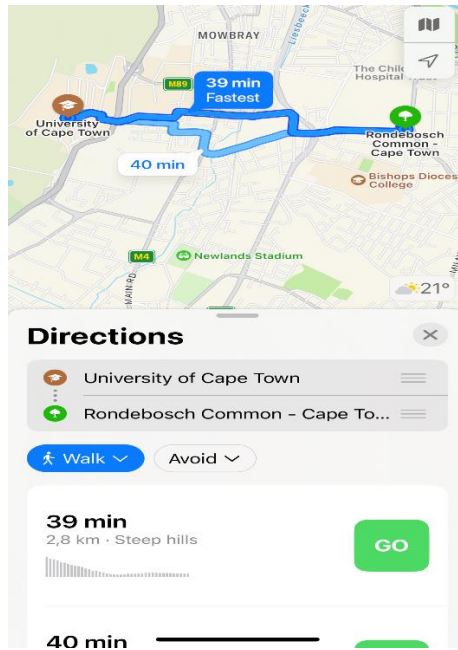


Figure 22: Screenshot of Apple Maps for Walking Trip (Cape Town)



Figure 23: Augmented reality in Google Street View Navigation (<https://arvr.google.com/ar/>)

- **Crowd management system:** Crowd management is the ability to monitor and, where necessary, direct a group of people to ensure their safety (GSMA, 2016). The same enabling technologies can also be used to help move people to their destination more efficiently and plan new services based on their behaviour. Crowd management technologies have advanced significantly over the past few years. Crowd management solutions relied on using video footage and facial recognition to count how many people were in certain areas. These expensive techniques have now largely been replaced by sensor technology (GSMA, 2016). Mobile operators are now particularly well placed to provide tools that can be used for

crowd management. Tracking the location of mobile phones and analysing data collected by mobile-enabled Internet of Things (IoT) sensors provides an extremely accurate way to monitor and manage crowds of people across all sorts of gatherings – whether they be in city centres, or in remote rural locations (GSMA, 2016). Figure 24 shows the interphase of such a tool and live statics into how overall crowd management can be handled.

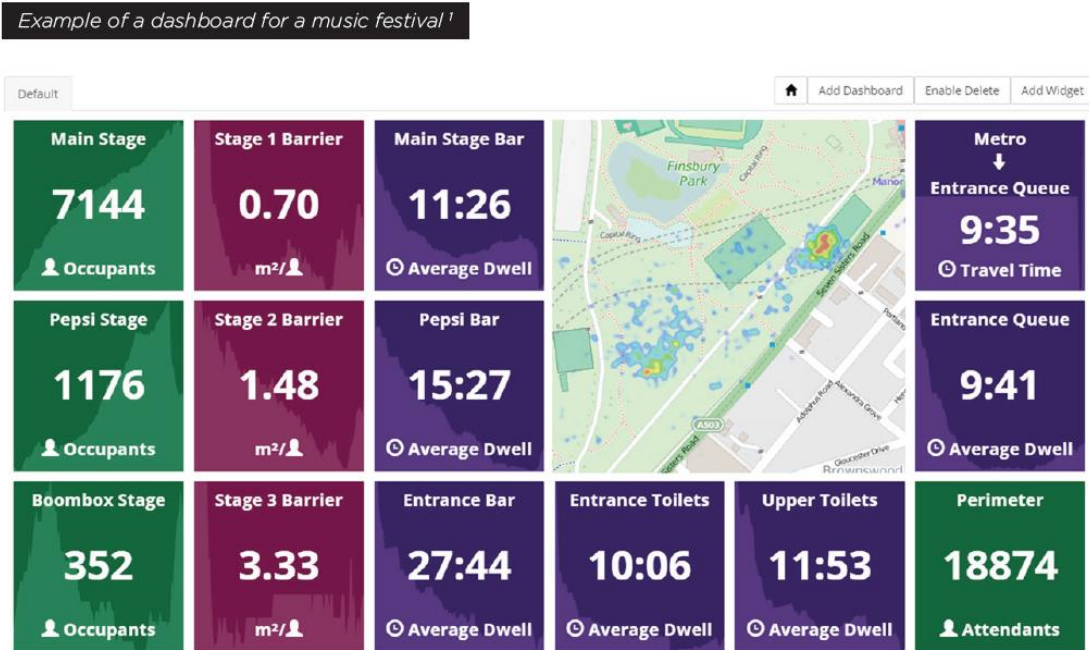


Figure 24: Application of Crowd Management at a music festival (GSMA, 2016)

- **CCTV Camera:** CCTV are cameras set up along strategic locations in the transport system used for safety and data collection. Live feed is sent to a Transport Management Centre where footage is stored and analysed for data collection purposes for further network advancements or to ensure quick incident response. Latest developments have brought about many different software variations that further enables CCTV footage using artificial intelligence, machine learning and facial recognition to analyse data instantaneously.
- **Smartphone-based P2V warning systems:** The pedestrian-to-vehicle warning (P2V) system in a connected vehicle environment is considered a promising countermeasure to reduce pedestrian crashes. Given that the era of connected vehicle technology is coming and traffic objects can easily “communicate” with each other, the P2V system has its technical feasibility. With P2V systems, a pedestrian could share his/her location information to nearby drivers within a certain range in case that the drivers failed to observe the pedestrian. Thus, drivers could be more alert of the potential upcoming events, such as pedestrian crossing (Wu Yet al., 2021).

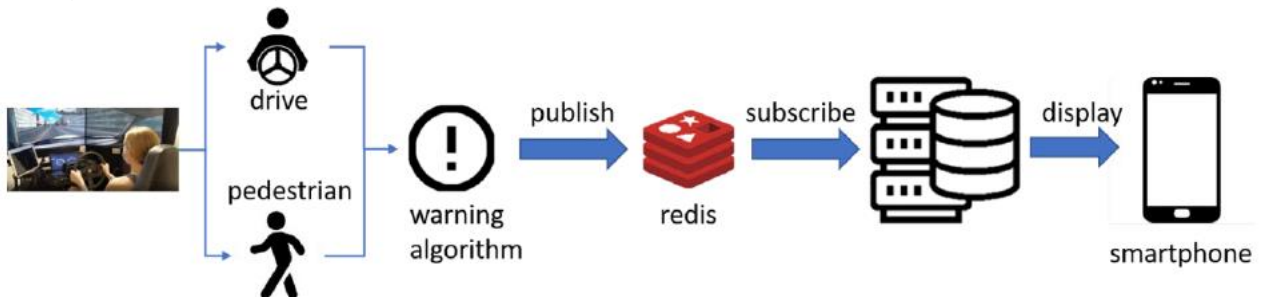


Figure 25: P2V Warning System (Wu Y., Abdel-Aty M. & Yue L., 2021).

- **Walkability app:** The Walkability app is a mobile application created by Wasswa, Zuidgeest and Vanderschuren (2016) which allows for the collection of data on the pedestrian experience and is a shift away from the mechanistic approach to understanding pedestrian challenges. Using the application, users

rate their walking environment along dimensions of safety, security, infrastructure and comfort, while geo-tagging walking routes. The dashboard is used to store and visualise the users' perception data and multimedia captured using the mobile phones (Wasswa et al., 2016).

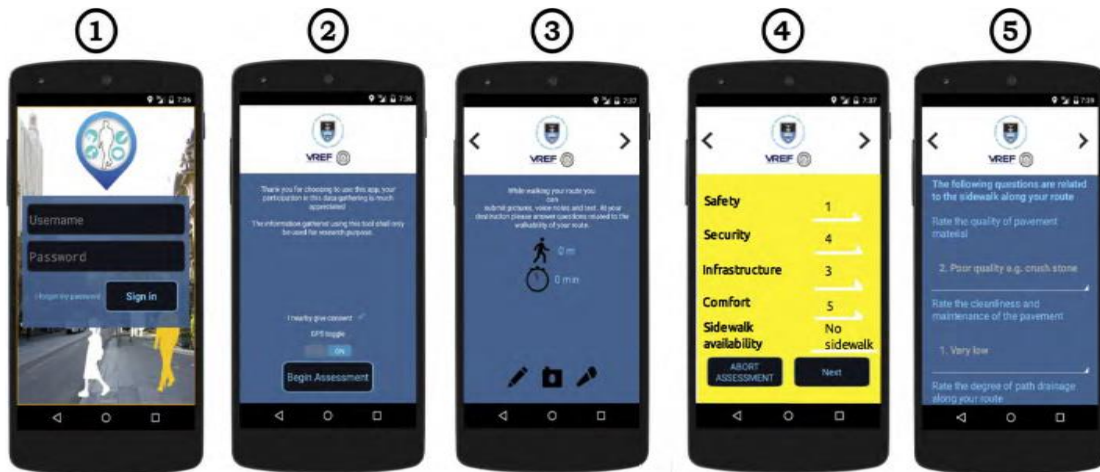


Figure 26: Walkability Application (Wasswa et al., 2016)

- *Glass (created by Google):* Glass Enterprise is a small, lightweight wearable computer with a transparent display for hands-free work. It has a built in display that enables users to match reality with applications. While still in the pilot phase of the project and applications in various fields will also include in the transport sector similarly as have seen some technology using augmented reality. This device will enable drivers and NMT users routing information and early warning systems to alert to hazards. The technology is still in the early stages and may be a few more years before it sees a wide usage (Google, 2022).



Figure 27: Glass created by Google (Google, 2022).

- *Mobility Assistance for people with cognitive disabilities* – Through the use of smartphone applications and GPS applications are able to assist step by step with visual and audio instruction guiding commuters through trips. The use of these app would allow greater independence for people with cognitive disabilities.
- *Virtual Reality Simulation – To educate and modify pedestrian behaviour* – A study conducted in China where young children were fully immersed in a Virtual Reality (VR) program developed by the Research and Innovation Learning (RAIL) lab and the University of Georgia where learners were able to freely

room within the tracking space which consisted (in virtual reality) of streets, five crosswalks, six pedestrian signalised crossings. The learners were prompted to complete three different crossing challenges in locations with 25 minutes to complete the challenges. While completing the crossing challenges in the VR environment for the first time, most of the children exhibited risky pedestrian behaviours, such as dashing into the street, crossing on a blinking green light, and failing to check for traffic. Safe pedestrian behaviour rate of Chinese children increased significantly between the two trials in the VR program. Showing that post education effects in a safe environment resulted in positive real world implementation (Luo, et al. 2020.). Figure 28 below shows the various stages of the study on the learners perspective on what the learners required to navigate.

(a)



(b)

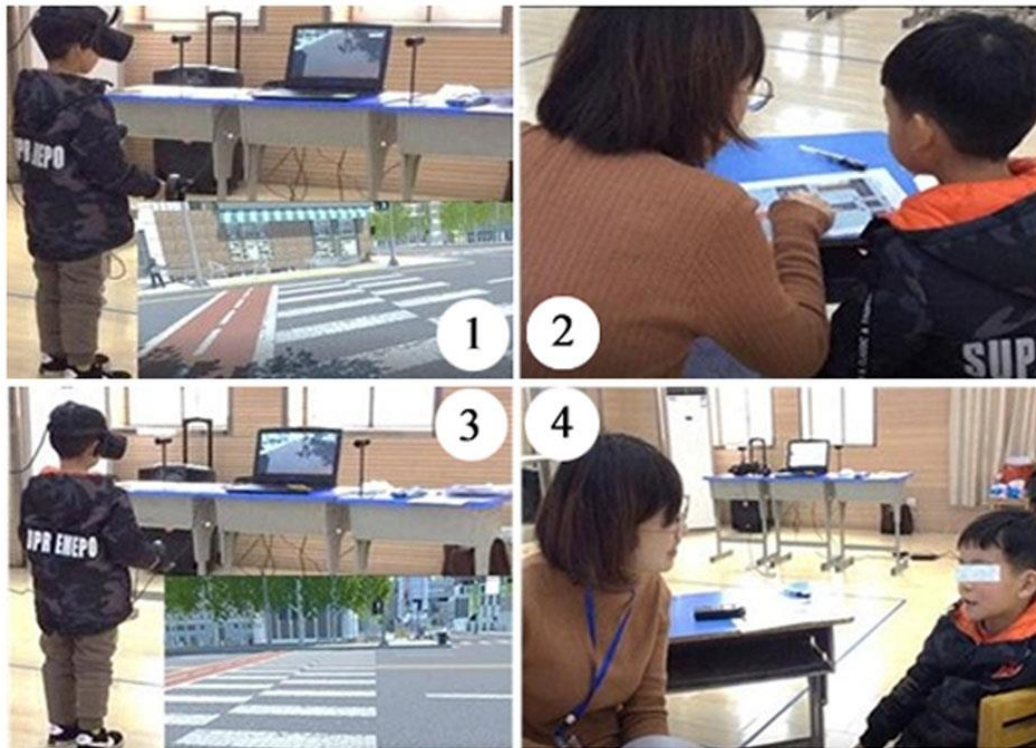


Figure 28: Virtual Reality Educational training for pedestrian crossing (Luo, H., et al. 2020.)

## 2.4. Effect of ITS measures

With the limited scope of this dissertation, it is not possible to unpack in depth the benefits of all various types of ITS measures, therefore, this dissertation will focus on a few established measures globally and identify key improvements and benefits. What is important to understand through studying literature is to see if there has been any success in implementing ITS measures internationally? What benefits have these measures yielded? This will be important in trying to decide which interventions could work in our local context.

## 2.5. International Case Studies

### 2.5.1. Pedestrian Countdown Signals (USA)

A study conducted by US Department of Transportation Federal Highway Administration (2019), evaluated the safety effectiveness of Pedestrian Countdown Signals (PCS) by conducting before-after empirical Bayes analysis on data from 115 treated intersections in Charlotte, USA and 218 treated intersections in Philadelphia, USA. The study results showed that after the implementation of PCSs, pedestrian crashes decreased by 9%, total crashes decreased by 8%, and rear-end crashes decreased by 12%. All these reductions were statistically significant. The economic analysis revealed a Benefit/Cost ratio of 23 (i.e. every for Dollar of investment the return on investment is 23 times in benefits), with a low of 13 and a high of 32. This report will benefit safety and traffic engineers and safety planners by providing greater insight into pedestrian safety (Srinivasan, et al. 2019).

*Table 1: Results of Countdown Pedestrian Signal (Srinivasan, et al. 2019).*

<b>Crash Type</b>	<b>Observed Number of Crashes in the After Period (With Treatment)</b>	<b>EB Estimate of Expected Number of Crashes in the After Period (Without Treatment)</b>	<b>Crash Modification Factors</b>	<b>Standard Error of Crash Modification Factor</b>
Total	4,499	4,885.8	0.921*	0.017
KABC	2,257	2,283.8	0.988	0.026
RE	1,542	1,761.3	0.875*	0.027
ANG	927	901.9	1.027	0.042
PED	397	434.9	0.912#	0.055

\*CMF is statistically significant at the 95 percent confidence level.

#CMF is statistically significant at the 90 percent confidence level.

### 2.5.2. The Effect of LED Lighting Crosswalk on Pedestrian Safety (Rome, Italy)

Results have shown a promising impact of the LED lighting system on pedestrian safety. In fact, cars' mean speed decreases by 19.3% at the crosswalk section in illuminated conditions. Moreover, a positive effect on safety, in terms of mean speed reduction (-16.4%), was found even in the absence of pedestrians (Patella, et al., 2020).

The study was aimed at evaluating the safety improvements obtained with a LED lighting system positioned at the crosswalk section. Each panel is 0.4 m x 0.4 m, it contains 9 LED stripes, it is supplied with both 12 Volt and 230 Volt, and the protection index is IP67 (One of the highest levels of protection offered by an IP rating which measures against grade of protection against ingress of dust or airborne particles and water resistance).



Figure 29: LED Crosswalk lighting system (Patella, S.M, et al., 2020).

Two scenarios were experimented within this study; the first case without the presence of pedestrian and the second with the pedestrian (Patella, et al, 2020). As can be seen in Figure 30, below a flow diagram on the methodology to test effectiveness of the ITS measure.

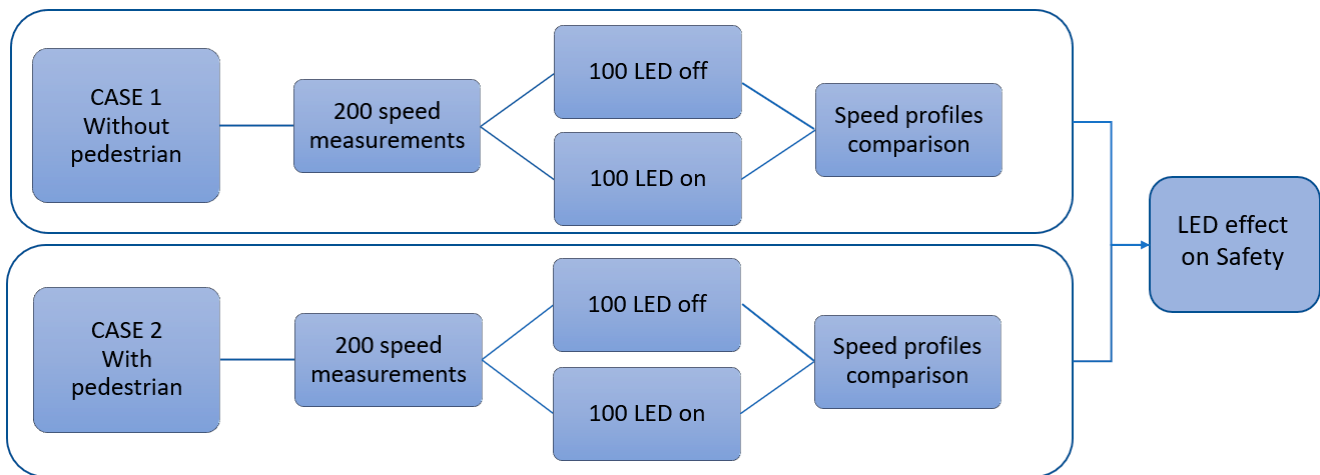


Figure 30: Methodology used to test LED effect on Safety (Patella, S.M, et al., 2020).

As can be seen in Figure 31 Case 1 (without pedestrians) speed reduced from 47.7km/h down to 39.9km/h at the crosswalk showing the reduction in speed of 16.3% whereas in the presence of pedestrians as shown in Figure 32 approaching speed reduces from 40.2km/h to 32.4km/h at the crosswalk showing a reduction of 19.4%.

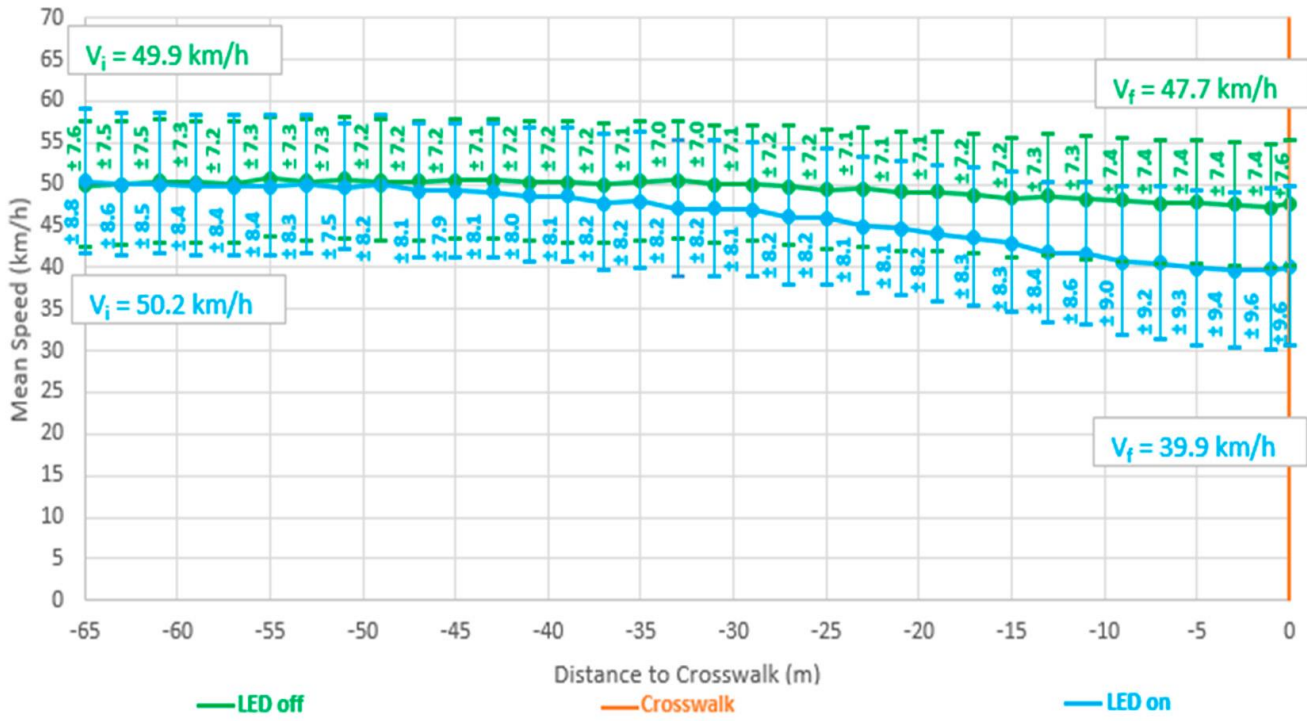


Figure 31: Case 1 - Mean speeds with no pedestrians (Patella, S.M, et al., 2020).

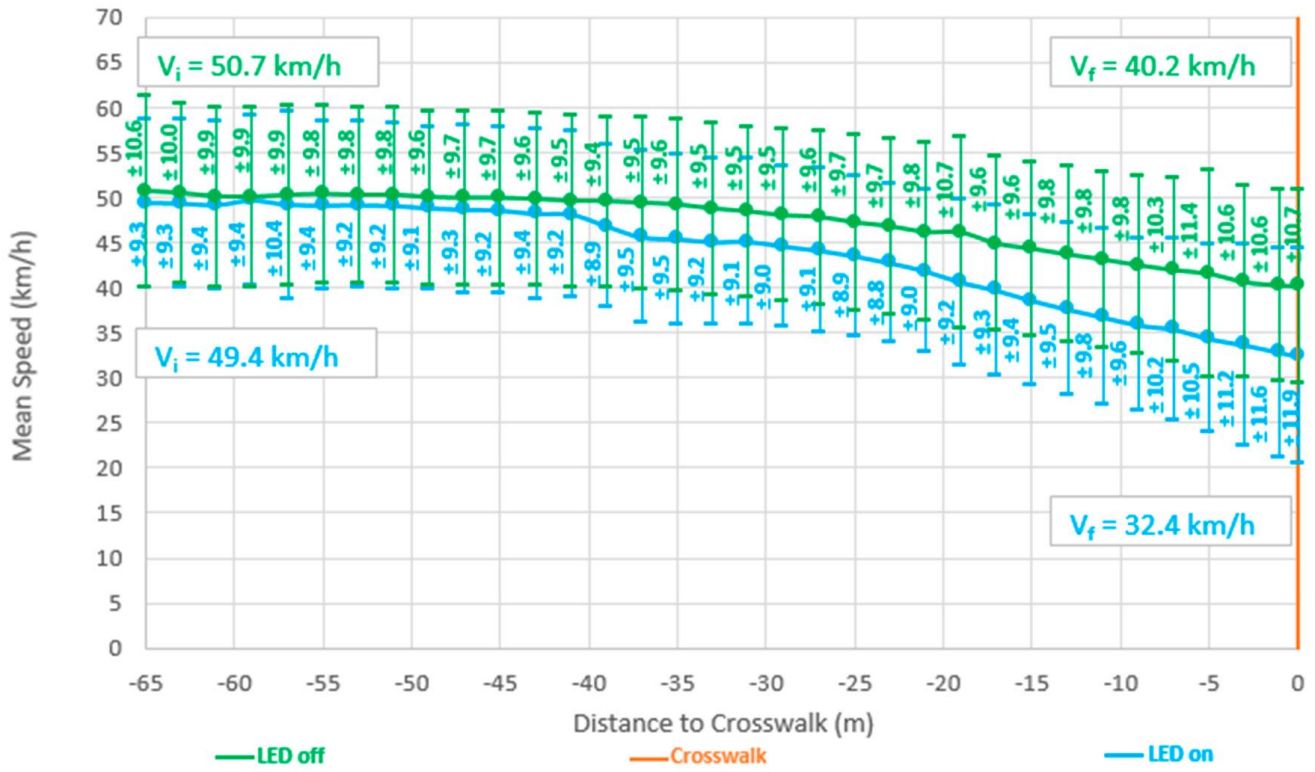
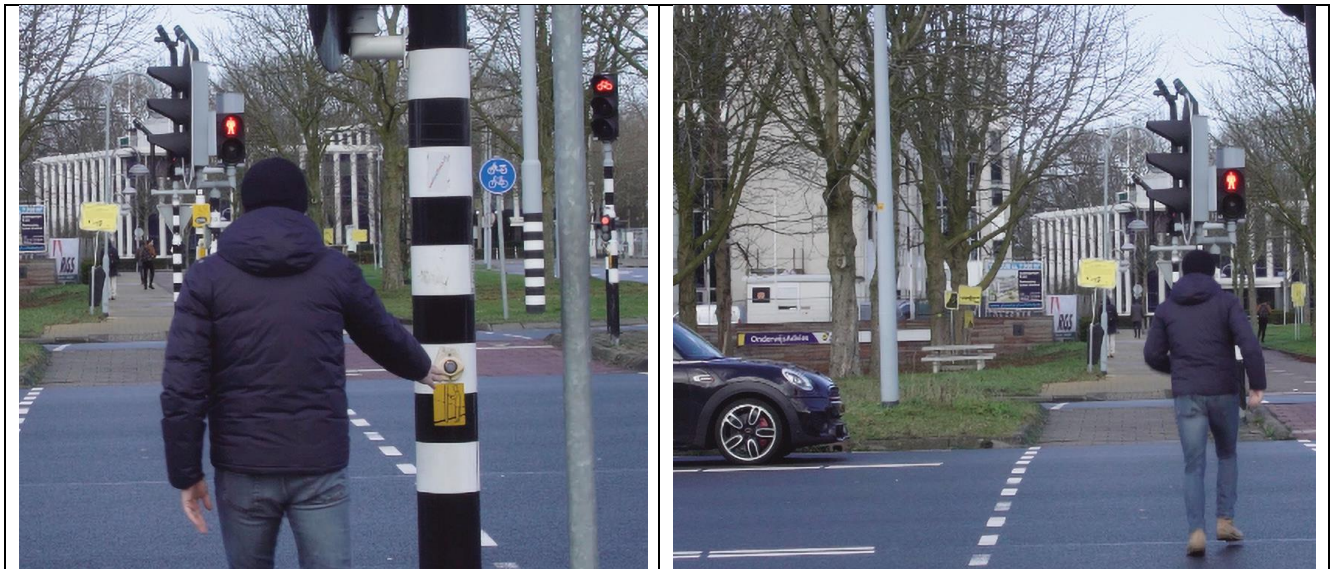


Figure 32: Case 2 - Mean speeds with pedestrians (Patella, S.M, et al., 2020).

### 2.5.3. Pedestrian sensors effect on vehicle idling in the Netherlands

Haarlemmermeer, Netherlands is using thermal detection sensors to improve the efficiency of pedestrian push buttons at signalised intersections for smoother traffic, less vehicle idling, and fewer frustrated motorists. Push-button cross signals are reliable ways for pedestrians to cross intersections and roads safely. However, there is one major drawback: once a button is pressed, these systems will cycle through to a green “Walk” signal whether or not pedestrians are present. This becomes a problem when pedestrians press crosswalk buttons, only to jaywalk before the green walk signal appears. By the time the signal finally turns green, the pedestrians are long gone, but vehicle traffic must still stop and wait for the automated cycle to finish, even though the crosswalk is empty (Teledyne FLIR, 2023).

This is a problem the district municipality of Haarlemmermeer, Netherlands faced. Municipal officials noticed that many of the inner-city traffic delays were caused by jaywalkers and needless pedestrian green calls. This interrupted vehicle flow and increased air pollution due to increased vehicle idling time (Teledyne FLIR, 2023).



*Figure 33: Impatient pedestrians who press for a green walk signal, only to jaywalk before it appears, can force vehicles to stop and wait at empty crosswalks (Teledyne FLIR, 2023).*

### 3. Literature Review (South African)

Although walking is the preferred means of transportation in African towns, neither cycling nor walking have received the proper attention in terms of funding or implementation. Perhaps as a result of colonialism's legacies and our current emphasis on automobile-dependent planning, which views non-motorised transportation as a means of transportation for the underprivileged and motorisation as an aspiring mode, African towns continue to be unsustainable focused on expanding the road networks and boosting motorization (Vanderschuren et al., 2017).

#### 3.1. Contextual and Systematic Challenges in South Africa

Historically, South Africa is an extremely complex society with systemic impacts incurred from racist policy through firstly colonialism for over 300 years followed by the Apartheid regime for another 46 years. It has been seen across all cities around the world that separating transportation and land use planning is one of the major reasons for a lack of accessibility in cities today. South Africa, historically, followed this planning philosophy. Further to this, South Africa's Apartheid policy added an additional racial segregation, which further made urban areas largely unsustainable (Vanderschuren and Galaria, 2003).

During the apartheid era, 'whites' stayed in the developed areas, close to all facilities and opportunities, whereas 'non-whites' ('blacks') stayed in the townships (technically not regarded as part of the city rather the outskirts of towns) away from the developed areas and job opportunities. As the non-white communities were largely lower income groups they were also public transport captives. Public transport used to act as a commuter service to take non-whites to their workplace early in the morning and bring them back in the evening regulated by 'dompas' (the official document that black people had to carry with them to prove their identity and where they could live or work). By living on the outskirts 'slower' sustainable modes (NMT) were not possible due to distances needed to travel and relied on either rail or road based public transport systems (Vanderschuren and Galaria, 2003).

As seen in Figure 34 Cape Town average trip length from home to work is approximately 14km. Reasonable distances to travel using NMT (walking or cycling) are up to 5km. It is therefore NMT is not a viable transport mode choice.

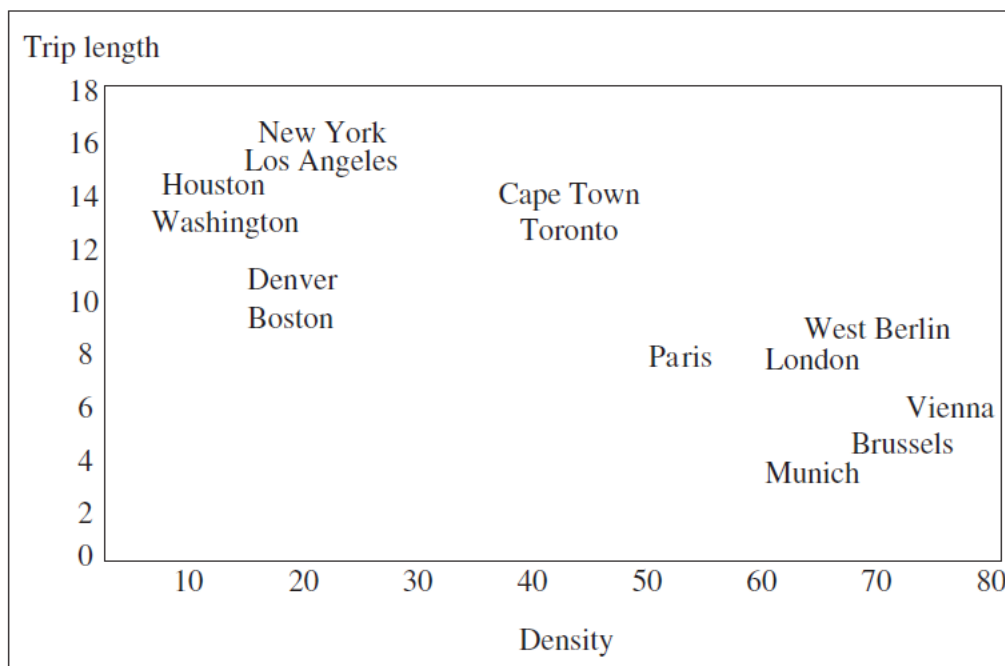
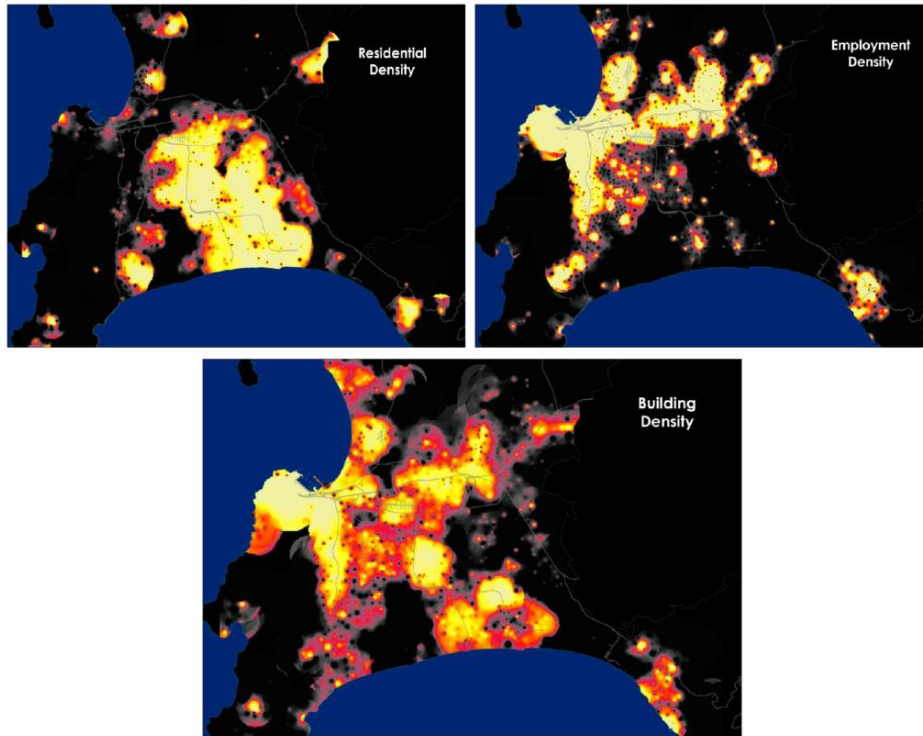


Figure 34: Average length of home-work trip (km) against density (persons/ha) (Vanderschuren and Galaria, 2003).



*Figure 35: Residential, Employment and Building Density in Cape Town (TDA, 2018)*

Figure 35 above illustrates an example of a South African City that is imbalanced with high residential density in the metro southeast whereas the job opportunities are concentrated around the Cape Town CBD (TDA, 2018). As has been reiterated in this dissertation, this is further evidence of the long home-work trips that is required to be made which; therefore, make NMT not a viable mode for most.

With the termination of apartheid, there are no more confined regions categorised by race. Consequently, the possibility of movement without constraint has been attained, allowing mobility for all individuals. However, this has led to a heightened demand for transportation. The current land-use is intensifying the inherited dormitory townships and long travel distances by locating the new low cost housing far away from the urban centres and existing transport infrastructure. Provision of low cost housing and access to opportunities for all are controversial issues. Unfortunately, the density of South African cities has decreased dramatically over the last century as compared to European cities as land is not as scarce a commodity (when compared to European norms) hence residential areas are less inclined to densification (Vanderschuren, and Galaria, 2003).

To address this, most South African Cities adopted a ‘Corridor City’ strategy whereby key areas (nodes) across the City are identified for mixed use densification. Mass Public Transport systems are used to connect nodes with further Transit Orientated Developments along the corridors (TDA, 2018). This can be seen as South African Cities are in the process of rolling out various mass transit public transport systems (BRT, Heavy Rail or high quality bus etc.). As can be seen in Figure 36, Figure 37 and Figure 38 below South African Cities have all adopted similar strategies to mitigate historic imbalance. Following this strategy looks to shape the City spatial landscape towards a more mixed use land use. Once traveling distance are reduced NMT modes inevitably become more viable.

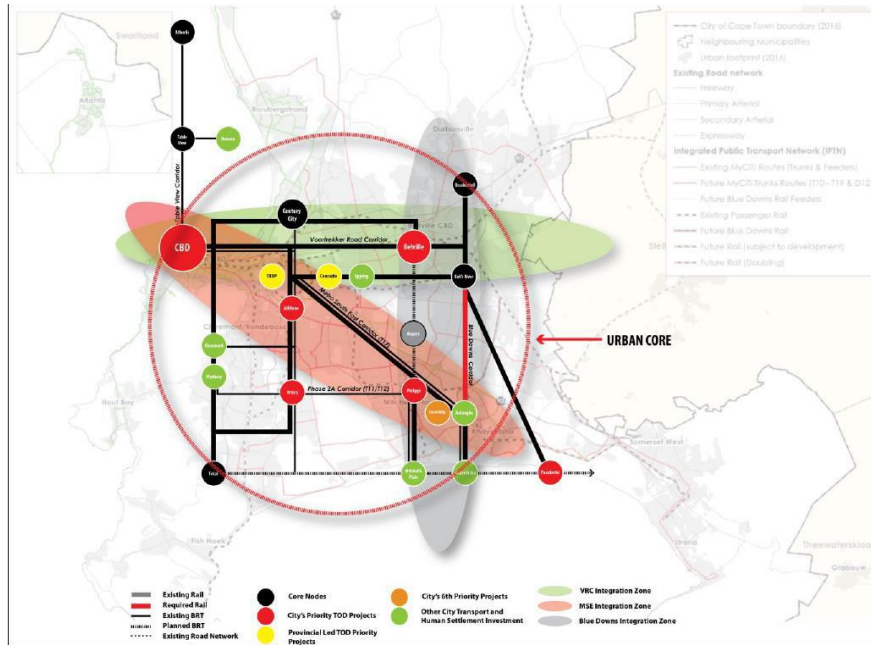


Figure 36: Spatial Development Plan for City of Cape Town (TDA, 2019)

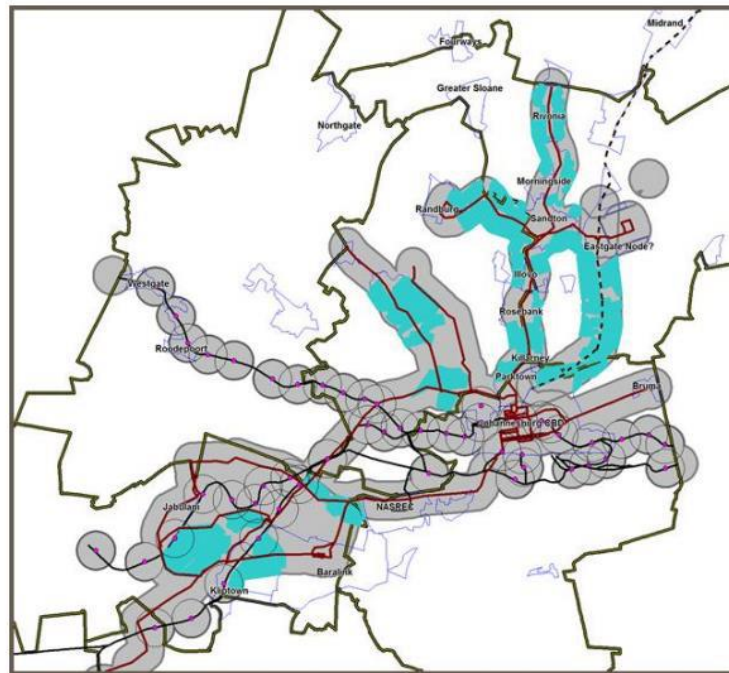


Figure 37: City of Johannesburg spatial Development Plan (City of Johannesburg, 2013)

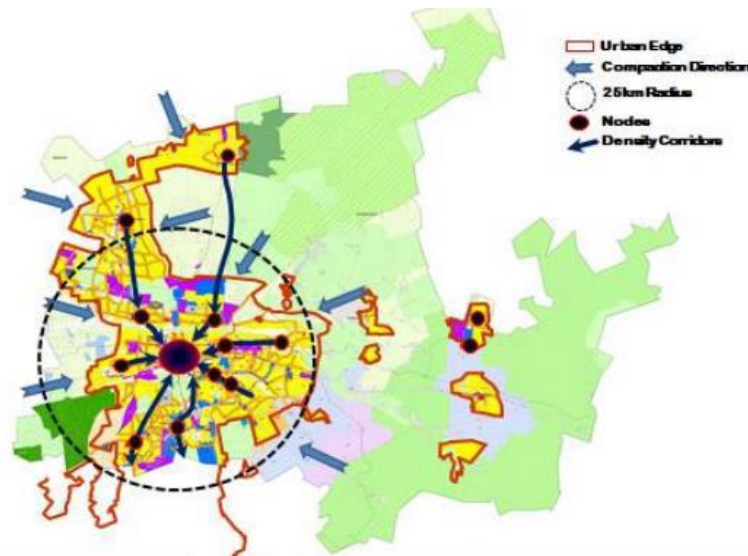


Figure 38: City of Tshwane Spatial Development Plan (City of Tshwane, 2014)

### 3.2. Road Safety Trends for NMT in South Africa

In the South African National Household Travel Survey (2020) results showed that 'walking all the way' was the main mode of travel used by household members to reach their destination. A little more than 17,4 million South Africans walked all the way to their destination, followed by 10,7 million individuals who made use of a taxi and 6,2 million who used a car/truck as the driver of such vehicle. Trains were the least used mode of travel by household members, except for Western Cape (1,6%) and Gauteng (1,5%), where more than 1% of household members used this mode of transport. It is also important to note that while 17.4 million individuals walk the full trip the majority of the 10.7 million people using public transport walk to public transport stops or stations, thus they can also be regarded as NMT users. Travelling to an educational institution was the main purpose of undertaking a trip by household members in South Africa, while trips to the usual workplace were cited as the second most common purpose for household members to travel (Statistics South Africa, 2021).

Mode of travel		Statistics (numbers in thousands)	Province									RSA
			WC	EC	NC	FS	KZN	NW	GP	MP	LP	
Public transport	Train	Number	74	12	*	*	32	*	181	4	*	305
		Per cent	1,6	0,3	*	*	0,5	*	1,5	0,1	*	0,7
	Bus	Number	242	117	38	72	351	125	430	294	217	1 886
		Per cent	5,2	2,7	4,1	3,5	5,1	4,5	3,6	8,8	4,4	4,5
	Taxi	Number	968	1 011	123	382	1 848	585	3 780	775	1 240	10 712
		Per cent	20,7	23,1	13,2	18,7	27,0	21,2	31,9	23,2	25,3	25,7
Private transport	Car/truck driver	Number	1 080	460	136	282	828	289	2 424	332	373	6 204
		Per cent	23,1	10,5	14,7	13,8	12,1	10,5	20,5	10,0	7,6	14,9
	Car/truck passenger	Number	783	450	113	168	901	244	1 268	272	380	4 579
		Per cent	16,7	10,3	12,2	8,2	13,1	8,8	10,7	8,1	7,7	11,0
Walking all the way		Number	1 473	2 282	500	1 123	2 807	1 442	3 489	1 630	2 664	17 409
		Per cent	31,5	52,2	53,9	54,9	40,9	52,2	29,5	48,8	54,3	41,7
Other		Number	59	40	19	19	91	78	259	32	32	630
		Per cent	1,3	0,9	2,0	0,9	1,3	2,8	2,2	0,9	0,7	1,5
Total		Number	4 679	4 372	927	2 047	6 858	2 764	11 832	3 338	4 908	41 726
		Per cent	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Figure 39: Main mode of Transport used by household members by province, 2020

South African road crash fatality rates are amongst the highest in the world with 22.4 fatalities per 100 000 inhabitants whereas European averages are closer to 4.9 fatalities per 100 000 inhabitants (International Transport Forum, 2019).

The State of Road Safety Report 2019 published by Road Traffic Management Cooperation shows that highest percentage of pedestrian fatalities are as a result of jay-walking pedestrians. As can be seen in Figure 40, jaywalking due to noncompliance of traffic laws is the main cause of fatalities and hence efforts are to be made to reduce these fatalities.

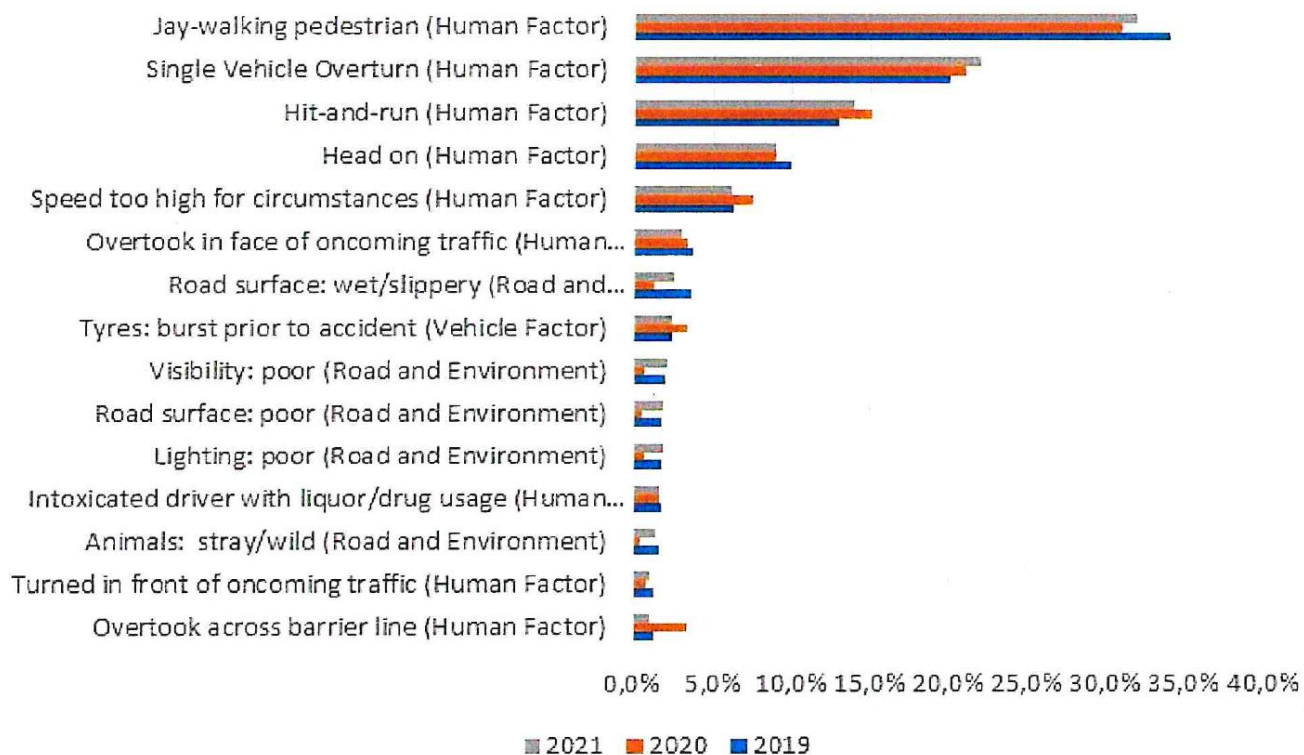


Figure 40: Percentage distribution of fatalities per contributory area (RTMC, 2021)

In Table 2 below pedestrian fatal crashes per province is presented with Gauteng and KwaZulu-Natal having the highest pedestrian fatalities recorded in 2021.

Table 2: Pedestrian fatal crashes per province (RTMC, 2021)

YEAR	EC	FS	GP	KZN	LP	MP	NC	NW	WC	RSA
2019	603	203	1178	1108	430	396	119	313	574	4924
2020	479	163	847	989	336	301	87	231	442	3875
2021	631	208	1231	1285	395	339	126	264	640	5119

### 3.3. Pedestrian street crossing behaviour in South Africa

As seen in section 2.1 and 2.2, pedestrians are most vulnerable to accidents at locations where there is conflict with other modes. This occurs largely at road crossings or at interface areas where speed differentials are high.

In a South African City, Cape Town pedestrians account for 40% of road crash fatalities. Pedestrians crossing the road without the use of crossing facilities are the greatest cause of fatal crashes accounting for around 36% of the factors contributing to all fatal crashes in South Africa (Behrens and Makajuma, 2017).

Cities with stronger levels of traffic law enforcement and related compliance than Cape Town are unlikely to exhibit comparable uncontrolled or illegal crossing behaviour. According to the results of the study conducted in Cape Town, up to 62% of highway crossings and 93% of arterial crossings (off desire lines) may be unaided or unlawful. Even within Cape Town, given findings with respect to the relationship between experience of city living and at-grade freeway crossing, behavioural patterns are likely to vary across different parts of the city on the basis of the different socio-demographic groups they accommodate. Other factors are also likely to play a role

in attitudinal and behavioural variation, as found, for instance with respect to the influence of neighbourhood design on perceptions of safety with respect to religiosity (Behrens and Makajuma, 2017).

The main implications of the findings presented in this study for the formulation of strategies to improve crossing safety by reducing unassisted and illegal pedestrian crossing behaviour are as follows (Behrens and Makajuma, 2017):

- “The provision of regularly spaced crossing facilities, on their own, is unlikely to lead to significant changes in pedestrian crossing behaviour. The studies in Cape Town suggest that crossing facilities are more likely to be used if they are located on the pedestrian’s desire line” (Behrens and Makajuma, 2017).
- “Consequently, understanding or estimating pedestrian desire lines and walking trip assignment is more important than understanding detour refusal distances in locating crossing facilities and in attempting to minimise unassisted or illegal crossing patterns” (Behrens, R. and Makajuma, G., 2017).
- “This necessitates that walking be routinely included in travel behaviour analysis, when in the past it has been omitted, and treated as a travel mode like any other. Trip stage and main mode walking trips need to be analysed in travel surveys, and methods for analysing and predicting walking trip generation, distribution and route choice need to be developed” (Behrens, R. and Makajuma, G., 2017).
- “Given the observed relationship between city living and crossing behaviour in Cape Town, is that key to the formulation of any strategy to improve pedestrian safety will be an acceleration of the learning experience and appreciation of traffic risk. This indicates that education and awareness programmes will be important, in parallel with improved enforcement of traffic rules pertaining to pedestrian crossing. For education and awareness campaigns to be most effective, research into variations in attitudes and behaviour across population segments will be necessary to identify the most appropriate communication medium and targeting of campaigns” (Behrens, R. and Makajuma, G., 2017).

As can be seen in the above conclusions from Behrens and Makajuma (2017) studies for pedestrian crossing behaviour to improve three measures are required namely:

- Increase crossing opportunities,
- Alignment between infrastructure and desire lines, and
- Education.

### **3.4. South African acceptance of new technology?**

ITS has shown to have provided benefit in other countries (see Chapter 2), especially when dealing with developing countries it is important to understand user acceptance. Would South Africans accept technologies that aim to improve the transportation system? It has been seen that in South Africa where levels of traffic law enforcement and associated compliance levels are generally low it is a valid concern if the investment is worth it especially as we have seen that the capital costs of many of these interventions can be quite high (Vanderschuren, 2006).

There has a steady increase in technological advancements in South Africa and associated acceptance of them. This is evidenced by the rise in smartphone ownership, increased access to the internet, and various other technological advancements. Therefore, it can be inferred that South Africans are receptive to new technologies, particularly if they perceive a personal benefit.

## 4. Research Method

This Chapter aims to reflect on key lessons learnt from the literature in order to path the way for the research design method. The focus of this thesis is to examine different advancements in the field of ITS that are specifically NMT based ITS measures. In Chapter 2, a variety of ITS measures used globally was explored. In this chapter, key lessons will be extracted from the literature review. This chapter will expand into applicability of ITS measures in a South African context, exploring applications in South Africa of ITS measures and finally establishing parameters used to evaluate case studies.

### 4.1. Literature Review Reflections & Lessons Learnt

A literature review was presented in Chapter 2 and 3 of this dissertation exploring literature of international best practice and lessons learnt. Thereafter exploring the local context to determine applicability of such measures in South African context.

#### 4.1.1. International Literature

In Chapter 2, the dissertation explored some key concepts outlined in ITS namely seven key objectives which have then been further sub-divided into 3 categories covering areas in mobility, safety and communication. It acknowledged that a critical shortcoming globally is that NMT based ITS measures have not been as widely developed in comparison to road-based ITS measures, therefore, there is a limited range of NMT based ITS measures. The other challenge found is that many ITS measures are mutually inclusive of NMT thus while some ITS measures are not specifically aimed at NMT some of the benefits results in a positive effect for NMT modes. Some of key findings from the literature:

- NMT based ITS measures are limited in enhancing mobility. Some of the existing technology before the establishment of ITS were already present such as elevators, escalators or people movers which seek to enhance pedestrian mobility (increase in speed, comfort etc.). Traditionally many of these ITS measures may have not originally been intended as an ITS measure, however according to the definitions they can be categorised as such.
- Pedestrian fatalities account for 23% of global road fatalities (WHO, 2018) thus all countries have room to improve. Literature shows that the location of most fatalities are at the interface (conflict points) of different modes such as pedestrian crossings or at intersections. In line with this finding ITS measures must be focused around attempting to improving safety around these interface points. LED lane lights and pedestrian detectors have been popular choices internationally with case studies showing positive results.
- Access to internet and smartphones have provided great platforms for ITS communication systems as majority of the population can have access to navigational systems which improves travel decision making.

#### 4.1.2. Local Literature

Exploring the local context in light of NMT based ITS measures some key findings are as follows:

- Historic racist spatial planning resulted in majority of the working force living in excess of 15-30km of job opportunities which is not conducive in promoting NMT. In order to remedy this, most South African cities have adopted a ‘Transit Orientated Development’ strategy which encourages densification along transit corridors in an attempt to convert cities into multi-nodal cities. One of the outcomes of such a strategy may result in increased usage of public transport which will also increase the NMT users.
- According to the National Household Travel Survey over 28 million NMT users in South Africa walk as their mode of transport for all or part of their daily trips.

- Literature shows that South African Cities have a low level of compliance to traffic rules and regulation which makes pedestrian crossing outside the allocated pedestrian signal phase a regular occurrence. Similarly crossing along the exact desire line instead of at the dedicated safe pedestrian crossing facilities are also a common occurrence. High unemployment rates and insufficient housing also has created environment for ‘beggars’ or street hawkers at intersections looking for some money to earn a living which has an influence on safe driver behaviour on the approach to intersections.
- South Africa is still a developing country and does not have the level of infrastructure in comparison to some of the more ‘developed’ counties. NMT networks within major cities are still being rollout over many years and thus limited separated dedicated right of way NMT networks exist. Without the basics of NMT infrastructure network completed it is premature to shift priority toward optimisation of NMT infrastructure.
- Due to the established low compliance of traffic rules careful consideration to ITS measures that requires compliance to be effective. In developed countries these measures may prove highly effective however our systems have not matured sufficient for it to bear results in our context yet.

## 4.2. Application ITS in South Africa

In South Africa, established infrastructure for NMT networks are still in the process of being established thus less emphasis on NMT based ITS measures and, consequently application of publically funded NMT based ITS measures are limited. Table 3 summarises the ITS measures reviewed in this dissertation with its intended objectives.

*Table 3: ITS Measures and Objectives*

Inteligent Transport System		Safety	Mobility	Efficiency	Productivity	Energy and Environment	Customer Satisfaction	Universal Accessibility
Mobility ITS	People Movers		X	X			X	
	Escalators and lifts		X	X			X	X
	Smart Intersection	X	X	X		X	X	
	Scamble signal phase	X	X	X		X	X	X
	Push button	X	X	X		X	X	X
	SCOOT	X	X	X		X	X	
	Dancing Traffic signal		X	X			X	
	Signal countdown timer		X	X			X	
Safety ITS	LED pedestrain crossing	X					X	
	HAWK	X					X	
	Pedestrain Detection technology	X	X	X			X	
Communication ITS	Navigational systems		X	X	X		X	
	crowd management system	X		X			X	
	CCTV camera	X			X		X	
	Smartphone P2V warning systems	X					X	
	Walkability app				X		X	X
	Google Glass		X				X	X
	Mobility Assistance	X	X				X	X
Virtual Reality Simulation	X					X	X	

As seen in Chapter 3 the pedestrian fatalities statistics presented in this dissertation are high, thus road authorities need to prioritise measures that improve road safety over optimisation. South Africa are still largely in the early stages of implementation of Safety ITS measures thus ITS measures are still in the planning or early construction stages or have not been implemented long enough to collect statistically significant data for the majority of measures. Some of the ITS measures use in South Africa are:

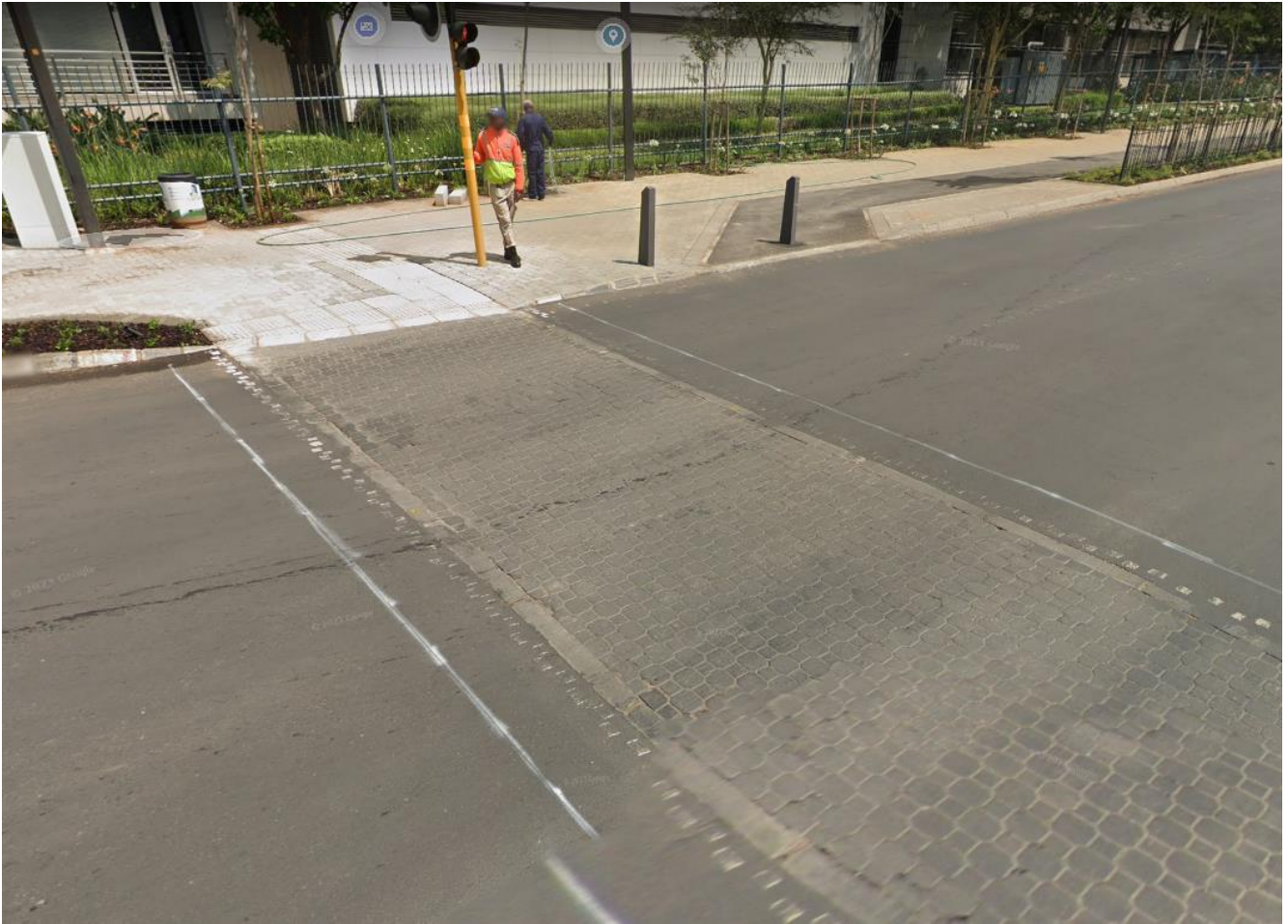
- LED lane Lights (Cape Town and Johannesburg)
- Pedestrian detectors (Cape Town)
- Navigational systems (nationally)

- Traffic signals (nationally)

An example of ITS lane lights recently being implemented can be seen below in Figure 41, Figure 42 and Figure 43. This ITS measure has been installed in October 2022 within Rosebank in Johannesburg. Unfortunately, insufficient data has been collected at this stage at this location, however, it is recommended that further studies are to be done to see if similar success is achieved at different major cities in South Africa.



*Figure 41: installation of LED Lane Lights in Rosebank (Oct 2022) (image from Google earth)*



*Figure 42: Rosebank LED Lane Lights*



*Figure 43: Live LED Lights in Rosebank, Johannesburg*

Communication ITS is largely driven by the private sector thus implementation across countries are seen to be more wide-spread, some of which are:

- GPS navigational systems (Google maps, Apple maps etc.)
- Virtual Reality (for education)
- Security and Safety systems

These systems are mostly actively used in the South African context and have been adopted into society. However, shortcomings are present in the education systems and to incorporate ITS or technologies within the education sector to teach publicly how to correctly interface with the road environment safety.

### **4.3. Data Availability**

Many other major cities (Johannesburg, Pretoria, and Durban) are still in the process of planning or implementing NMT-related ITS measures, and those that have implemented these measures have insufficient data to evaluate their effectiveness. Although the City of Cape Town does not entirely represent all South African cities, it is one of the most populous cities in the country, and conclusions drawn from the data are still valid. In subsequent chapters, further research will be discussed, which will aim to include additional cities to assess whether the case study's results can be replicated in other major cities in South Africa. This dissertation will explore two types of measures, with the first case study aiming to enhance pedestrian safety by influencing pedestrian behaviour, and the second case study focusing on improving system efficiency.

The first was a recent study conducted by Transport Planning and Network Management Directorate for the City of Cape Town conducted a traffic survey at the intersection Buitengracht Street and Walter Sisulu Avenue to assess vehicle stop line violation during the red signal phase. This is as a result of installing a combination of traffic signal countdown timer and LED lane lines. If proven successful, could be extended to other parts of the City.

The second set of data was data received for thermal pedestrian sensor installed pedestrian crossings along the West Coast of Cape Town. City approval was granted to use the raw data for both case studies to further analyse thus data used in the case study is secondary data however is still valid for this dissertation. To ensure compliance with ethics codes and intellectual property ethics clearance was sought from University of Cape Town, as well as approval for the use of data from City of Cape Town.

### **4.4. Research Method**

One of the key questions of this dissertation is to test appropriateness of an ITS measure in a South African context. As the research explored international examples case studies as well as the local context of South Africa using local case studies already applied within South Africa to measure it's appropriateness and if it valid to expand to more cities within South Africa. The following methodology will be used to assess the case studies:

1. Identify NMT ITS measures within South Africa
2. Source Data
3. SWOT Analysis
4. Analyse or review analysis
5. Interpretation of final analysis and reflection on applicability

## 5. South African Case Study Assessment

### 5.1. Case Study 1 – Cape Town Pedestrian Crossing

#### 5.1.1. Study Intersection and Period

In the City of Cape Town, located at the start of the N1 out of the city is the intersection of Buitengracht Street and Walter Sisulu Avenue, one of the most congested intersections in the City with heavy traffic flow from all directions. In the afternoon peak large volumes of vehicles exit the city funnelling through this intersection from the CBD and from the western leg as this is the main access point to the Waterfront precinct large densities of offices, residential and commercial spaces further adds to major congestion from the west leg of the intersection.

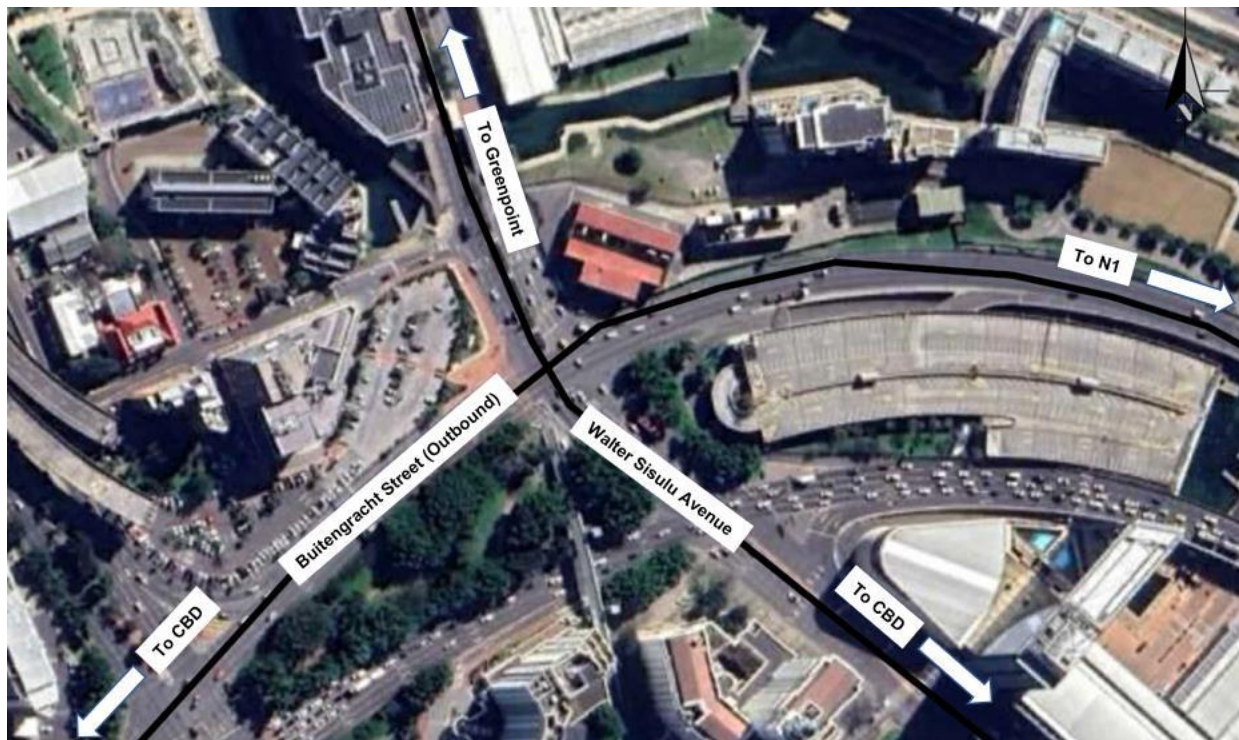


Figure 44: Intersection of Buitengracht Street and Walter Sisulu Avenue

#### i) Intersection Configuration

The current intersection configuration as can be seen in the Figure 45 below. The only NMT movement accommodated along this intersection eastbound leg with has been demarcated with red paving blocks and later installing ITS measures along the pedestrian crossing.



*Figure 45: Intersection Configuration of Buitengracht Street and Walter Sisulu Avenue*

ii) Existing Traffic data

The intersection has a recorded approximately 10 500 vehicles in peak hour and more importantly for the purpose of this dissertation during the course of the day 17 460 pedestrians were observed.

iii) Pedestrian desire lines

NMT desire lines within the City Centre are in all directions with various micro origin and destinations scattered throughout the city bowl. However, some of the key travel patterns within city can be seen below in Figure 46

showing existing and proposed class of cycle routes. Some of the key travel patterns characteristics for NMT within the City of Cape Town are:

- High percentage of trips in and out from work via private passenger vehicles. Resulting in shorter walking trips from parking to office and vice versa in the afternoons.
- People that reside in Cape Town walking trips are widely spread throughout the city.
- Walking trips generated by public transport is concentrated at 3 major nodes:
  - Cape Town Train Station (which includes mini-bus taxi rank on upper deck),
  - Civic Centre MyCiti Station, and
  - Golden Arrow Bus terminus.

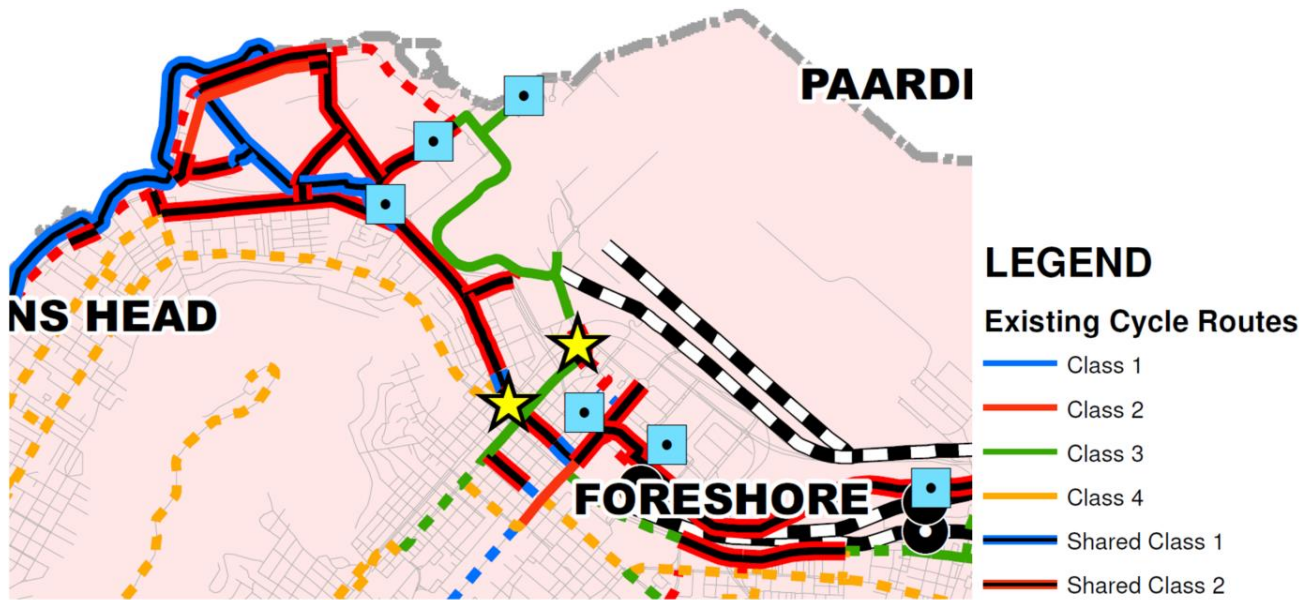


Figure 46: City of Cape Town NMT Masterplan: (TDA, 2018)

As depicted in Figure 47 below some key routes include strong desire lines which originate from public transport stations walking through the CBD towards waterfront and/or various other offices along the way. During 2010, Cape Town was one of the major cities in hosting the FIFA 2010 World Cup, which forced the city to ensure this very important link was accessible to stadium and important tourist nodes within the city. To this effect, a pedestrian bridge was built along the path as can be seen in Aerial view Figure 48. However, the pedestrian bridge was not taken through the entire intersection and returns at grade for last leg on the intersection. This was done, due to the future foreshore freeway scheme would clash and therefore would add additional cost to implement

future project. The application of an ITS measure was sought to make a lengthy crossing a safe yet efficient crossing.

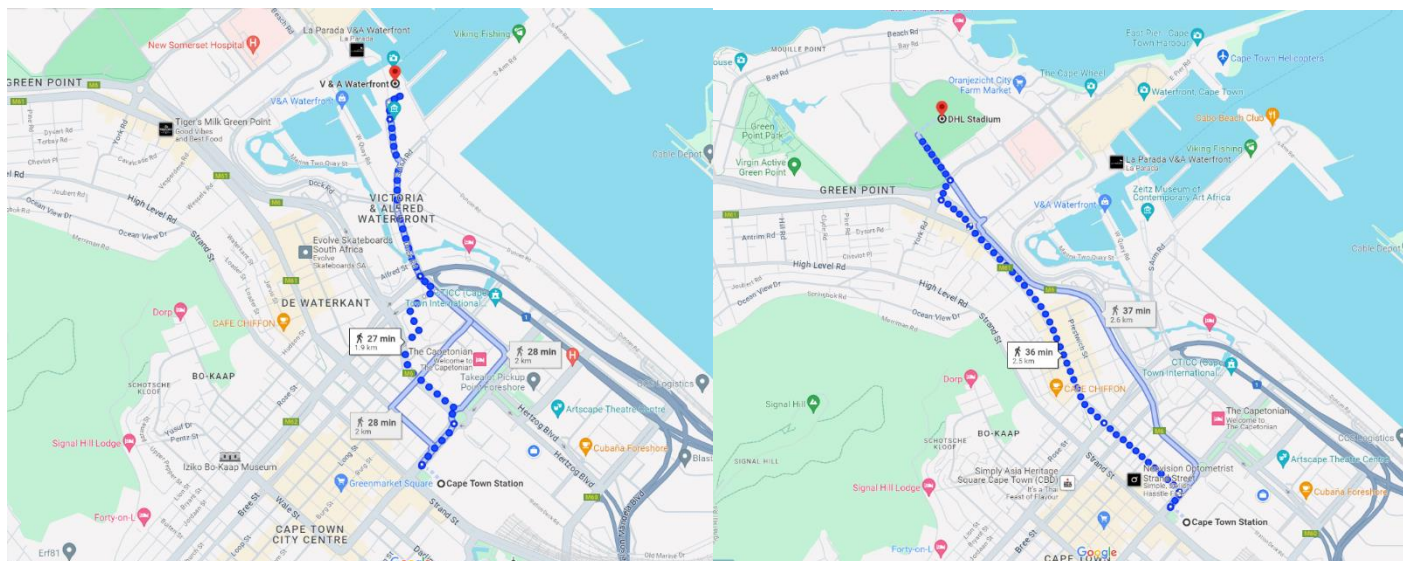


Figure 47: Key NMT Desire lines

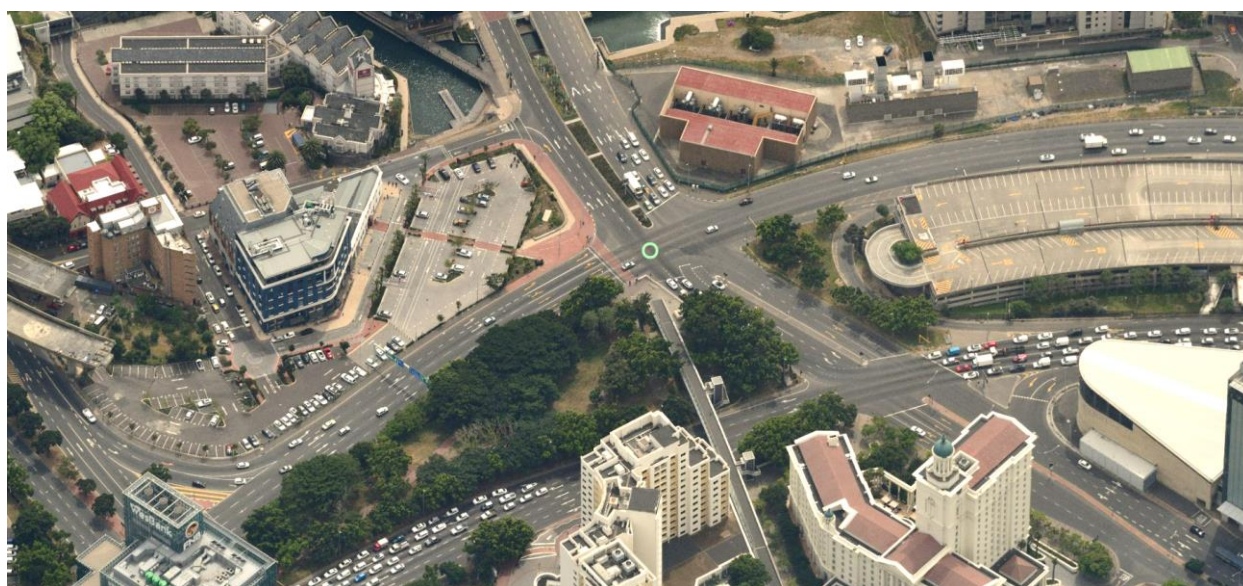


Figure 48: Aerial View of Pedestrian Bridge and Crossing

## 5.1.2. ITS Measures and Objectives

The City of Cape Town installed LED Lane Lights and Pedestrian Countdown signals in 2010 in anticipation of a major influx of tourists and boosted NMT facilities to major tourist hubs. LED Lane lights were installed synced with pedestrian signal phase thus when active LED lane Lights turn red to provide drivers awareness that it is the pedestrian phase and; secondary to create a safer environment for the pedestrian to make crossing over, such a length more comfortable (refer to Figure 49 below).

The objective of this measure is to firstly:

- Reduce Stop Line Violation i.e. vehicles to stop behind the solid line to keep pedestrian crossing clear. Often drivers ignore the road marking resulting in pedestrians needing to weave between vehicle increasing crossing distances, therefore as a result making crossing no longer universally accessible as physically impaired people would be further challenged in crossing the road.
- LED lighting also provides pedestrians further reassurance and protection while crossing which will attempt to alter behaviour to cross during the designated pedestrian phase.
- A common occurrence at the intersection are beggars and hawkers at intersection which inadvertently stand in the pedestrian crossing area which further impeded pedestrians using the crossing. If LED Lights are effective and reduces stop line violations it may inadvertently force beggars or hawkers further in the lane and clear of the pedestrian crossing area to allow for more effective crossing.



*Figure 49: LED Lane Lights (Buitengracht Street outbound)*

The second measure applied at this intersection is a traffic signal countdown timer was also installed to allow pedestrians to better judge when to enter intersection crossing area due to the length of the crossing as seen below in Figure 50.

As been reviewed in Chapter 2, the purpose of a traffic signal countdown timer is to attempt to reduce perceived waiting time. The signal has a countdown to show how much time is left in the pedestrian signal phase. Due to the length of crossing (5 lanes – 22.4m) it informs the pedestrian how much time he has left to cross. Traffic signal timers have shown to reduce perceived waiting time for crossing and therefore are more compliant to traffic signal phases. The ultimate purpose of this measure is try to achieve higher percentage of user compliance of traffic signals and therefore improve overall safety of pedestrians.



*Figure 50: Pedestrian signal countdown timer (Buitengracht Street inbound)*

### **5.1.3. Data Capture**

As mentioned in section 5.3 data was supplied by the City of Cape Town. Cameras are set up at the study area intersection and using specialised software automated counting of vehicles and pedestrians. In order to ensure accurate measurements fixed planes are used as a counting gate once either pedestrian or vehicle passes gate it is able to register as a count. Data is recorded over 5 second intervals. The gate set up can be seen in the Figure 51 below:



Figure 51: Data log Entry and Exit Gate set up

By the use of entry and exit gates it eliminates ‘beggars’ from the count as they generally do not cross the intersection rather are stationary in between general traffic lanes. The data captured both week day and weekend as it is likely that this intersection will have higher volumes of vehicles during the week peak periods and higher pedestrian activity over the weekend. Cameras run for 3 hour periods at a time during the morning peak period and afternoon peak period. On weekends cameras were left overnight to capture pedestrian activity. To ensure comparative analysis when comparing data the same time period was used for pre and post ITS intervention. The amount of video footage assessed is as summarised in Table 4:

Table 4: Amount of video footage assessed

Period	Number of Cycles Observed	Hours of Footage Assessed
Pre LED lane lights installation	291	≈12 Hours – Weekend footage in March 2022.
Post LED lane lights installation	564	≈22 Hours – Weekend footage (14 hours) in August and weekday footage (9 hours) in September 2022.

The effectiveness of the LED lane lights at the Buitengracht Street/Hans Strijdom Street intersection (Inbound) was not assessed as footage for the pre-lane light condition was not usable. This is, due to a combination of rain on the day and the camera malfunctioning.

## 5.1.4. Analysis and Results

To determine how effective the implementation of LED lane lights and signal countdown timer are required to analysed the pre and post pedestrian movements.

To understand its effectiveness, the purpose of each ITS intervention requires to be understood to ensure correct metrics are being used to measure performance.

### a) Signal Countdown timers

When activated by a pedestrian pushing the button, the countdown pedestrian cycle consists of three stages:

- Solid Green: Pedestrian permitted to enter intersection to cross.
- Flashing Red: No new pedestrians are permitted to enter intersection, however, if pedestrian had already entered intersection in previous phase is to complete crossing.
- Solid Red: Pedestrians are not permitted to enter or cross intersection.



Figure 52: Pedestrian phases in Cape Town (Meder M et al., 2016)

Table 5, shows the duration of each stage, as well as the total number of pedestrians observed from all video footage.

Table 5: Pedestrian Stages and Pedestrians Observed

Pedestrian Signal Stage	Duration of stage	Total number of pedestrians observed
Solid green	5 seconds	184
Flashing red (countdown)	20 seconds	237
Solid red	100 seconds	545

To determine the efficiency of the countdown pedestrian signal, the number of pedestrians crossing in all traffic signal stages was determined and this was compared with historic data before installation of signal countdown timer. Since the stages vary in length, the number of crossings per stage was normalised as a percentage of the overall number crossing during a cycle. Refer to Figure 53 which indicates both the percentage of pedestrians crossing per stage as well as the actual flow rate during each stage for pre and post ITS measure installation.

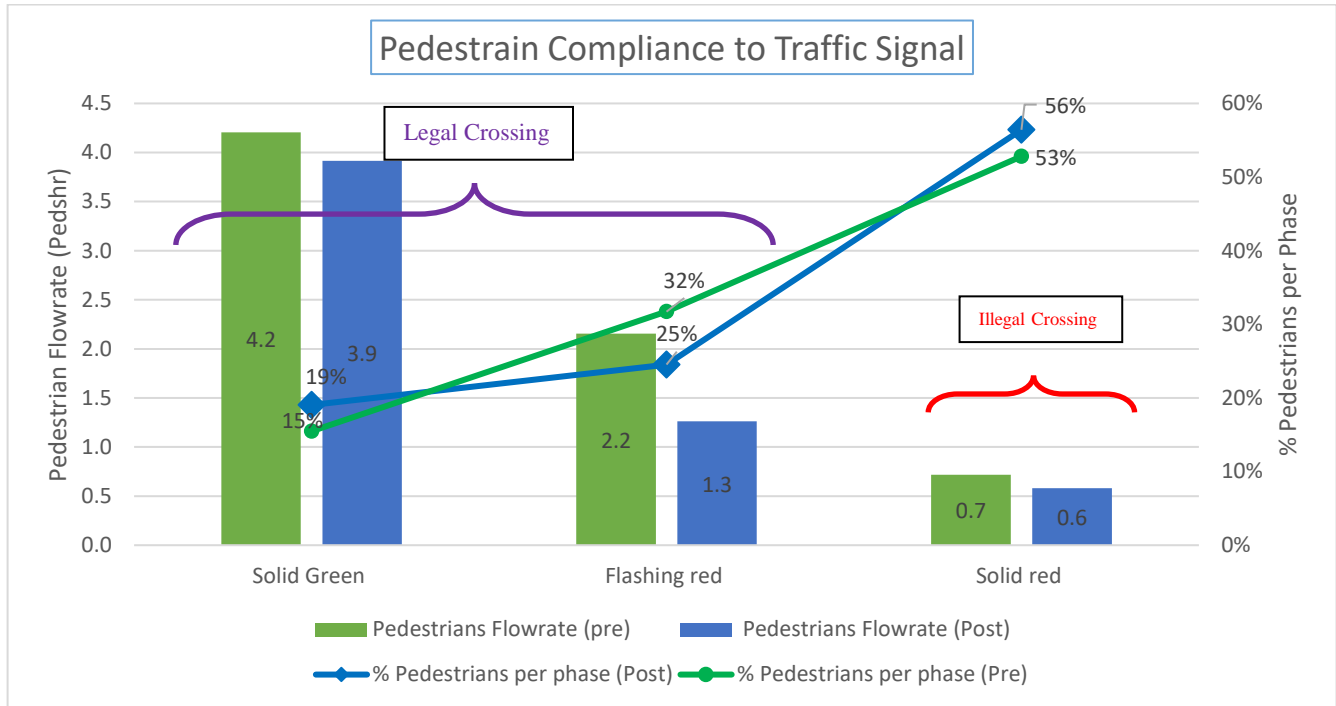


Figure 53: Pedestrian Compliance to traffic signal

As can be interpreted by the above Figure 53, green bars displays pedestrian flowrate during each phase of traffic signal, whereas the blue shows post ITS intervention and the blue and green line displaying the percentage of pedestrians crossing during the respective phase.

In the solid green phase where pedestrians are expected to cross it can be seen that flowrates are the highest as is expected as those pedestrians that are complaint to traffic rules would wait and queue at the signal waiting for the appropriate phase to cross. Once the phase is triggered queue of people all cross which pushes up the flowrate. Looking at this phase, previous literature deems to hold true in this case study as there is only a 15% compliance level and post ITS intervention 19% compliance level resulting in a 4% point change.

In the flashing red phase (do not start but finish crossing) as crowd clears it is logical to see a drop in flowrate which is reflective in the graph. From the video footage it was clear that many pedestrians are still entering crossing during this phase forced to walk/run to cross within the phase. Having the countdown timer provided insight to make a decision for those willing to start to cross during this phase if they are able to make it. While technically not permitted, traffic signal phases are designed to average walking speeds whereas some pedestrians are able to walk/run well beyond the average thus can comfortably cross within the allocated time therefore high numbers of pedestrians crossing in this phase are still present (32% and 25% respectively).

In the solid red phase, as expected flowrates are expected to be zero, however, with pedestrians crossing and having to navigate between traffic it slows down the flowrate one can achieve. It is noteworthy that over 50% of pedestrians cross during this phase. Post ITS intervention 56% crossing illegally resulting in non-compliance in a 3% point change.

For the full pedestrian cycle, the largest proportion of pedestrians used the crossing during the solid red pedestrian phase in both pre and post ITS measure with 56% and 49%, respectively.

A key observation after assessing the video footage is that pedestrians do not always activate the countdown signal with the push button. When the countdown signal is not activated and consequently the green man is not displayed, pedestrians will wait and cross anyway once the conflicting vehicle movements are stopped even though the pedestrian signal displays a red man.

Table 6: Pre vs Post compliance of traffic signal

	Pre	Post	% Difference	Comment
<b>Solid Green</b>	15.48%	19.05%	-3.57%	As this is a compliant legal crossing phase results are not significant due and more a reflection of increased pedestrian demand for crossing at the intersection.
<b>Flashing red</b>	31.71%	24.53%	7.18%	
<b>Solid red</b>	52.81%	56.42%	-3.61%	This indicates a decrease in signal compliance by 3.61%.

Above in Table 6 it is clear that a minor decrease in compliance post intervention occurred. Based on this dataset it appears that compliance to traffic signals have not improved by implementation of traffic signal countdown timer hence in this case study the countdown pedestrian signal appears to be ineffective in influencing pedestrian behaviour.

Lastly, to complete the analysis a SWOT analysis was completed below to summarise effects.

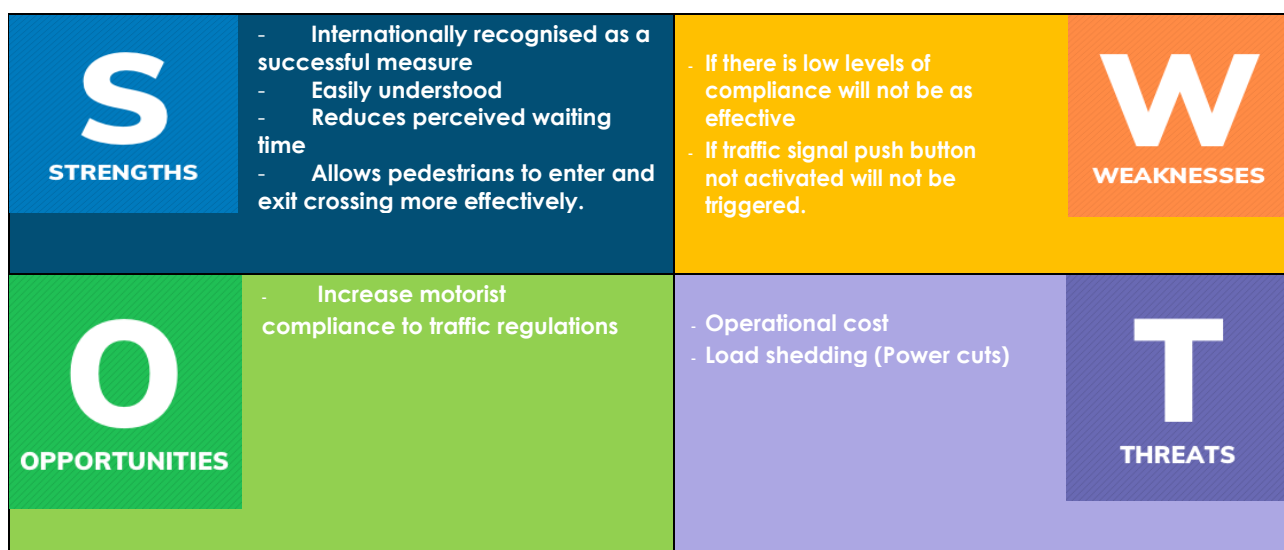


Figure 54: SWOT analysis for Signal Countdown timer

b) LED lane lights

As been reviewed in Chapter 2, the purpose of LED lane lights are to reduce approaching vehicle speed and specifically at signalised intersections to keep the pedestrian crossing clear and prevent stop line violations.

To determine how effective the implementation of the LED lane lights is, the number of drivers adhering to the solid-white stop line (during the vehicle-red signal phase) pre-and-post lane lights were compared. Each time a stop line violation was committed, the time was logged. Refer to Figure 55 which indicates a stop line violation.



Figure 55: Example of a stop line violation captured

In order for the footage pre-and-post lane lights to be compared, it was normalised to show the proportion of stop line violations per video period. This was done by averaging the number of front row vehicles per cycle (vehicle-red phase), and comparing it to the average number of stop line violations per cycle. On average, there were 4.5 vehicles in the front row during the red-phase. Table 7 summarises the outcome of this investigation.

Table 7: Outcome of stop line violation investigation:

Period	Total number of vehicles that stopped at stop line	Proportion of stop line violations for all cycles
Pre LED lane lights installation	1 457	26%
Post LED lane lights installation	1 378	8%

Due to the data set provided only weekend values pre LED lane lights was useable therefore unfortunately only weekend pre and post comparisons can be made, however, can be seen below in Figure 56 using 26% as the base both weekday and weekend significantly improved to 6% and 10% respectively.

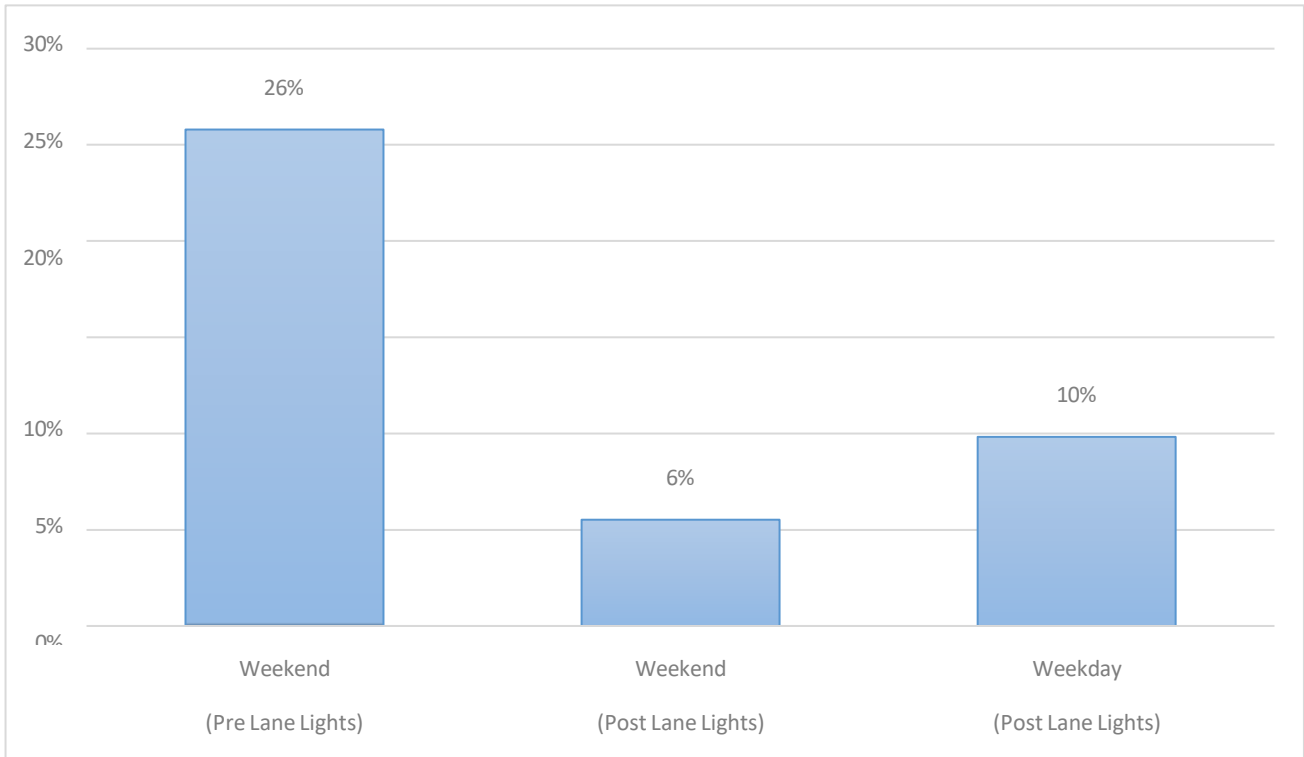


Figure 56: Percentage of vehicles violating stop line pre-and-post LED lane light installation

To further analyse the impact in Figure 57 one peak hour was extracted to assess the cumulative reduction in stop line violations. As discussed previously, due to corrupted data only weekend data was valid to assess for comparison purposes, thus the pre-LED lights (March 2022) and post-LED (August 2022) for both Saturday and Sunday are displayed with pre-installation with a solid line and post with a dashed line. As can be seen below Saturday showed 30% decrease in stop line violations.

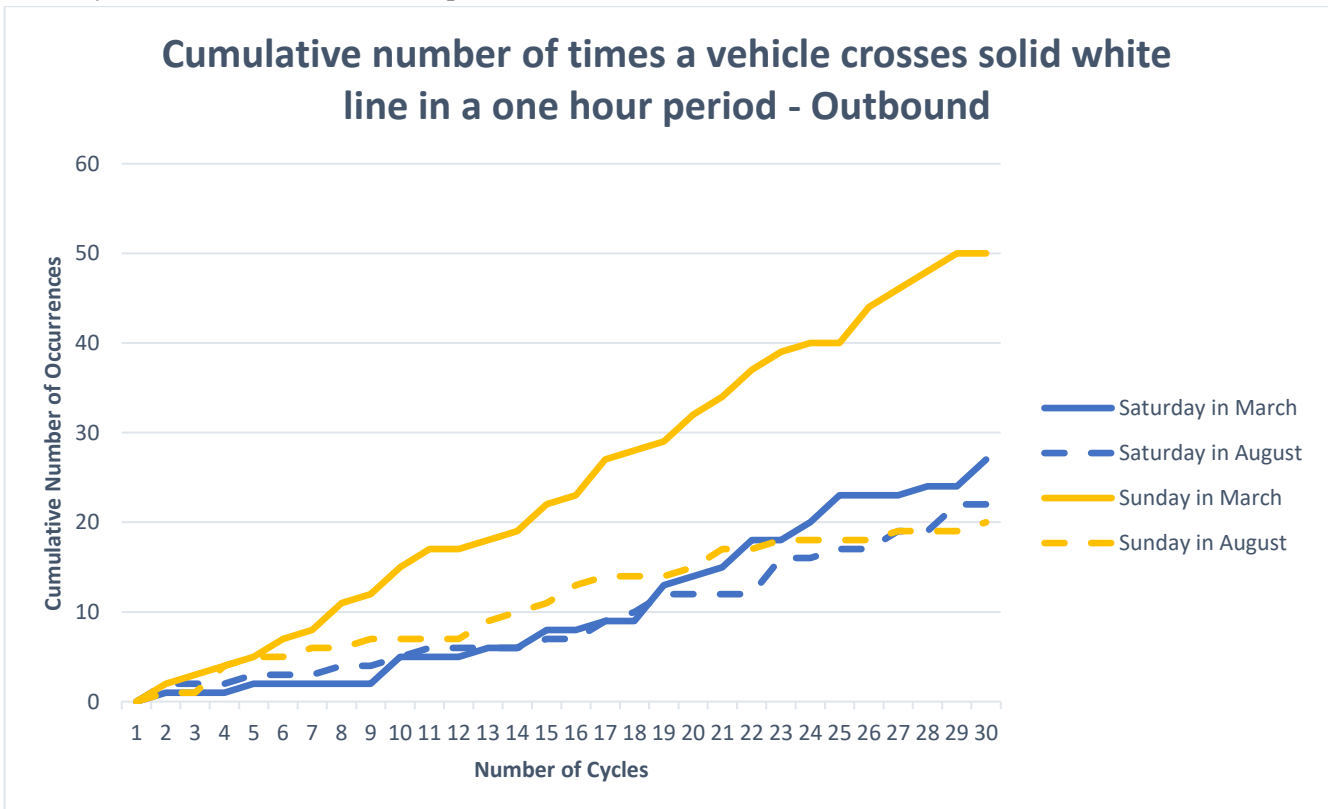


Figure 57: Cumulative number of times a vehicle crosses solid white line in a one hour period

Another metric analysed to gain further insight in the evaluation is to test if there is a particular lane that is responsible for violations. There may be some other underlying factors that required to be assessed. In order to test this 10 traffic signal cycle's data were grouped and used as a base testing period and the number of occurrence per 10 cycles are shown below in Figure 58. Interestingly, historically lane 4 (dedicated through lane) had the most violations were as post ITS intervention lane 1 (dedicated left turn lane) became the worst while lane 4 remained poor. From the video footage there is no clear evidence why this shift has occurred.

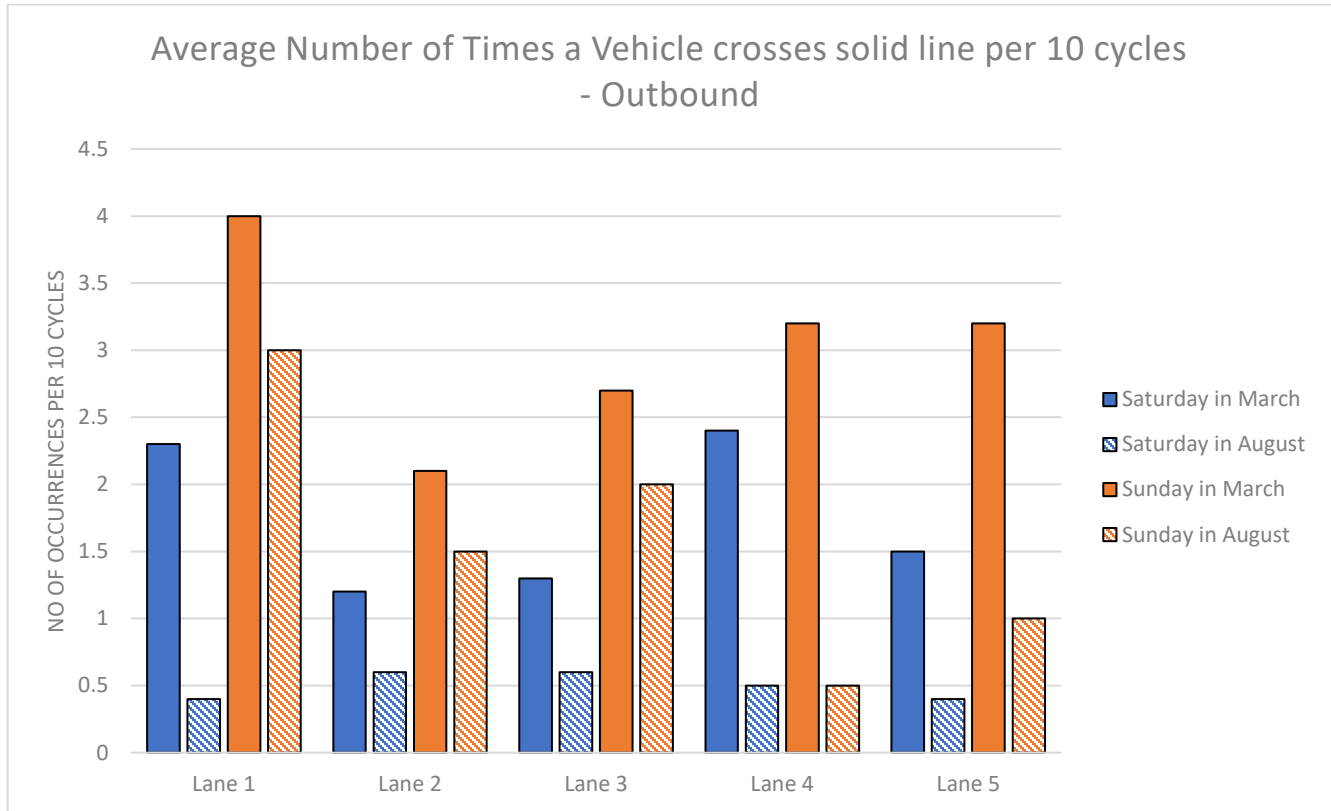


Figure 58: Average Number of Times a vehicle crosses solid line per 10 cycles

It is evident from Figure 56 that there is a clear reduction (from 26% to 6%) in the average number of stop line violations, specifically on weekends. However, driver behaviour during the week is expected to be relatively more aggressive compared to weekends. Therefore, weekday stop line violations could be relatively higher than during weekends. The low percentage of violations of only 10% is encouraging.

Lastly, to complete the analysis a SWOT analysis was completed below to summarise effects.

<p><b>S</b> STRENGTHS</p>	<ul style="list-style-type: none"> <li>- Enforces traffic compliance</li> <li>- Visually clear and provides sense of security to pedestrians</li> <li>- Relatively resistant to vandalism</li> <li>- Solar powered</li> </ul>	<ul style="list-style-type: none"> <li>- Can easily be blocked by a stop lane violation</li> <li>- Short lifespan</li> <li>- Requires some level of traffic compliance. In other cities or intersections may not be able to replicate results</li> </ul>	<p><b>W</b> WEAKNESSES</p>
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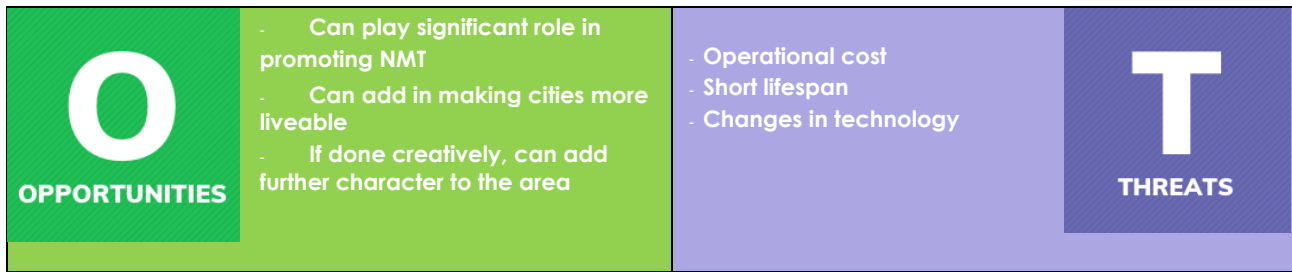


Figure 59: SWOT Analysis for LED Lane Lights

## 5.1.5. Discussion

### a) Signal Countdown Timer

From the above Section 6.1.4, the case study shows that the pedestrian flow rate during the green and countdown red pedestrian phases are higher than during the solid red phases, most pedestrians cross during the red pedestrian phase. This is plausible as the law-abiding pedestrians (15%-19%) presumably arrive at the intersection at different times with a portion of them during the red phase of which thereafter they will bunch and wait for green pedestrian phase. Once the green phase is triggered allows a relatively clear path to cross unopposed resulting in higher flowrates. In contrast, while majority (53%- 56%) crossing during red phase in opposing traffic would require to wait for a gap and cross in phases from lane to lane, which results in a lower flowrate as expected.



Figure 60: Typical bunching of pedestrians awaiting green phase

The countdown pedestrian signal appears to be ineffective in influencing pedestrian behaviour. Without more data in a wider study area it is not possible to conclusively define exact cause of its ineffectiveness, which has been recommended in the final chapter in this dissertation. However, based on video footage and the literature review it can be speculated based on the data that underlying causes for ineffectiveness are:

- As discussed in Section 3.3 suggest that as much as 62% of pedestrian crossings on freeways, and 93% on arterials (off desire lines), may be unassisted or illegal (Behrens, R. and Makajuma, G., 2017).
- The influence of neighbourhood design on perceptions of safety with respect to religiosity (Behrens, R. and Makajuma, G., 2017).
- Due to this intersection being such a critical intersection (highly congested) in the city, a short portion of the overall cycle time is allocated to pedestrians, as to not gridlock the city traffic network and, as a result, pedestrians are not willing to wait to legally cross.

- Not pushing push button to call up pedestrian phase earlier. By not pushing button traffic cycle remains on default settings and waiting pedestrians may not receive any further priority. If push button were engaged more frequently perhaps compliance may have increased. Perhaps a lack of education of pushing the button will prioritise pedestrian phase is also prevalent.
- It is also worth mentioning that the behavioural norm in South African to have a very low pedestrian compliance to traffic regulation with jaywalking are common occurrence. ITS measures that are based on compliance of basic traffic rules will likely not yield much success.

## **b) LED Lane Lights**

From the data and the analyses summarised, it is evident that LED lane lights appear to improve the stop line behaviour of motorist. A 75% reduction in stop line violations was observed during weekends and at least a 60% improvement during weekdays. It is worth bearing in mind that due to the fact that the weekday dataset being corrupted, an analysis is incomplete. The data collection was also completed in March (Pre ITS intervention) and August (Post ITS intervention) which are two different seasons thus especially for NMT users could influence behaviour. For example in colder temperatures or wet weather pedestrians may be willing to take higher risks to shorten travel time in comparison to warmer weather where pedestrians be more risk adverse.

## **5.2. Case Study 2 – Pedestrian detection system using thermal sensors in Cape Town**

### **5.2.1. Background**

Around South Africa various pedestrian mid-block crossings are present throughout the road network at high volume crossing locations. To ensure these crossings are universally accessible they are often accompanied with the traffic signal push button as described in Chapter 2. By pushing the signal push button it calls up pedestrian phase stopping traffic to allow sufficient time for pedestrians to cross safely.

In Cape Town, a unique problem emerged whereby push buttons are being vandalised. Vagrant/hawkers have realised that jamming the push buttons (by the use of twigs or other materials) ensures the pedestrian phase is called up on every cycle with the purpose of slowing down or stopping traffic to maximise the time vagrants or hawkers have to sell products or beg. This has caused major safety issues, as over time drivers believe traffic signal is faulty and they no longer respect the signals due no pedestrians crossing, which results in no safe opportunities to cross for pedestrians. In turn, this forces pedestrians to cross illegally as they are unable to use the signal push button. To commuters not familiar with the area who are compliant to red phase end up causing unnecessary delay for no pedestrians crossing thus increasing driver frustration. This vandalism also costs the South African tax payer approximately R85 000.00 per pole per occurrence draining an already constraint budget. To attempt to solve this issue the City of Cape Town implemented pedestrian detection system.

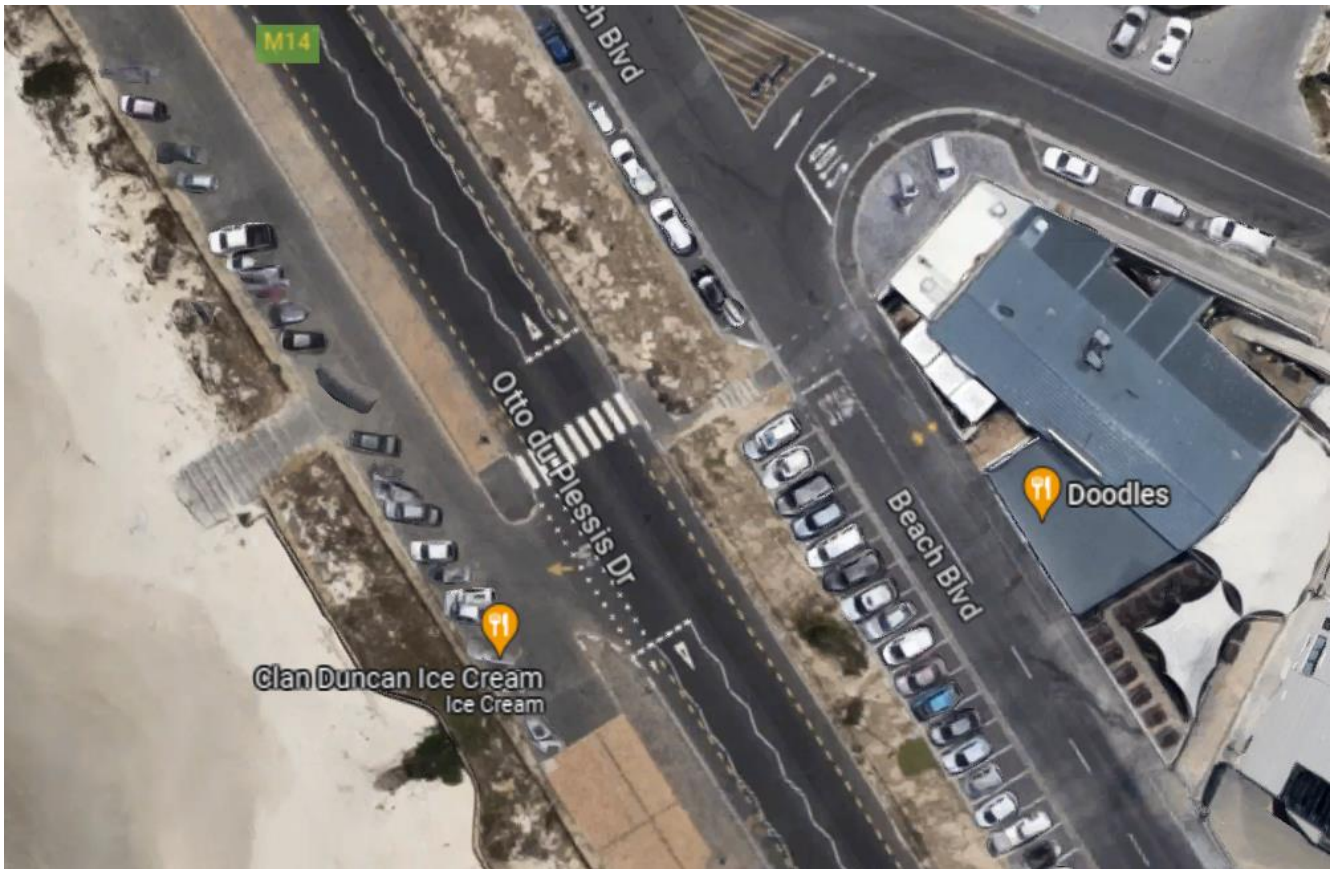


Figure 61: Pedestrian Crossing with Thermal scanner (Otto du Plessis Dr)

## 5.2.2. ITS Measures

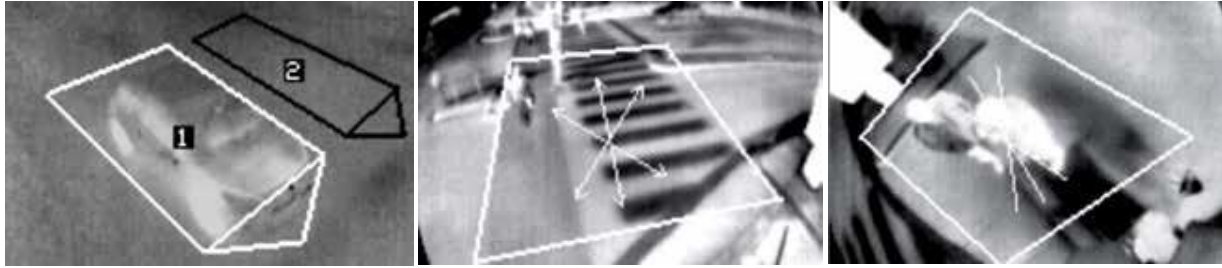
In order to address the root issue around vandalism of the traffic signal push button, the City of Cape Town piloted thermal imaging sensor (FLIR TrafiOne – Smart City Sensor) at 4 intersections along the West Coast. FLIR TrafiOne is an all-round detection sensor for traffic monitoring and dynamic traffic signal control (Teledyne FLIR, 2023).



Figure 62: FLIR TrafiOne - Smart City Sensor

The FLIR TrafiOne uses thermal imaging and Wi-Fi technology to adapt traffic signals based on the presence detection of vehicles, bicycles and pedestrians while, at the same time, generating high resolution data at

intersections and in urban environments. The sensor uses thermal imaging to detect both the presence of vehicles and bicyclists at the kerbside (Teledyne FLIR, 2023).



*Figure 63: Thermal imaging to detect the presence of vehicles, bicycles and pedestrians at intersections and urban environments*

Thermal imaging cameras are suitable for all weather environments and thus provide reliable traffic detection. The sensor is connected to the traffic signal controller to allow for a control of traffic signals based on presence or volume information. Sensors are Wi-Fi enabled which allow for configuration of detection zones remotely. As it is Wi-Fi enabled the data can be processed at Traffic Management Centre (TMC) to determine travel & route times along road. The TMC assigns traffic engineers/technicians that are able to use the dashboard to generate reports and start taking measures where they are needed (Teledyne FLIR, 2023).

### **5.2.3. Analysis and Results**

Unfortunately, this case study does not have any data before the installation of the sensors hence comparisons of full effectiveness of the ITS measure cannot be drawn however using the new system some analysis can be undertaken.

Pedestrian crossings are designed according to South African Road Traffic Signs Manual historically as piloted signals are on-demand pedestrian crossings signals would have only been activated on call up by activating push button. The length of the pedestrian crossings at the pilot study (Otto Du Plessis Dr, M14) is 17m which results in a fixed time 15 seconds. Due to fixed time nature of the signal traffic engineers are required to take into consideration all users (and possible multiple users) and set a reasonable time to allow pedestrians to cross safely without causing significant delay to the general traffic. This approach, while unavoidable with fixed time settings can cause driver frustration as the norm walking speed to cater for majority of people is 0.8m/s whereas pedestrians depending on fitness levels can walk up to 4 times as fast. When faster walking pedestrians cross (within 4-6 seconds) motorists are often forced to wait an additional 10 seconds per cycle which increases driver frustration which is a unintended inefficiency created by signals.

With the use of sensor as signal phase is activated and switch off immediately as pedestrian has safely crossed intersection there is a dramatic time saving as can be seen in Figure 64 below. As can be seen 11 pedestrians crossed within this hour period of data but notably all under 9 seconds meaning 6 seconds faster than fixed time signal which already shows significant improvement to system efficiency.

At the time of this dissertation, as the system is relatively new, only one month of data was captured and used to demonstrate performance below.

## Pedestrian Crossing Time (1-Hour Period)

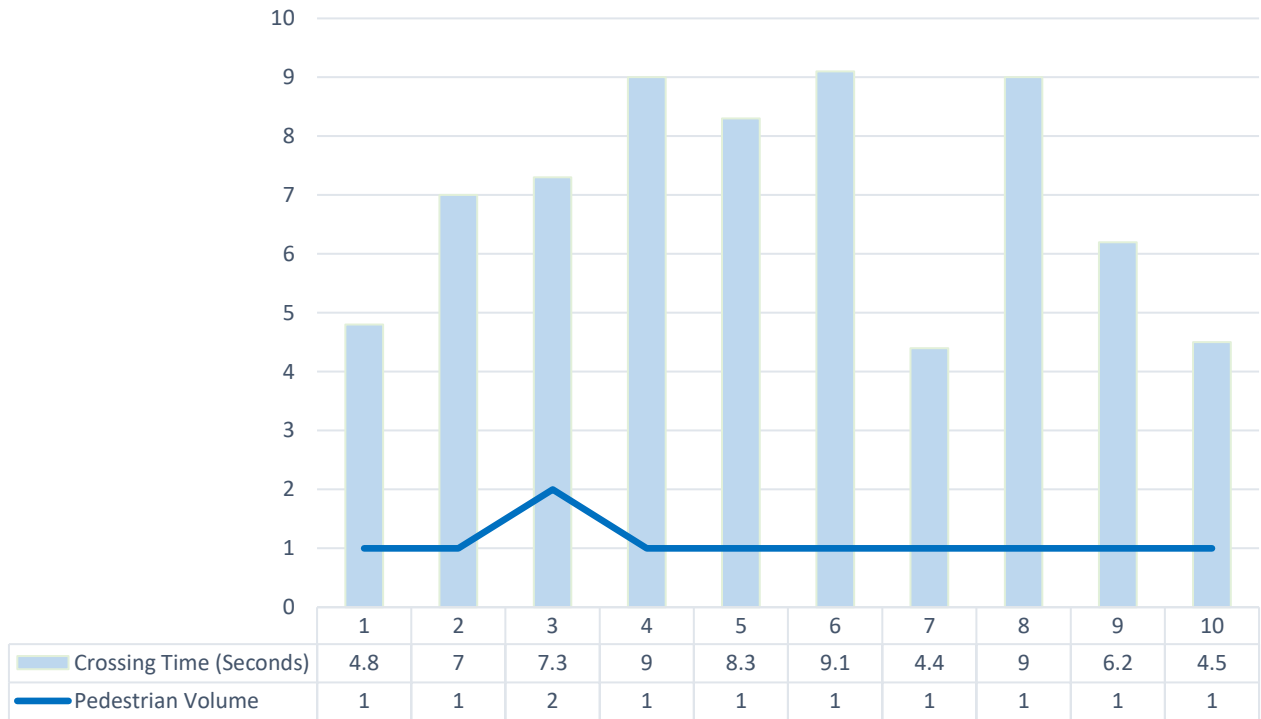


Figure 64: Pedestrian Crossing time

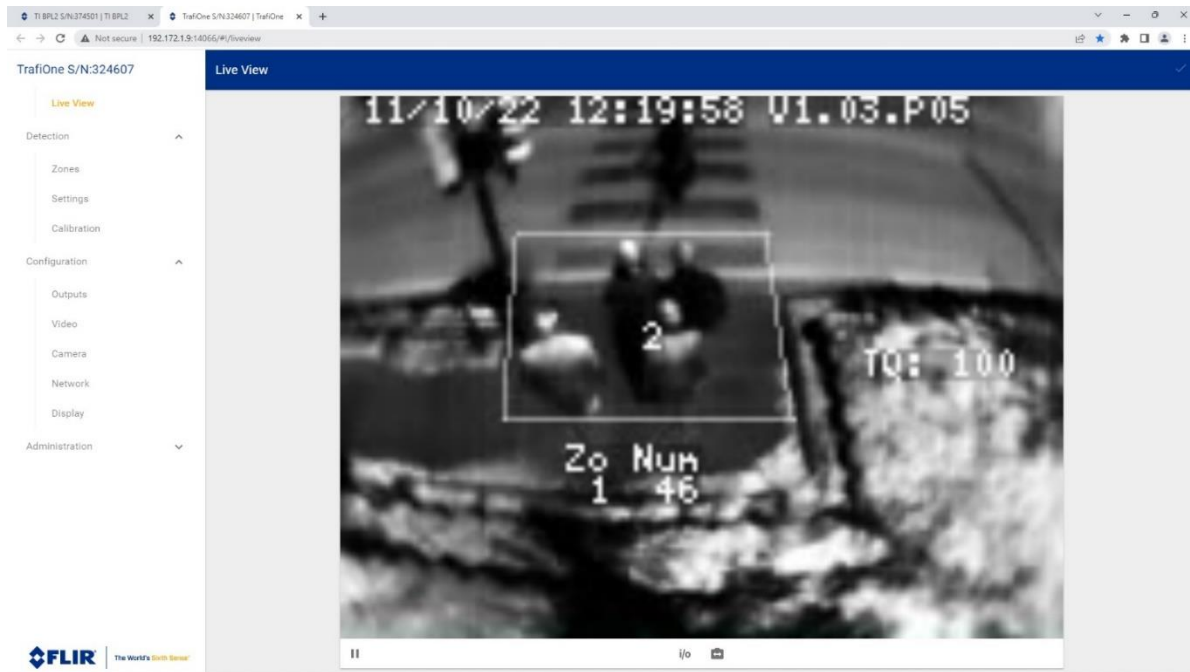


Figure 65: Thermal sensor output

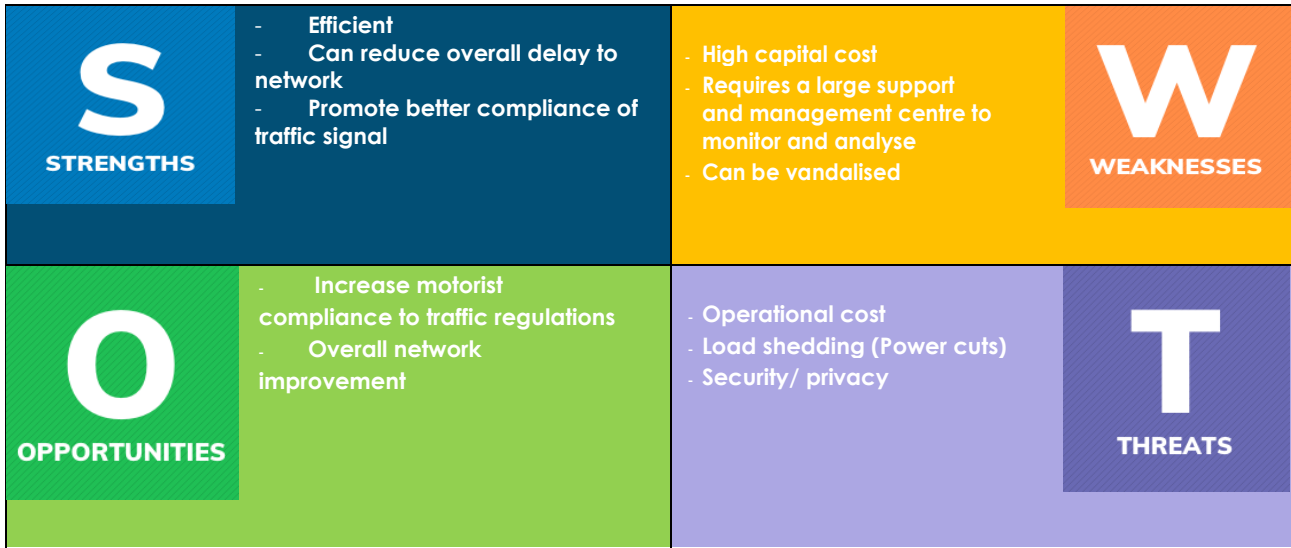


Figure 66: SWOT analysis for Pedestrian sensors

### 5.2.4. Application and Discussion

The City of Cape Town piloted pedestrian sensors recently to 4 intersection along the west coast at various significant pedestrian crossings. In news article by Venter he quotes the City of Cape Town’s Mayoral Committee for Urban Mobility:

*“With this innovative system, the thermal sensors at pedestrian crossings are used to detect whether there is any pedestrian movement. Should the pedestrian leave the detection zone before the pedestrian cycle is activated, the pedestrian request will be cancelled altogether. Thus, vehicles will not be stopped unnecessarily. Hopefully, with the thermal sensors at these crossings, we will have fewer red light violations and frustrated drivers. The system will also assist with traffic flow and pollution from idling vehicles. A huge bonus is that this system is less prone to vandalism – we often find the pushbuttons at pedestrian crossings are jammed with sticks or broken. A thermal pedestrian crossing does not require pushbuttons, seeing that it operates automatically” (Venter, 2022).*

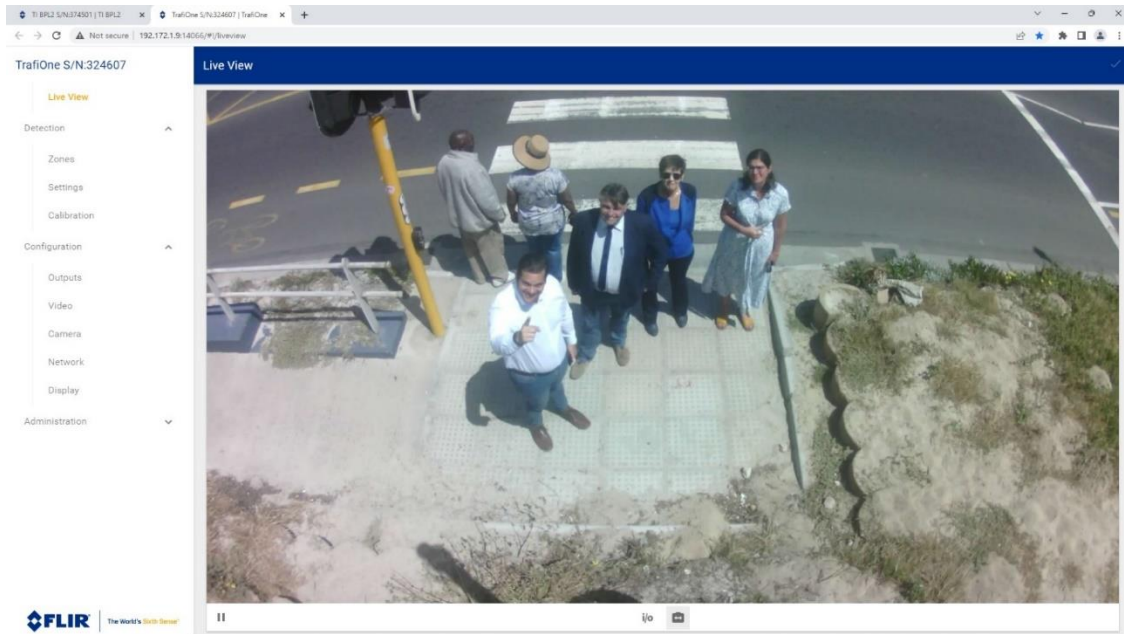


Figure 67: MAYCO Urban Mobility Member using thermal sensor

The limited data and perception thus far of the application of thermal sensors appears to be positive. Since installation no more cases of signal vandalism have been reported and it appears that pedestrian crossing efficiency has been improved. However these claims are backed by very limited periods of data and a more statistically significant amount of time is required for conclusive proof. It is recommended that the ITS measure based of early indications to be a possible successful intervention and should be analysed for more accurate assessment.

## 6. Conclusions and further recommended studies

The main objective of conducting this dissertation was to investigate two problem statements:

### 6.1. What NMT based ITS measures are available?

Upon commencement with this dissertation the intent was to firstly explore different advancements in the field of ITS that are specifically targeted towards Non-Motorised Transport (NMT). To this end, in Chapter 2, this dissertation expanded on the key objectives of ITS measures using Vanderschuren (2006) research as a basis which further broke down ITS measures in 3 broad categories namely Mobility ITS, Safety ITS and Communication ITS. While it is acknowledged that it is challenging to cover all ITS measures available on the market some of the key notable technologies was presented. All measures explored was presented and covered in Table 3: ITS Measures and Objectives.

After reviewing literature of technology available this dissertation explored the applicability of ITS measures within the South African Context. To this end, after reviewing local literature, as well as having explored results of some case studies of ITS measures applied in Cape Town, South Africa. Some of the key findings are as followings:

- i) Literature shows that the most dangerous areas for pedestrians and cyclist are at crossing points at intersections. The majority of accidents occur at these intersection conflict points.
- ii) Research suggests that South African NMT users are, generally, not compliant of traffic rules and, therefore, results in frequent jaywalking or non-compliance to traffic regulation measures.

### 6.2. Are any of these NMT based ITS measures applicable in South Africa?

Chapter 2 demonstrated the wide-range of ITS measures that are available in the market and as technology advances more innovations will come. To answer the thesis problem statement, it is required to take a first principle approach. In this dissertation the social-economic landscape of South Africa has been laid out as well as failures to implement NMT infrastructure despite strong progressive policy. Bearing in mind the South African context, opportunities for Mobility ITS measures are limited. Mobility ITS measures for NMT are still unproven in a South African context and will likely take away priority (and funding) to constructing basic NMT infrastructure. Therefore, until such time that South African Cities have established the basics of the NMT network, any investment into Mobility ITS measures is premature.

In Chapter 3 some of the major challenges within the transport sector in South Africa were outlined. As presented in local and international literature road safety is a major concern within Africa due high fatality rates for both road based accidents as well as pedestrian fatalities. To address this, South African policy is geared to improving safety of infrastructure (through standards and guidelines) and through road safety education both of which can benefit from the use of ITS measures. In Chapter 4, Table 3: ITS Measures and Objectives Table 3 shows NMT based ITS measures that have safety benefits that could be used as potential safety improvement measures. However, due to dependency on high levels of traffic rule compliance testing and further studies are required before wide-spread application.

ITS measures that form part of ‘Communication ITS’ be it guidance systems or educational ITS measures are relevant and important in South African context as these measures are likely to improve overall traffic rules compliance. These measures, although costly, are applicable to the South African context and can be applied.

In Chapter 6, case studies presented showed the signal countdown timer appeared to be ineffective while there was some improvement with application of LED Lane lights and pedestrian sensors. These findings correlate with findings during the literature review in Chapter 2 and 3. In countries where traffic rules have low levels of compliance, using any ITS measure that requires high level of traffic law obedience will likely be ineffective, thus ITS measures that form part of ‘Safety ITS’ should be applied with caution. Before implementation careful review of the context should be understood to test if a measure will be successful as well and the objective of the ITS measure. From the case studies it would appear that ITS measures that aim to increase or influence greater levels of traffic rules compliance in some context can be successful, however, ITS measures which purpose are to improve system efficiency does not perform well as it requires a base level of compliance to be effective.

In summary, the literature and case studies support the idea that ITS measures that requires high levels of traffic compliance are likely to be ineffective in the South African context but ITS measures that do not require high levels of traffic compliance are applicable to South African context. The challenge is prioritisation and lack of infrastructure, as road safety is such a prominent problem in South Africa funding and focus are geared towards making road environments safe before funding is spent in optimisation. The secondary challenge is that the NMT network within South Africa is not to level of developed counties thus before seeking to optimise NMT network through ITS measures requires the NMT infrastructure networks to be fully established.

### **6.3. Further recommended studies**

Following the conclusions of this dissertation several research questions can be further investigated which include but not limited to the following:

1. Further studying this dissertation’s 1<sup>st</sup> case study (Cape Town Pedestrian crossing with LED lane lights). This research dissertation used secondary data which focused on stop line violation and lacked the user experience and perceived safety improvement. Primary data can be collected for example by means of questionnaires to get a better understanding of the user experience for pedestrians with insights to the effectiveness or perceived improvement and user experience of the ITS measure.
2. Using similar methodology, analyse the impact of recent similar ITS measures installed in Rosebank (Johannesburg). This could verify whether the research methods used in this research are transferable to other South African cities. Further investigations of Johannesburg, Pretoria, Durban and Bloemfontein would help establish a more comprehensive understanding of the effectiveness of such measures within the South African context.
3. Technology is a rapid moving industry and therefore the ITS catalogue presented in Chapter 2 should be reviewed and updated with latest technological advancement every 3-5 years.
4. In depth assessment of effectiveness of Pedestrian detection system using thermal scanners (Case study 2). At the time of this dissertation, thermal sensors were recently installed and data was limited. In future, sufficient data can be collected and a more in-depth assessment of its effectiveness can be assessed.
5. Testing of other Mobility ITS measures and their effectiveness within a South African context. While this dissertation found current available Mobility ITS measures not effective in South Africa further studies with pilot study may reveal some applicability especially Mobility ITS measures that require low levels of traffic rules and regulation compliance.
6. Further testing on Communication ITS measures within the education sector. Limited case studies were found within South Africa however Chapter 2 demonstrates the use of Virtual Reality Simulations for educating young students on road safety were highly effective in China.

NMT based ITS measures is still a largely not extensively researched as the primary focus has been on ITS measures supporting motorised transport modes. As Cities attempt to evolve into more liveable walkable sustainable cities NMT becomes increasingly important and therefore it becomes equally important that research and development into NMT based ITS measures are researched.

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