



UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

A LOCATION – ALLOCATION MODEL FOR PEDESTRIAN FOOTBRIDGE INFRASTRUCTURE

**A Case Study on the South Africa’s National Roads Agency
Limited (SANRAL) Network in Gauteng Province**

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Minor dissertation submitted to the Faculty of Engineering and Build Environment of the University of Cape Town in partial fulfilment of the academic requirements for the degree of Masters in Engineering Transport Studies.

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**A Location – Allocation Model for Pedestrian Footbridge Infrastructure: A Case Study on the
South Africa’s National Roads Agency Limited (SANRAL) Network in GAUTENG
PROVINCE**

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ABSTRACT

Road fatalities are one of the leading causes of unnatural deaths in developing countries, such as South Africa. According to the Road Traffic Management Corporation (2017), the number of road traffic fatalities were recorded to be 11 676 in the year 2016 and 42.6% of these road traffic fatalities involved pedestrian. According to the National Road Safety Strategy 2016 – 2030 most pedestrian crashes are due to illegal pedestrian crossings mainly across high speed roads (highways) (Department of Transport, 2011). The research study aims to develop a geo-spatial model to determine the most suitable location to allocate pedestrian footbridge infrastructure along the South African National Road Agency Limited (SANRAL) network in Gauteng Province.

Previously road planning and design in South Africa followed international best practices, with development of the highway road system mainly orientated to serve motorised transport by primarily providing infrastructure for vehicular traffic along the highways, as pedestrians and highways were not expected to coexist in any proximity to each other. The presence of pedestrians along highways can no longer be ignored and there is a great need to overcome the highly fragmented spatial planning formed by the apartheid policies. For most non-motorised transport (NMT) users in South Africa, highways offer the shortest and most efficient direct routes, but also represent a major obstacle for many pedestrians who are separated by them.

Limited studies on the location and allocation of the pedestrian footbridge for pedestrians are reported in the literature, further research in this field should be considered, especially along the SANRAL network where there are high number of residential areas along high-speed roads, this behaviour is unique and common in South Africa.

Based on a literature review the factors affecting the location and allocation of pedestrian footbridges were identified, the following were factors identified: population density (served by the pedestrian footbridge), land use activities, socio-economic characteristics of the population (e.g. Gender, employment, race, and income level), crash hotspots/statistics (along the route), distance to access bridge and vehicle traffic volume along the route. From these factors spatial data was gathered to carry out spatial multi-criteria analyses (SMCA).

The results from the spatial analysis showed that high population densities adjacent to highway, accessibility and land use are key in the location of pedestrian footbridge. The results also show that there is a strong correlation between: land use diversity, socio-economic, crash hotspots/statistics (along the route), vehicle traffic volume and population density (served by the pedestrian footbridge). The

higher an area has these factors, the *Higher the Pedestrian Footbridge location index (high pedestrian footbridge location demand)*, hence the recommendation to allocate in those locations.

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I would like to thank God for the opportunity given to conduct this research and hope this work will add new knowledge into the road safety engineering and planning sphere.

I thank the SANRAL Chair, Professor Mark Zuidgeest for the amazing support and unfailing patience and direction in this research, your expertise was invaluable in formulating this research topic and data analysis process. I am honoured to have had you as my supervisor, you're a true legend. You have stretched my thinking capabilities and creativity.

I would like to thank the UCT GIS Lab staff for your amazing guidance, you provided me with tools that I needed to successfully complete my data analysis, more especially Thomas Slingsby I thank you.

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Many thanks to my family and friends, thank you for understanding my absence and limited availability at times, you never made me feel bad for the lifestyle change and you always checked, supported and encouraged me to do great. To Mmane Mpule a promise is kept, and I kept mine.

To my life partner Thabiso Mafiri, I thank you for your support throughout my countless sleepless nights and the push for me to start the MEng journey, your great push has brought these results, perseverance and great love for my calling to serve the most vulnerable.

This research is dedicated to the lives lost daily in traffic fatalities particularly those involving the most vulnerable road users (NMT). The two victims dear to my heart were Koko Mampe Ramaboea and Mandisa Mhlanga. In the year 1994 my Gran Mother Mampe Ramaboea was involved in a fatal crash while crossing a road from a nearby village in Limpopo Botlokwa. Moreover, in 2016 young Mandisa was involved in a fatal crash while crossing a road from a Primary School in Durban. These two lives lost show the importance of providing safe grade or at-grade crossing facilities and how these facilities can save a life. May their souls rest in peace.

Lastly, I hope this research will be used by road authorities and other professionals in the field of road safety planning and traffic engineering for VRUs along high speed roads where access NMT demand is high use this research as guidance.

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1 Introduction

1.1 Background

Over the years there has been a rise in road traffic fatalities mainly in developing countries, according to the World Health Organization (2017), more than 1.24 million people die and 20–50 million people get injured or disabled in road crashes annually. Moreover, the number of registered vehicles in these developing countries are 52% of the world total, yet 80% of road traffic deaths occur in these countries (Kaygisiz, Senbil and Yildiz, 2017). Furthermore, the highest number of traffic deaths compared to other continents occur in Africa, while Africa has only less than 2% of all registered vehicles in the world.

South Africa is one such developing country where road fatalities are one of the leading causes of unnatural deaths. The South African society is highly impacted by road traffic crashes and this impact is measured not only by the human lives lost, but it is also measured from the pain, grief and suffering felt, as well as the increasing cost to economy. According to the CSIR Built Environment (2016), as road traffic crashes increase, the socio-economic development is hampered and there is high impact on the well-being of South Africans.

Figure 1.1, shows the road traffic deaths trend in South Africa between the year 2000 and 2009. In the year 2006 an estimated 32 deaths per 100 000 population were recorded.

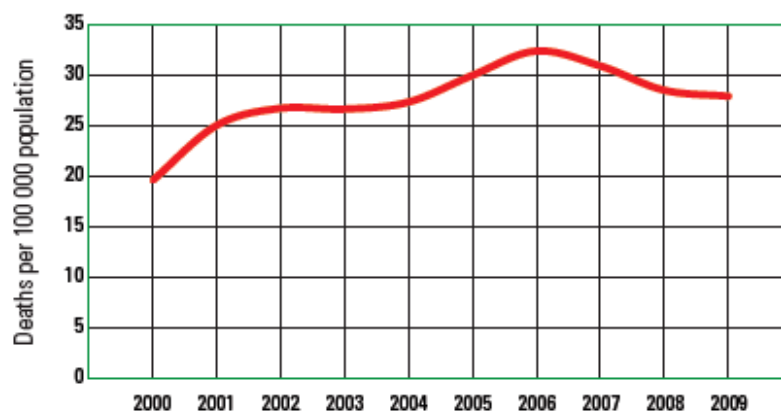


Figure 1.1 Trends in road traffic deaths (Source: Road Traffic Management Corporation, 2016)

There was a rise in the number of deaths per 100 000 population between the year 2000 and 2006. According, Norman et al. (2007) in Lehoula and Africa (2009) the increasing trend was attributed by the “unsafe road environments, poor enforcement of existing traffic laws, road rage and aggressive driving as well as alcohol misuse”. While, there was a decrease in the number of road traffic deaths between the year 2006 and 2009. In the year 2009 the reported number of traffic fatalities were recorded to be 13, 768, the decreasing trend was attributed to the improvements in the reporting of road traffic crashes, improved policy implementation and law enforcement and improved road infrastructure. According to Sukhai, Jones and Haynes(2009), “in South Africa, the extent and nature of underreporting is unknown but is likely to be higher”.

In the year 2011 the Department of Transport in South Africa announced that road traffic fatalities were the major cause of unnatural deaths, with 40 deaths and 20 permanently disabled occurring per day and 15 000 occurring annually (Department of Transport, 2011).

In 2014, the number of traffic deaths per 100 000 population in South Africa was 23.53, while in the European Region was 10.1. According to the World Health Organisation (2017), South Africa is ranked 15th among the 47 African countries with death rates due to road traffic injuries accounting 25.1 road traffic mortality rate per 100 000 population.

In 2016 the number of road traffic fatalities were recorded to be 11 676 and 42.6% of the road traffic fatalities involved pedestrian(Road Traffic Management Corporation, 2017). The National Road Safety Strategy 2016 – 2030, reported that most pedestrian fatalities were caused by at-grade crossings as pedestrians cross at undesignated area (Department of Transport, 2011).

According to Peden et al. (2004) in Sukhai, Jones and Haynes (2009), the exposure to crashes is a significant component of traffic-related risk. “For instance, the risk of a pedestrian accident is up to five times greater for children living in urban areas than for those living in rural settlements” Petch and Henson (2000) in Priyantha Wedagama, Bird and Metcalfe (2006). This shows the relatively strong link between pedestrian fatalities and urbanisation. The South Africa Committee of Transport Officials (1999), argue that the high casualty rate associated with pedestrians identifies them as the most vulnerable group of road users.

In South Africa, the high number of illegal pedestrian crossings are mainly attributed to the fragmented spatial and transport planning, that was formed by the apartheid government, studies by Anesh, Jones and Robin (2009) show that “South Africa’s legacy of ‘apartheid’ that dictated place of residence and controlled the movement of people, may also have a significant impact on the distribution and magnitude of road traffic deaths in the country, and these largely unmeasured ‘socio-ecological’ effects should be investigated”. Furthermore, the Group Areas Act 41 of 1950 shows that the apartheid government catalysed racial segregation as this Act gave restrictions in occupation of areas for non-

white racial groups (Republic of South Africa Parliament, 1950). According to Baloyi and Sebola (2012), this resulted in the creation of dormitory 'jail-like barracks and caused sprawl as locations' for black communities were placed at considerable distances from the city centre, in peripheral areas and adjacent to high speed roads (Baloyi and Sebola, 2012).

Moreover, according to Ribbens et al. (2008) and WHO (2013) in (Obeng-Atuah, Poku-Boansi and Cobbinah, 2017) "reported that in South Africa, the provision of pedestrian facilities during planning and construction of road projects is often neglected, and they are considered as ancillary if they incorporated in the planning stage, thus threatening pedestrian activities." Road planning and design in South Africa for development of freeway road system mainly focused on providing infrastructure to serve motorised transport, as pedestrians and freeways were not expected to coexist in any proximity to each other (Sinclair and Zuidgeest, 2016). This is however not the case in South Africa, as pedestrians and freeways do coexist. Pedestrian activity along and across the freeways in South Africa occur as most pedestrians have no alternative available to use in improving their mobility and accessibility to facilities to meet their needs.

The provision of road infrastructure previously mainly focused on providing infrastructure for motorised transport and with little to no mention of infrastructure provision for non-motorised transport (NMT) to serve user such as pedestrians. In turn this has at least been part of the reason why city authorities are confronted with significant levels of pedestrian activity along and across freeways.

The presence of pedestrians along freeways can no longer be ignored and there is a great need to overcome the highly fragmented spatial planning formed by the apartheid policies. For most NMT users in South Africa, freeways offer the shortest and most efficient direct routes, but also represent a major obstacle for many pedestrians who are separated by them (Sinclair and Zuidgeest, 2016).

Unlike other road users', pedestrians are the most vulnerable road users (VRUs). According to studies by Tingvall and Haworth (1999), the human tolerance for mechanical forces in a crash is limited, for instance the human tolerance of pedestrians to mechanical forces will be exceeded if the vehicle is travelling at over 30km/h. Various ways to reduce the exposure of pedestrians to mechanical forces is through: enforcement, education and engineering. This can be achieved by introducing law enforcement directed to all road users, educating road users on the risks of at-grade crossing or improved road engineering through modification of road systems through the introduction of protective systems.

The improved road engineering involves the introduction of forgiving road designs and provision of infrastructure to separate the motorised and non-motorised transport users. Such separation can be achieved through physical separation by the provision of adequate non-motorised transport infrastructure along and across the freeways, through provision of pedestrian footbridges and other measures. Pedestrian footbridges separate pedestrians from vehicle traffic and offer an improved road safety for all road users, by reducing pedestrian exposure to crashes. Also, pedestrian footbridges enable

equitable access, improved mobility and encourage safe interaction amongst communities separated by freeways. Despite the provision of pedestrian footbridges across the freeways, pedestrian movement across the freeways still exists adjacent to some of these footbridges.

According to Sinclair and Zuidgeest (2016) there is limited research explaining pedestrians walking along freeways or crossing freeways, their study added new understanding to the problem. The location and allocation of pedestrian bridge is poorly understood as this is complex and involves multidisciplinary approach to solve this problem. The aim of this study is to add new understanding to the phenomena, through a detail study on the location allocation modelling of pedestrian footbridge along the South African National Road in Gauteng Province.

1.2 Objective of Study

South Africa is a fast growing and developing country, yet this growth is taking place very unequally. There is a great need to overcome the highly fragmented spatial planning. Road authorities are confronted with significant levels of pedestrian activity along and across freeways. Over the years' mitigation measures to create safe accessibility for pedestrian movement along and across freeways have been implemented to improve road safety and reduce fatalities involving pedestrians through provision of pedestrian footbridges. Despite the provision of pedestrian footbridges across the freeways, pedestrian movement across the freeways still exists adjacent to some of these footbridges. This problem is poorly understood and there are no comprehensive spatial tools of measurement that quantify the existing levels of location and allocation of pedestrian footbridge across high-speed roads.

The proposed research study aims to develop a geo-spatial model on how to formally allocate pedestrian crossing infrastructure given a set of spatial and non-spatial built-environment and socio-economic criteria which assist in location selection. This will be done by optimising the locations of pedestrian footbridge infrastructure along high-speed roads.

The study by Anesh, Jones and Robin (2009), Sukhai, Jones and Haynes (2009) formed initial contributions to study the risk and geographical variations of road traffic deaths in South Africa. This research aims to expand on the risk and geographical variations from the available crash data. The study aims to use geo-spatial modelling techniques to analyse the most suitable location to allocate pedestrian footbridge. To achieve this the study explores the factors affecting the location and allocation of pedestrian footbridges from literature review.

The results from the research study can be used by Road Authorities to better identify the suitable locations to allocate pedestrian footbridges to improve accessibility for the vulnerable groups. Currently, this phenomenon is poorly understood as there is no comprehensive geo-spatial analysis study conducted that quantify the acceptable levels of the location of pedestrian footbridge across high-speed roads. The study will assist the most vulnerable socio-economic groups who are victims of road safety due to at-grade crossing (also known as jaywalking) across high speed roads, by allowing for improved spatial assessment to understand the mobility and access needs of pedestrians in these settlements.

1.3 Scope and Limitations of Research

The following limitations to the study are as follows:

- Limited research work has been done on provision of pedestrian infrastructure along freeways in South Africa. The research study will draw on available work.
- There is limited literature work addressing the presence of pedestrians along freeways and how to provide infrastructure to cater for this. Literature mainly drawn from other countries.
- Previous studies only done in areas where there are existing pedestrian bridges and not in areas where there are none.
- Focus made on a limited area in Gauteng Province, Northern part of South Africa, where there is high pedestrian crash statistics according to the Freeway Management System.
- The scope of the research aims to cover works on spatial multi-criteria analyses (SMCA) for the location and allocation of pedestrian footbridge infrastructure.
- The model presented in this research assumes that the results from the model will be presented to the community (living adjacent the high-speed road) and the affected parties before implementation. This recommendation is in-line with policy interventions recommendations made by Dada and Zuidgeest (2017). Stakeholder engagement enables transport authorities and agencies to enlighten community dwellers on the risk of crossing the freeways.
- Limited work on the effects of human behaviour in road and incidents.

1.4 Methodology

The study will be done through development of a geo-spatial analysis model that can be used to assess the most suitable location for allocating pedestrian footbridge along a freeway from a settlement user point of view, based on a set of spatially explicit criteria. The research aims at developing pedestrian footbridge location-allocation index model for identifying suitable positions of pedestrian bridges over high-speed roads along densely populated areas using spatial multi criteria analysis (SMCA).

Multi-criteria analysis (MCA) is defined as a “technique used to consider many different criteria when making a decision” and it allows for suitability to be analysed by allowing different alternative solutions to be considered and ranked; while, spatial multi-criteria analyses (SMCA) “is used for decisions with a geographical element, most often in site selection processes where multiple factors need to be considered” (GIS People, 2019).

The research involves:

- **Literature review** to understand the research made on the phenomena.
- **Data Collection** which involves the collection and analysis of data, using a mixture of qualitative and quantitative approaches in the research process.
 - The quantitative data involves crash records from: SANRAL Road incident management records. This also involves the collection of GIS data from SANRAL Road Incident Management System (RIMS), computing indicators for potential pedestrian footbridge location – allocation index using GIS.
 - The qualitative data involves site inventory to observe infrastructure condition and usage, and review of the Detail Design Reports from SANRAL registry and past publications.
- **Assessment of results** to find the optimal location for pedestrian footbridge using spatial multi-criteria analyses (SMCA), drawing suitability maps and identify hot-spot areas using ArcGIS.

An overview of the research framework and process is provided in Figure 1.2.

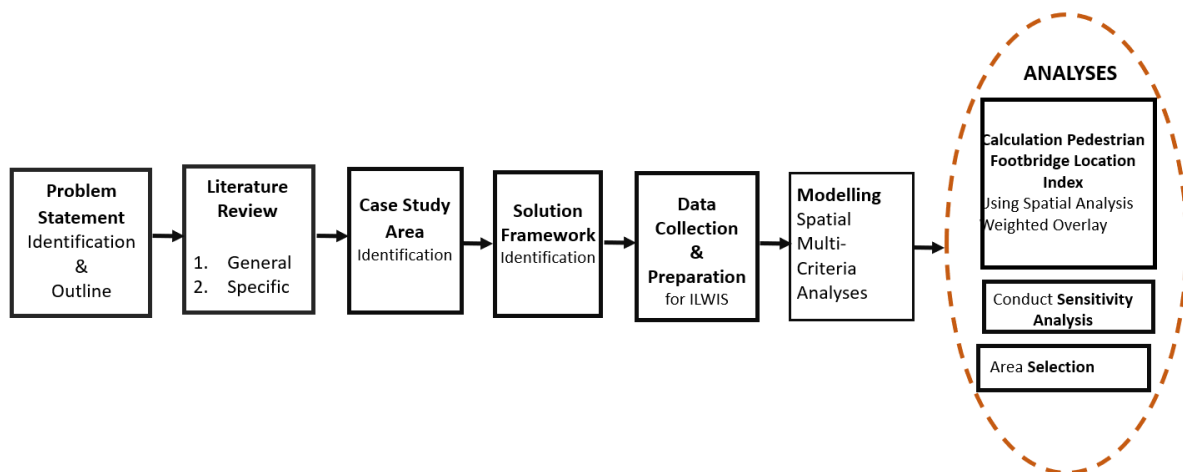


Figure 1.2 Research Framework

1.5 Organisation of Report

Chapter 1, the current chapter, this chapter covers the introduction to the thesis and provides background to the research, the scope and limitations of research and the methodology followed.

Chapter 2, covers the literature review, which shows the literature study methods used;

Chapter 3, case study area used is discussed;

Chapter 4, discussed in detail the research problem data gathered is listed and analysed. The method used and applied to solve the problem;

Chapter 5, discussion of the data analysis;

Chapter 6, study objective and conclusions are discussed and recommendations for further studies or investigation are given.

2 Literature Review

2.1 Introduction

The literature review introduces the available literature that relates to the concepts important to the investigation of location and allocation of pedestrian footbridge (along high-speed roads). The chapter starts with a review of the interaction of pedestrians with freeways and the safe system approach for developing countries. The review of some location and allocation models and how were these models used. The causes of at-grade crossing along freeways are investigated. This is followed by a discussion on the factors influencing exposure of pedestrians to risk for at-grade crossing. The pedestrian's preference of footbridge/overpass are then discussed in detail. The chapter concludes with a summary of the literature review that is noteworthy for the remainder of the report.

2.2 Pedestrians Interaction with Freeways – The Safe System Approach

Road traffic fatalities are one of the major causes of unnatural deaths in the world. This is largely attributed by un-road worthy vehicles, high speeds, lack of appropriate infrastructure for all road users and the high presence of vulnerable road users (VRUs) on major freeways (Damsere-Derry, Palk and King, 2017b). Vulnerable road users are defined as road users who do not have outer protective shells which reduce severities in the event of crashes they include pedestrians, cyclists, and motorcyclists; with pedestrians being the most vulnerable users (Otte et al, 2012 in Damsere-Derry et al. 2017). The high risk of exposure of pedestrians forms a major component of all road fatalities, while South Africa has about 40% of NMT users, especially pedestrians (Sinclair, 2017). On the other-hand protected road users are those road users who usually have protective shells which reduce impact of crash, they are automobile drivers and passengers. The level of protection for the different users have resulted in the different relative risks of injuries and deaths.

In developed countries the use of non-motorised transport (NMT) is mainly promoted to encourage active living, social interaction and improve public health. While in developing countries, the use of NMT is not only seen to encourage the above mentioned, but it is also seen as the main mode used for accessing key economic and social areas as many are solely dependent on NMT (captive NMT users). In developing countries there is a high presence of pedestrian along high speed road (freeways), however the road infrastructure in developing countries does not cater for pedestrians. Road designs in developing countries adopted road designs for freeways in developed countries, which catered for vehicular traffic mainly as “pedestrians and freeways are not expected to coexist in any proximity to

each other” (Sinclair & Zuidgeest, 2016), however this is not the case for developing countries such as South Africa as pedestrian and freeways exist in close proximity.

According to Macozoma and Ribbens (2004), the lack of pedestrian and cyclists facilities contributes to road casualties, especially in less developed areas and in the rural areas, as pedestrians are exposed to higher risks due to high speeds, wider roads and higher traffic volumes. A study by the CSIR (n.d) in Sinclair (2017), revealed the severity by area, in the study it was shown that 1 out of 10 pedestrians involved in road traffic crashes (RTC) are killed on urban roads. While 1 out of 3 pedestrians involved in RTC are killed on rural roads, as a result of the higher speeds and human error to judge safe gap acceptance to cross.

Also, in urban areas shorter routes to the city centres (major economic hubs) are accessed using freeways and often involve walking along and across these roads. Freeways form an important part for access and mobility for all road users, as motorised together with non-motorised transport users (mainly pedestrians) use freeways for commuting.

However, the presence of non-motorised transport users along the freeways, and the interaction between motorised and non-motorised transport users should be sufficiently catered for through the Safe System Approach. Safe System is an approach to road safety which aims to provide a road transport network which does not compromise the need to travel by providing more forgiving road system that protects all road users from fatality or serious injury by taking to account all road users ‘s human fallibility and vulnerability. The safe system is made up of the four main components being:

- Provision of safer roads
- Safer speeds
- Safer vehicles
- Safer road use

This research will form part of the safe system approach through the provision of safer roads for vulnerable road users, by better understanding the location of pedestrian footbridge.

2.3 Location-allocation Models

The location-allocation models are models used to identify the best optimal sites to locate facility (more often this public facilities). Location–allocation models are often applied within a search heuristic rather than deterministically (Bischoff and Dächert, 2009), (Bonneu and Thomas-Agnan, 2009), (Ko *et al.*, 2015) and (Comber *et al.*, 2015).

According to Comber et al.(2015), location–allocation models have three inputs namely:

1. Potential supply points (Trip generators point e.g. origin).
2. Spatially distributed demand often reduced from areas to points (Trip attractor e.g. Industrial areas, Health centre or Educational Institution).
3. Distance measure between supply and demand locations (e.g road distance or travel time).

Furthermore, location-allocation models are used , to identify gaps in service provision and to highlight geographic regions with low service coverage (for specific public facility) (Comber et al., 2015).

The literature on location-allocation models to locate pedestrian footbridge is still scarce and only the location allocation study for other service facilities were found in literature:

Studies by Rahman and Smith (2000) and Mestre, Oliveira and Barbosa-Póvoa (2014), assessed the location-allocation model to find the best location to allocate a hospital in developing nations. The use of location–allocation models have been used to assist hospital planning, as these models allow for simultaneous analysis of decisions for the opening, closing or resizing of facilities, by considering the pursuit of multiple objectives (Mestre, Oliveira and Barbosa-Póvoa, 2014).

The following are some models that were identified in the location-allocation models to find a suitable location to allocate a hospital (service) study by Rahman and Smith (2000) and Mestre, Oliveira and Barbosa-Póvoa (2014) and the study on the locating of bioenergy facilities by Comber et al. (2015):

1. The **p-median** problem model – The problem with this model is that the model uses the shortest travel distance “which minimises the demand weighted distance” (Comber et al., 2015);or time between the facilities and the demand points to find the best location to allocate facilities and does not account for other external factors. According to Rahman and Smith (2000) “solutions which minimise the weighted travel distance may be inequitable, forcing a few users to travel far. This may mean that the remoter users do not actually travel to their nearest facility, or to any facility”. Moreover, facilities that are positioned using the p-median problem have frequently been observed to have a rapid decline in the usage of the service facilities when the travel time (distance) exceeds some critical value, “therefore it is quite reasonable to consider maximum distance or time constraints in formulating a location problem” (Rahman and Smith, 2000).

Location set covering problem (LSCP) – “which seeks to that minimise the number of facilities to satisfy some demand coverage”(Comber et al., 2015). This aims at finding the “minimum number of facilities and their locations such that each and every demand centre is covered by at least one facility within a given maximal service” (Rahman and Smith, 2000). The pq-median problem is related to the

LSCP as it is concerned with finding an efficient set of facility locations which can be associated with districting the catchment areas for two or more levels of facility (Rahman and Smith, 2000). The p-q-median problem uses some heuristic approaches. The problem with this model is feasibility, According to Rahman and Smith (2000) in reality there may not be enough resources to provide for the number of required facilities to reach the optimum solution to this problem and this is particularly the case in developing nations. “Then, the decision maker may abandon the goal of total coverage and attempt instead to locate the facilities in such a way that as few people as possible lie outside the desired service distance” (Rahman and Smith, 2000).

2. The maximal covering location problem MCLP “which seeks to satisfy a distance or travel criterion” (Comber et al., 2015); is to locate a fixed number of facilities to maximise the coverage within a desired service distance (Rahman and Smith, 2000).
3. Cost benefit analysis – This was used in locating facilities in a new area. The LSCP was used to formulate the problem. The study “provided the local health consultants with a cost/benefit analysis using accessibility to the health care delivery system (S) as the main parameter”(Rahman and Smith, 2000).
4. The study by Comber et al. (2015), on the “locating of bioenergy facilities, in this study the modified GIS-based location-allocation algorithm (modified p-median algorithm) was used. This involved identification of potential location and determining the supply locations within the catchments. The modified p-median minimises the demand weighted distance and accounts for the spatial overlap by reducing the catchment overlap”. This model addresses the need to consider the “spatial distribution of resources, the resource catchments of potentially suitable locations and the need to evaluate sets of potential locations together and not one by one”. The benefits with this method are that it allows one to capture the spatial variability that exists in locating facilities

The following were recorded as key functions used in the above location-allocation models (Comber *et al.*, 2015), (Mestre, Oliveira and Barbosa-Póvoa, 2014) and (Rahman and Smith, 2000):

- Maximum travel distance,
- Accessible,
- Population served,
- Intuitive judgement of the planner in developing countries,
- Geographical constrains,
- Availability of services,
- Integrated area planning

The above studies reviewed have used some kind of single criterion objective functions, whether political, user centric or economical. According to Rahman and Smith (2000), a multi-criteria decision analysis seems to be more suitable, as the multi-criteria decision analysis allows for multiple scenarios to be assessed to show “trade-offs between several performance measures. However, little mention is made of the possibility of formulating the problem in this way, which would seem to be a more appropriate approach.” Rahman and Smith (2000), further argue that, most location decisions are complex problems and require multi-criteria objective models.

The above studies were mainly based on facilities that are trip generators (e.g. hospitals and bioenergy facilities). While the objective of the proposed research study is to develop a geo-spatial model on how to formally allocate pedestrian crossing infrastructure which is a throughfare for pedestrians (NMT) trips to pass through.

Studies from literature by Singh *et al* (2014), measured transit oriented development (TOD) for the City Region Arnhem and Nijmegen (a regional planning body in Netherlands). TOD main goal is to “encourage people to walk, cycle and use public transit instead of cars, which is typically achieved by developing mixed use communities around transit nodes, with moderate to high densities and a walkable environment” (Singh *et al.*, 2017). According to Singh *et al.* (2014), measuring TOD and combining this into TOD index is important as this “help in making justified planning decisions, such as for location decision-making”. The spatial analytical tools were used to measure TOD levels, this involved the use of Geographic Information System (GIS) and spatial multi criteria analysis (SMCA). The following method was used namely:

- Identification of criteria and indicators that characterise TOD.
- Data collection and preparing it for spatial analysis in GIS.
- Calculation of individual indicators in ArcGIS.
- Comprehensive calculation of TOD Index using Spatial Multiple Criteria Analysis (SMCA).
- Comparison of different areas based on TOD Index value.
- Recommendations on: which areas need higher TOD levels; which areas have high TOD levels but need transit connectivity.
- Possibility of involving all stakeholder groups to discuss and decide on detailed TOD planning proposals. Requires a Spatial Decision Support System (SDSS).

This study (Singh *et al.*, 2014) revealed the following:

- Higher density development as an indication of high travel demand.
- Acceptable walkable limits of 500-800m of a transit node.

- the presence of diverse land use promotes livelier, safer, and better interaction among people from all walks of life.

2.4 Causes of At-grade Crossing along Freeways

Numerous studies have been conducted and have revealed that various reasons exist for the prevalence of at-grade crossing. Most of the recorded causes of at-grade crossing were done on low speed roads. However, limited literature on the causes of at-grade crossing along high speed roads (freeways) has been documented. According to Behrens (2010) “little research appears to have been undertaken on illegal at-grade freeway crossing behaviour”. To achieve the Safe system approach, a good understanding of the causes of at-grade crossing along freeways is required.

The following is the summary list of some of the most important causes of at-grade recorded in the literature Obeng-Atuah, Poku-Boansi and Cobbinah, 2017; Räsänen *et al.*, 2007; Sinclair and Zuidgeest, 2016; Wu *et al.*, 2014; Dada and Zuidgeest, 2017; Cantillo, Arellana and Rolong, 2015; Behrens, 2010.; Sinclair and Zuidgeest, 2016; Obeng-Atuah, Poku-Boansi and Cobbinah, 2017; Damsere-Derry, Palk and King, 2017a; Sisiopiku and Akin, 2003):

- Accessibility
- Convenience
- Comfort
- Safety
- Security
- Time Delay
- Lack of infrastructure
- Unsafe human behaviour
- Lack of law enforcement
- Lack of Road Safety Education.

These important causes of at-grade crossing and how they affect road traffic crashes are discussed below.

2.4.1 Operations: Accessibility/Convenience and Comfort

According to Sisiopiku & Akin (2003), accessibility is one of the most important factors cited by pedestrians in deciding to cross at a designated crossing location; most pedestrians associate accessibility with the distance required to reach the crosswalk to desired destinations of pedestrians. Furthermore, studies show that accessibility was cited by pedestrian as an important factor in the use

and non-use of the designated crossing facility. For instance, pedestrians are more unlikely to use pedestrian bridges if the walking distance when using the pedestrian footbridge is longer than the level crossing.

A study by Moore (1953); Moore & Older (1965) in Räsänen et al. (2007), was done to assess the use of pedestrian bridges and underpass in London, their study showed that approximately 80% of pedestrians would use the safe path if it takes the same time as at-grade crossing. Moreover, the study by Räsänen et al. (2007), suggest that pedestrians would not use the safe path if the required time to cross using the pedestrian bridge was 1.5 times or higher compared to level crossing. Also, according to Sisiopiku & Akin (2003) the use rate of pedestrian footbridge increases when the facilities are properly designed and placed at correct locations with easy access, as pedestrian tend to value direct routes that are quick (Agrawal, Schlossberg and Irvin, 2008).

Sisiopiku & Akin (2003), also reported convenience as the most imported factor for pedestrians. Thus, the design of pedestrian crossing facilities should be responsive to pedestrian needs and improve convenience for pedestrian and provide comfort in the use of these facilities. According to Sinclair (2017) the following are some of the key factors in improving the comfort: the grades for the ramp should be gentle and allow Universal Access (UA) principles which should be used to accommodate for persons with special needs. Also, to ensure comfort the design of pedestrian crossing facilities should provide shelter for adverse weather, be clean and free any hazardous objects.

2.4.2 Safety and Security

According to Handy (1996) and Shiver (1997) in Sisiopiku & Akin (2003), the design of pedestrian facilities should encourage walking without compromising the safety and convenience. Räsänen et al. (2007), argues that pedestrian bridge use rate is likely to improve, if the safety benefits and convenience of using the bridge are clearly visible to the user. Likewise, in the study conducted by Sinclair & Zuidgeest (2016) and Behrens (2010), pedestrians are highly concerned with their personal security when making crossing decisions. However, in South Africa, crime and perceived safety are complex issues. Thus, safety is defined in two ways, one being how safe one feels crossing on the bridge (fear of criminals) and the other being how safe one feels crossing at-grade, the safety from traffic. Figure 2.1 shows the relative safety experienced by bridge users while crossing on the bridge, majority of the pedestrians do not feel safe while crossing on the bridge.

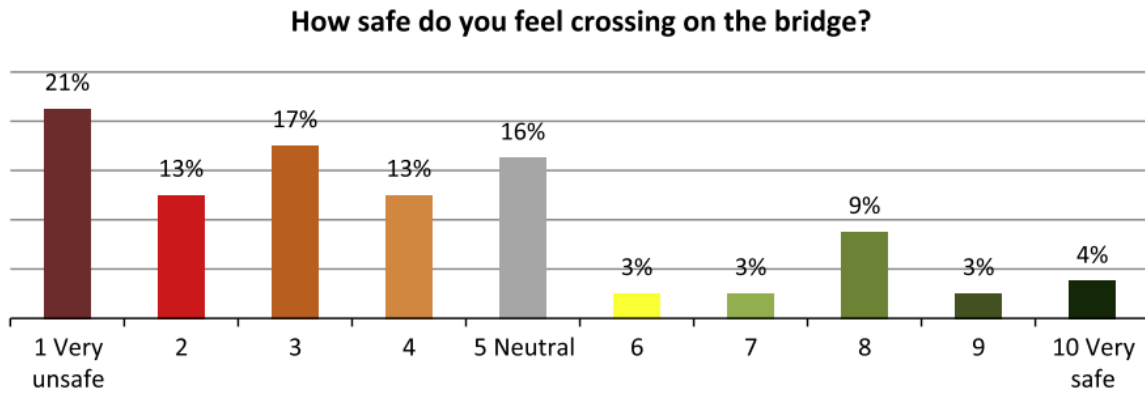


Figure 2.1 Relative safety experienced by bridge users

Source: (Sinclair and Zuidgeest, 2016)

While figure 2.2, shows the relative safety experienced by at-grade crossers, high percentage of bridge users do not feel safe while crossing at-grade as there are high traffic risks.

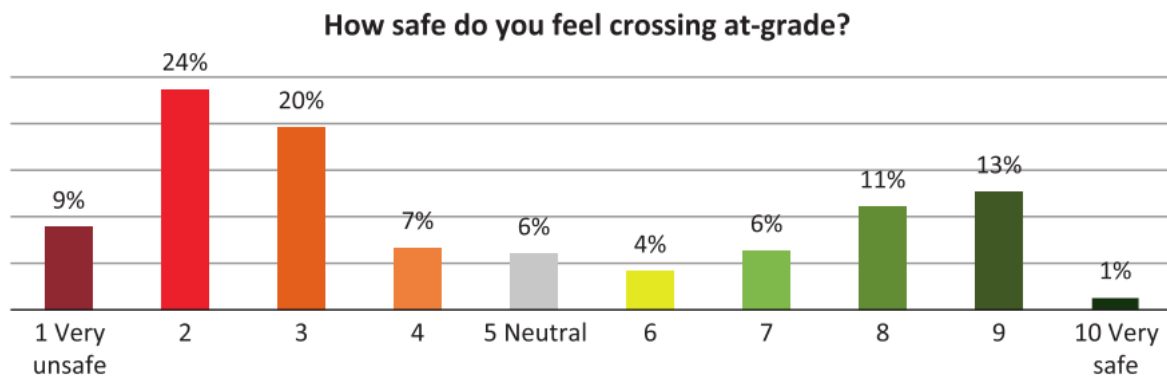


Figure 2.2 Relative safety experienced by at-grade crossers

Source: (Sinclair and Zuidgeest, 2016)

2.4.3 Time Delay

The study done by Fortythe and Berger (1973) in Sisiopiku & Akin (2003) on assessing the pedestrian crossing behaviour at signalized crosswalks, reported that pedestrians crossing unsafe during DON'T WALK signal indication or pedestrian red interval was mainly related to time delay. Sisiopiku & Akin (2003), define the main reason to this as a need by pedestrians to hurry and a desire to keep moving which ultimately leads to lack of compliance with pedestrian signals.

According to Pawar & Patil (2016) pedestrians are exposed to high risk when crossing freeways at-grade, "because a wrong judgment in gap acceptance can result in a crash". For instance, in India drivers and pedestrians do not follow the traffic rules strictly, as vehicles do not yield for pedestrians at dedicated yield areas. Majority of this occurrences result in higher time delays for pedestrians as they must wait for longer time for passing traffic, and the wait is even longer with increased traffic. Similarly,

pedestrians crossing freeways at-grade experience time delays when looking who the acceptable gap. Also, their risk to crashes increases with increased traffic, these pedestrians are forced to accept smaller gaps which expose them to higher risk.

2.2.1 Lack of / No infrastructure

The South Africa Committee of Transport Officials (1999), noted the following design elements that influence road safety namely:

- Access control
- Intersection design
- Number of lanes
- Medians
- Geometric Features – such as horizontal alignment, vertical alignment, cross-section, roadside, intersection, and interchange
- Pavement condition
- Weather
- Lighting
- Traffic
- Traffic regulations
- Driver characteristics – such as intoxication and age
- Vehicle characteristics – such as size, mass, and braking ability.

Also, the South African Road Safety Manual *Volume 7 - Design for Safety*, records various multilane design alternatives and the advantages and disadvantages they have on pedestrians use (for instance median vs no median the latter does not offer safe refuge for pedestrians crossing the multilane). The above design manuals have limited standards for NMT infrastructure namely pedestrian footbridge.

According to Sisiopiku & Akin (2003), “The major responsibility of providing physical facilities that encourage pedestrian travel and help protect the pedestrians resides with traffic engineer. Such facilities include roadways, sidewalks, traffic control devices (TCDs), medians, etc.” Moreover, the Sisiopiku & Akin (2003) study suggest that “pedestrian friendly and safe environments involve separation of pedestrian and vehicle traffic, control of flow of pedestrians and vehicles, improvement of visibility, proper communication through signs and assistance of pedestrians with special needs”. In order to achieve this an improved walking environment in urban areas adequate provision and maintenance of pedestrian infrastructure is imperative, to ensure pedestrian safety (Obeng-Atuah, Poku-Boansi and Cobbinah, 2017). Behrens (2010) suggests the allocation of pedestrian foot bridge to be done at regularly spaced crossing facilities to increase the chance of using pedestrian footbridge. Also, Wu *et*

al. (2014) also suggests reasonable pedestrian crossing facilities should be built such as overpass which separate pedestrians and motor vehicle traffic.

2.2.2 Unsafe Human behaviour

Human behaviour plays a pivotal role, for both pedestrians and drivers and an important influencing factor on road traffic crashes. According to Behrens (2010), it is essential to understand pedestrian-driver interaction and pedestrian crossing behaviour and attitudes, along the major arterials and freeways (national roads). The high occurrences of jaywalk along freeways, is poorly understood, and requires further research.

Sinclair (2017), proposes the need to understand the rationale behind pedestrian behaviour and suggest the following as the various human factors that impact on the road user behaviour such as:

- Perception of safety
- Risk taking
- Response times
- Time prepared to wait or be delayed
- Group behaviour

According to Evans and Norman (1998), when pedestrian perceive the behavioural pattern of crossing at-grade to be easy to perform, then the pedestrian is more likely to engage in at-grade crossing which is a hazardous road safety behaviour. Studies have shown that pedestrians crossing at-grade on high speed roads increase the high-risk factors to traffic collisions. In a study conducted by Sinclair & Zuidgeest (2016), it was shown that regular at-grade crossers are more astute and are aware of the risks they face, while the infrequent at-grade crossers view at-grade as a safer activity. Similarly, Sisiopiku & Akin, (2003), suggest that occasional users of crossing areas/facilities appear to be more conservative in their crossing choices, for instance when pedestrians are regular users of the crossing areas/facilities they tend to use it more (34% of daily users) than occasional users (18% of occasional users). This shows the perception to risk factors associated with crossing at-grade increase with regular crossing.

Another influence on unsafe human behaviour with at-grade crossers is associated with the blood alcohol concentration (BAC). Studies by du Plessis et al. (2016) and Volpe, Ladeira and Fantoni, (2016) show that pedestrians under the influence of alcohol increase the likelihood of being involved in road traffic crashes. According to the SANRAL Strategy (2017), high levels of alcohol abuse result in drunk people walking on the roads, this has resulted in 70% fatality of adult pedestrians who are killed on the SANRAL roads. Currently the BAC law in South Africa is enforced mainly on drivers with little enforcement on pedestrians, for instance “Driving while under the influence of intoxicating liquor or drug having narcotic effect, or with excessive amount of alcohol in blood or breath” (NDoT, 2010). As shown in figure 2.3, BAC limits apply to drink and driving, however road-users are categorised into

seven groups namely drivers, passengers, pedestrians, motorcyclist, cyclists, motorcyclist/ cyclist and unknown.

| National drink-driving law | Yes |
|---|------------------------|
| BAC limit – general population | 0.05 g/dl |
| BAC limit – young or novice drivers | 0.05 g/dl |
| BAC limit – professional/commercial drivers | 0.02 g/dl |
| Random breath testing and/or police checkpoints | Yes |
| Enforcement | 0 1 ② 3 4 5 6 7 8 9 10 |
| % road traffic deaths involving alcohol | 55% ^b |

Figure 2.3 South Africa National drink-driving law

Source: World Health Organization Traffic South Africa (2014)

According to (du Plessis, Hlase and Blumenthal, 2016), ethanol is one of the leading risk factors contributing to road traffic fatalities with drivers being the highest victims with positive BAC followed by passengers and pedestrians. More research in this area is required as the phenomenon is poorly understood and there is a need to develop a programme aimed at all road-users, followed by stricter law enforcement for BAC in South Africa.

Unsafe human behaviour is also influenced by habit. Studies by Räsänen et al. (2007) and Sinclair & Zuidgeest (2016), suggest pedestrians' choice in making a safe or unsafe choice in crossing is influenced by factors such as habit, peer pressure and over confidence. According to Räsänen et al. (2007), footbridge use is rather a habit than coincidental behaviour. In South Africa there are instances where there are grade-separated facilities, however many pedestrians are reluctant to detour to use a grade-separated facility, due to adaptive non-compliant and habitual crossing behaviour. Human behaviour is influenced by habit, acquired through repetition. Sinclair (2017), suggests this as behavioural patterns which humans repeat and become imprinted in neural pathways, but it is possible to form new habits through repetition. Sisiopiku & Akin (2003), also suggest that traffic engineers and planners need to understand comprehensively the behaviour of pedestrian and their attitudes at/towards pedestrian crosswalks as this has an influence on the use and non-use of the pedestrian facilities.

2.2.3 Lack of Law Enforcement and Road Safety Education

The lack of law enforcement and road safety education are some of the causes of at-grade crossing along freeways. As such to improve pedestrian behaviour, countermeasures such as road safety education, improved law enforcement and pedestrian environment through engineering are key. A study conducted by Behrens (2010), suggests the implementation of road safety education and awareness

programmes to improve road human behaviour, is paramount. Also, Preusser and Blomberg (1984) argue that road safety education can be improved by educating children on safe street crossing at an early age as this will influence the behavioural patterns of crossing at a dedicated crossing areas only and avoid risk taking. Likewise, Gichaga (2016) suggests that for any road improvement of a high-class or high traffic volume, there needs to be a fully comprehensive road safety design and evaluation. However, studies by Ebbecke and Shuster (1997) in Evans and Norman (1998), suggest that “while remedial treatment at crash blackspots reduces the number of crashes at the treated site, there is often an increase in crashes in the surrounding area”. Thus, the need for road safety education/awareness.

Quimby and Drake (1989) in Evans and Norman (1998), suggest the need to focus on the internal control factors which involve “making pedestrians more aware of the difficulty of, and risks associated with, crossing the road in potentially dangerous situations in comparison with the use of road crossing facilities” and this could be achieved through road safety education and effective law enforcement. According to Yang et al. (2006) law enforcement plays a pivotal role as pedestrians are classified into two categories namely: the law-obeying and opportunistic ones. The opportunistic pedestrians their behaviour can be changed through safety consciousness and effective punishment through stricter government policeman Through law enforcement there would be an improvement in pedestrian crossing behaviour as this would promote more safety-conscious approach to road crossing and may encourage safer road crossing behaviour.

2.3 Factors Influencing Exposure to Risk (for At-grade Crossing)

The road traffic crashes resulting in fatality in 1958 were recognised by the World Health Organisation (WHO) as a burden of disease and were classified as such. Following this a study by the WHO in 1961 revealed young people as the most vulnerable group and this being a serious economic loss to the community Borowy (2013) in RTMC (2016). Moreover, to facilitate economic development in low and middle-income countries, the WHO focused investments in the 1980s aimed at economic infrastructure and development projects promoting safe driving. However, no focus was made on infrastructure provision to safeguard pedestrians and other non-motorised transport users Borowy (2013) in RTMC (2016).

In 2004, after the WHO report was published which was a five-year strategy for road safety and facilitated studies to inform the World Report on Road Traffic Injury Prevention. This report indicated that Road Traffic Crash prevention should be considered a shared responsibility, and this led to the period between the years 2011 – 2020 being proclaimed as the Decade of Action (DoA) for Road Safety.

The DoA strategy has five pillars namely:

1. Road Safety Management
2. Improvement of safety of traffic related infrastructure
3. Improve the inherent safety of vehicles through better designs
4. Enhancing the behaviour of road users
5. Improving post-crash care

For this research study, focus will be made on Pillar 2. The improvement of safety through improved traffic related infrastructure. To address the improvement of safety of traffic related infrastructure better understanding of the challenges faced by vulnerable road users (VRUs).

The following are some of the factors influencing exposure to risk faced by VRUs in low and medium – income countries (all these factors are discussed in detail below):

- Social Deprivation
- Demographic
- Engineering Shortcomings
- Vehicular Speed
- Limited Resources and Funding

2.3.1 Social Deprivation

Pedestrian fatalities will perpetuate human, socio and economic losses. According to Moeketsi (2002) and Sinclair & Zuidgeest (2016) there is a close link between low income housing, low education levels and at-grade crossing activity. A study by Sandovic & Juozapaitis (2012) found that higher education level of pedestrian affects the usage of the pedestrian overpass/ footbridge.

According, to Moeketsi (2002), the existence of communities near high speeds roads in South Africa is influenced by individuals who are in search of better economic opportunities migrating from the rural areas into the urban areas; as many of these people migrate from the rural homelands into the urban areas in search of job opportunities and majority of these people get low income job opportunities. This in turn has resulted in many low-income/ urban poor communities in South Africa living in the city fringes adjacent to high speeds (national) roads and to improve their mobility and access they hitch-hiking for work and schools as they have the “least access to private transport and for whom public transport is irregular, expensive and often unsafe” and result in many of them using walking as a means to access (Moeketsi, 2002).

Not only does this trend of communities near high speeds roads exists in urban areas, but this also exist in the rural areas. Over the years this trend has increased tremendously with many of the South African rural communities growing linearly along the national roads. Furthermore, Moeketsi (2002) suggest that many of these individuals end up being victims of road traffic collisions.

2.3.2 Demographic

In Northern Ghana the general pattern of relative risk of casualty of pedestrian road fatality are U-shaped, with children and older adults at the extreme ends (Damsere-Derry, Palk and King, 2017b). According to the World Health Organization the VRUs are classified as follows: children, elderly and medically unfit and disabled as their more exposed. Children in traffic conditions are more exposed to traffic crashes as they have certain limitations which increase their vulnerability, for instance unlike adults' children have a field vision different than those of adults as they are shorter with limited sight distance, with a typical eye height of about one meter above the ground and lack visual acuity and peripheral vision to judge vehicular speeds of oncoming traffic and the gap acceptance. Coupled with this, children are less able to determine the direction of sounds, have poor judgement of the dangerous traffic conditions they face and have shorter attention span and are impatient at crossings (Sinclair, 2017).

Moreover, unlike the children, elderly pedestrians have physical constraints such as reduced vision, hearing and reaction time as their slower than other pedestrians with an average walking speed of less than the average walking speed of pedestrians of 1.2 m per seconds While, the disable road users have physical, visual and auditory constraints which increase their risks as their slower.

According to the study conducted by Sandovic and Juozapaitis (2012), the increase of age, increases the probability of using an overpass, this study showed that “elderly group is 1.996 (1/0.501) likely to use an overpass, while the young and middle-aged group are 1.789 (1/0.559) times more likely to select overpass.

Moreover, studies show “within the adult population the risk of being involved in a pedestrian accident varies not just with age, but also with gender” (Holland and Hill, 2010). The studies by Twisk *et al.* (2014) show that boys have a riskier behaviour than girls. Moreover, according studies by Dada and Zuidgeest (2017) argue that the most affected vulnerable road users in South Africa are males, as males are more inclined to take risky behaviour than females, with more males involved in road crashes than women in all age groups as they are more aggressive. According to Sandovic and Juozapaitis (2012) in Wu *et al.* (2014) females were found to be more likely to use the overpass, mainly because most females feel securer using the overpass/ footbridge than crossing at-grade.

2.3.3 Engineering shortcomings

The lack of crossing facilities contributes to pedestrian-motor vehicle collisions. Previously highway road designs in developing countries followed the developed countries standards (international road designs) which mainly catered for vehicular traffic along freeways. Most of these designs assumed that pedestrians and freeways are not expected to coexist in any proximity to each other; however this is not

the case in many developing countries (Sinclair & Zuidgeest, 2016). For instance, in South Africa the lack of proper public transport facilities within disadvantaged communities due to poor road infrastructure has directed many pedestrians to use major roads such as high-speed roads (freeways) to access public transport. This has led to high potential conflicts between pedestrians and motorised transport (Macozoma and Ribbens, 2004).

In South Africa efforts from transport authorities have been made to address road safety concerns, one such transport authority is the South African National Roads Agency Limited (SANRAL). SANRAL is responsible for the planning, design, construction, and road maintenance for the National Roads in South Africa. SANRAL has over the years become acutely aware of the need not to concentrate only on road infrastructure provision and maintenance but have become more aware that the National Roads are not only used by the motorised transport but more evident the presence of the non-motorised transport (NMT) users. As such conventional engineering design required retrofitting infrastructure to accommodate the NMT, an endeavour to creating safer environments for road users along national roads (Moeketsi, 2002). Lastly, according to Sinclair (2017), there is “insufficient attention to integration of road function with decisions about speed limits, road layout and design”.

2.3.4 Vehicular Speed

According to Jobanputra (2013), most South African cities have road environments that allow high speed on their road networks, coupled with this there are low levels of adherence to the regulated speeds and in most instances the travelling speeds are in excess of the posted speeds. Moreover, “most cities are characterised by (many) informal settlements located close to, or next to arterials or major highways, in order to gain easy access to transport and thus, employment nodes” (Jobanputra, 2013).

In their study, Sinclair and Zuidgeest (2016), assessed pedestrians crossing movements along the freeway in Cape Town. The study assessed pedestrians crossing using footbridges and pedestrians crossing at grade (jaywalking) and the aim of the study was to understand factors influencing pedestrians’ decision for crossing at-grade or using pedestrian footbridge. Table 1 shows the risk factors identified by at-grade crossers from the study.

Table 2.1 Factors identified by at-grade crossers as contributing to traffic risk
Source: (Sinclair & Zuigeest, 2016)

| Specific traffic risk | Percentage of respondents (%) |
|-----------------------------------|-------------------------------|
| Traffic volume | 31.1 |
| Speed | 30.1 |
| Personalised risk of being struck | 24.6 |
| Crime | 5.5 |
| Peak | 5.5 |
| Effort required | 1.1 |
| General traffic | 1.1 |
| Darkness | 0.5 |
| Minibus Taxis | 0.5 |

Traffic volume, speed, and personalised risk of being struck were identified as the most important factors by grade crossers as the contributing factors to traffic risk.

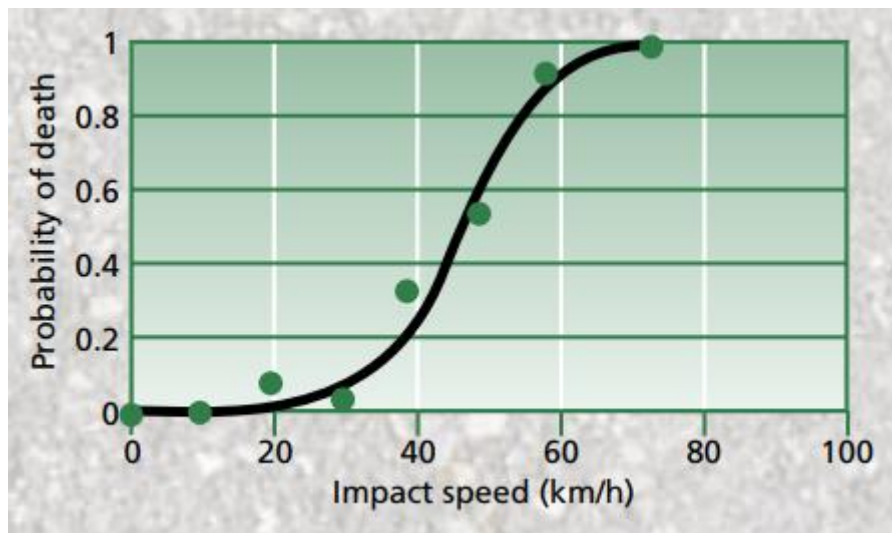


Figure 2.4: Impact speed of car – Pedestrian Fatality risk
Source: (WHO, 2004)

According to Gichaga (2016) pedestrians crossing the road at undesignated locations especially on high-speed road have the unfortunate consequence of speeding vehicles colliding with pedestrians and the probability of death rises with increase in impact speed. Figure 2.4 shows pedestrians' survival decreases with an increase in the impact speed; for instance, at an impact speed of 80km/h survival the probability of death is almost one ($P = 1$).

In South Africa most Class 1 roads mainly have 120km/h posted speeds and pedestrians exposed to traffic traveling at these speeds have almost no chance of surviving the vehicle-pedestrian crash. Studies by Ribbens (1990) in Behrens (2010), also state that with greater speed differential high occurrence of fatal pedestrian crashes mostly on arterials and freeways.

2.3.5 Limited Resources and Funding

According to Moeketsi (2002), from the early sixties the road traffic crash statistics available show that pedestrian fatalities form a significant part of road traffic fatalities in South Africa. In most developing countries such as South Africa, road traffic crashes are the major cause for human and economic losses and have become a major problem and concern, “largely because of limited resources to develop the necessary countermeasure regime to effect a reduction in the accident situation” (Moeketsi, 2002). In most developing countries there is a high absence of sidewalks and crossing facilities and often pedestrians are forced to share roads with motorised vehicles.

A study by Albers et al. (2010), suggest the roadside environment to be an important factor influencing the nature and frequency of pedestrian fatalities. This studies suggest that the presence of pedestrians is significant where there is public transport, however there’s an absence of pedestrian facilities on these routes to assist pedestrian in accessing public transport. Furthermore, the study suggest important factors that could increase pedestrian vulnerability are the lack of sidewalks, crime and security, pedestrian crossing and pedestrian lighting and thus more attention required to improve the pedestrian physical environment, by providing safer, user-friendly pedestrian environment and road safety educational programmes (Albers, Wright and Olwoch, 2010). Similarly, Macozoma & Ribbens (2004) argue that the planning and provision of pedestrian and bicycle infrastructure should be done when roads are being developed, to ensure proactive provision of facilities that are adequate to meet the most vulnerable road users’ needs and safety.

For instance, in northern Ghana the safety of the most vulnerable road users has worsened due to the paucity of road infrastructure development (Damsere-Derry, Palk and King, 2017b). In China about 15% of all the traffic crashes involve by pedestrian violation (Wu *et al.*, 2014). While, in South Africa approximately 36% of road fatal crashes nationally involve pedestrians crossing the road without the use of crossing facilities (Behrens, 2010).

In addition to this, according to the autopsy study done by Toro et al, 2005 in Damsere-Derry et al. (2017) and du Plessis et al. (2016), most pedestrian sustain multiple injuries followed by head injuries. Damsere-Derry, Palk and King (2017b) showed that crashes involving pedestrians predominantly occur at night time in predominantly unlit settlements. This study shows that lighting plays a huge role in protecting pedestrians by making them visible to motorised traffic at night.

There is a high need for infrastructure, however most pedestrian facilities have been unsuccessful in Asian Cities due to lack of financial resources to provide for mobility needs of the growing population that are involved in road traffic collisions (Obeng-Atuah, Poku-Boansi and Cobbinah, 2017).

2.4 Footbridge Location and Allocation Preference

According to Rahman and Smith (2000), the most important process in solving location problems is in determining the selection of the suitable criterion or objective function.

A combination of independent variables such as traffic, environmental and individual characteristics affect the pedestrian crossing. Individual characteristics such as gender, age, career, education level, license, detour wishes, detour distance and crossing time affect pedestrian crossing choice (Wu *et al.*, 2014). Also, according to Räsänen *et al.* (2007) time saving and safe performance of pedestrian footbridge were key performance indicators on the frequency of using the pedestrian bridge.

Xiong *et al.* 2008 in Wu *et al.* (2014) suggests that the convenience, safety and comfort of the pedestrians' crossing facilities were main factors that affected the pedestrians' selection. Also, human factors in traffic collisions through pedestrians' violation psychology and herd mentality were also important factors. Similarly Sisiopiku & Akin (2003) studied pedestrian selection behaviours and perceptions towards various pedestrian facilities and based on observation and survey of data gathered, it was found that the factors influencing the main use of crossing facilities were convenience, safety, and visibility. Likewise, Sinclair & Zuidgeest (2016) suggest some of the factors important to pedestrians are: time saving, shortest route, convenience and safety; where safety is the safety from fast moving vehicles and safety from crime on the footbridge itself and lack of alternatives.

Below some of the factors important for pedestrian in the location and allocation of pedestrian footbridge, these are discussed more in detail below.

2.4.1 Time Saving

According to Moore 1953 in Wu *et al.* (2014) no pedestrians used the overpass if the travel time was 1.5 times or larger than that of grade crossing. Also, about 80% of pedestrians are more willing to use the pedestrian bridges provided it takes the same time as grade crossing (Räsänen *et al.*, 2007). Moreover, Räsänen *et al.* (2007), suggested that the major concern when pedestrians choose their route was the time related, for instance the time required to travel time and the perceived easiness of bridge use.

Pedestrians associate their crossing selection to time saving (crossing time and no waiting time), convenience, comfort, efficiency, and distance saving and security. This is associated with the utility

maximisation method. The expected-utility theory assumes that "An individual consciously weighs up the expected benefits of alternative courses of action in terms of some expected utility value. Each alternative is calculated to be the sum of the utility associated with multiple factors" (Sinclair and Zuidgeest, 2016). However, the "utility theory does not always accurately explain people's decisions" as "people tend to be more conservative in their choices than what the utility model suggest", particularly when stakes are high (Allais, 1953 in Sinclair & Zuidgeest 2016). The findings also showed that the probability of selecting overpass decreases with an increase of crossing time.

2.4.2 Access Distance

Figure 2.5 shows that distance saving and having no choice are the major factors to at-grade crossing, this is followed by time saving. The bridge must be within an acceptable distance and in close proximity to the users/pedestrian desire lines (Sinclair and Zuidgeest, 2016). The desire line is defined as the informal foot path or cyclepath next to a road or over a vacant piece of land which connects origin and destinations in the shortest distance possible (OR Tambo District Municipality, 2017). According to, Sandovic and Juozapaitis (2012) in Sinclair & Zuidgeest (2016), the probability of selecting an overpass decreases with an increase of detour distance in reaching the pedestrian facilities. Thus minimizing the distance walked is the most important factor influencing pedestrian's route choice (Agrawal, Schlossberg and Irvin, 2008).

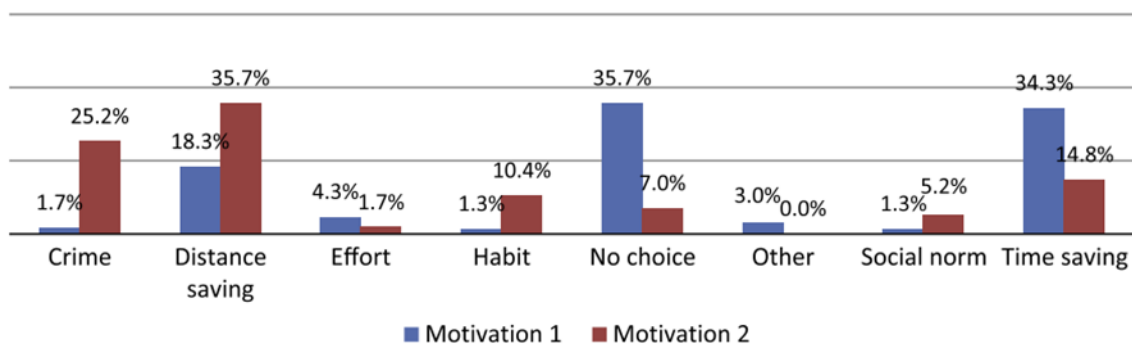


Figure 2.5 At-grade crossing motivations
Source: (Sinclair and Zuidgeest, 2016)

2.4.3 Aesthetics

In a study conducted by Agrawal et al. (2017), one of the attributes influencing pedestrians choice on the routes was the attractiveness of the route. To attract the use of the pedestrian footbridge, the infrastructure should be appealing aesthetically and should allow and support direct access to pedestrian bridge, by channelling pedestrians towards the pedestrian footbridge through enforcement. Platte (2013), states that the channelling should be done "by means of a sturdy fence or barricade and in some

cases; these barricades should be high enough as to prevent anyone from climbing over”. A typical example of this channelling is shown in Figure 6.1, using a wall along the National Road N1 in Mookgophong, Limpopo. The wall is used as self-enforcing feature to channel pedestrians into using the pedestrian footbridge.



Figure 2.6 Brick Wall Self Enforcing Feature at Mookgophong , N1 in Limpopo
Source: Google Earth, 2017

Therefore, to improve the safety of vulnerable road user infrastructure development must make provision for non-motorised transport which separates vulnerable road users from motorists, especially along high speed roads.

According to Sisiopiku & Akin (2003), “a proper design of facilities can encourage walking without compromising safety and convenience”, Kruger (2014) argues that pedestrian bridges in South Africa have previously reflected almost exclusively a utilitarian function and little visual appeal given towards creating sustainable aesthetically pleasing pedestrian bridge infrastructure. Aspects such as:

- Location of other structures near a bridge should not obstruct vision from the bridge and the pedestrian bridge should always be in a proper context of the surroundings. One such example is with the N1 Seventh (7th) Avenue pedestrian bridge (Gauteng Province). During construction of the pedestrian bridge, the bridge management team at the South African National Road Agency Limited (SANRAL) realised that there was a toll gantry being constructed 200m from this bridge, as a result the designer of the toll gantry was approached to re-design the gantry to look similarly with the pedestrian bridge.
- The number of ramp or stairs legs leading to the pedestrian bridges should be kept minimal as this can have an effect on the use rate and if long may not increase the use rate (Räsänen *et al.*, 2007). Also, the ramp and stairs should be provided alongside one another where terrain permits. With most ramps in South Africa constructed to a gradient of 1:12. Whereas in certain locations steeper gradients of 1:5 can be used. Where possible designers should opt for ramps.

However, in the study conducted by Räsänen et al. (2007), escalators are seen to be a good solution in increasing pedestrian bridge use, but this is not an economically viable option for developing countries such as South Africa according to Kruger (2014).

- Enclosing pedestrian bridges with screens or cages, can have an influence on the use of pedestrian bridges hence the application of screens or enclosed cages on pedestrian bridges should be location specific.
- Durability and long-term maintenance should be feasible and sustainable.
- Lighting and colour are some of the key aspects influencing the use and non-use of pedestrian bridges. According to the South African Pedestrian Environment Assessment Tool (PEAT) lighting alongside the lack of pavements and pedestrian crossing could increase pedestrian vulnerability (Albers, Wright and Olwoch, 2010).

Kruger (2014) further stipulates the need for training of engineers in aesthetics, preferably at undergraduate level and it is important for client bodies to support the aesthetically pleasing infrastructure to encourage usage of footbridge structures. Moreover, Sisiopiku & Akin (2003) also argue that city planners and traffic engineers should consider the perceptions and preference of pedestrians when designing facilities for pedestrians that are efficient and user friendly.

2.4.4 Land use planning

According to (Wu *et al.*, 2014), high population density and rapid urbanization coupled with lack of adherence to traffic regulations by both drivers and pedestrians in developing countries, exacerbated road traffic crashes involving pedestrians, as this influence the level of exposure to risk.

In a study done by Sinclair & Zuidgeest (2016) and Damsere-Derry, Palk and King (2017b), there is a major link between poverty and transport; with restricted mobility among urban poor there is generally high restrictions to escaping poverty with long walking distances and exposure to high speed traffic. Many of these communities are poorly spatially planned and have virtually no access management plan. Sisiopiku & Akin (2003), argues that “traffic engineers should pay extra attention to land uses that may generate increased needs for pedestrian movement and consider these needs when making decisions on placement of pedestrian crosswalks at certain locations”. According to Behrens (2010), the positioning of the crossing facilities should be guided by the dominant presences of desire lines and the crosswalk locations. Moreover, the distance between crosswalk location and the desired location should be clear.

2.4.5 Understanding Pedestrian Trip Making

Pedestrian trip making should be assessed to determine and improve access, mobility, and safety of pedestrian (non-motorised transport). According to Behrens (2010), travel behaviour analysis should include walking as a travel mode as this was previously omitted in the analysis, studies need to analyse

in detailed the walking trip generation, distribution and develop route choice. Studies done by Ribbens and Gamoo (2006) suggests pedestrians desire lines and overall travel patterns are key aspects to take to account when planning for NMT facilities. To achieve high use rate of the pedestrian footbridge, the footbridge should be positioned on the normal path of pedestrian movements as much as possible and coupled with this a self-enforcing feature (such as fences and topography) which channels the pedestrians into using the bridge should also be implemented.

Plattee (2013) states that the channelling should be done “by means of a sturdy fence or barricade and in some cases; these barricades should be high enough as to prevent anyone from climbing over”. Likewise, Wu et al. (2014), “suggests that a self-enforcing feature (topography, fences, etc.) that can guide the pedestrian to use the overpass should be installed”. Moreover, to discourage at-grade crossing Evans and Norman, (1998) suggests the implementation of the possible road environment through engineering interventions, for instance through adding a barrier to the median treatment. This will make it harder to cross the road in potentially dangerous situations and promote the use of available road crossing facilities.

2.5 Summary of Literature Review

The location and allocation of pedestrian footbridge/crosswalks requires the consideration of multiple factors. According to Sisiopiku and Akin (2003), “traffic engineers should pay extra attention to land uses, location of crosswalk and desired destination that may generate increased needs for pedestrian movement and consider these needs when making decisions on the location and placement of pedestrian crosswalks”.

Although considerable research studies have been done in the very recent years to address the pedestrian crossing and the use of pedestrian footbridge, there are virtually no studies on analysing the location and allocation pedestrian footbridge along freeways. Among these recent studies, a study on pedestrian crossing choices on Cape Town freeways by Sinclair & Zuidgeest (2016), showed that even though pedestrian crossing behaviour has been extensively researched in many parts of the world, almost none have so far been carried out in the context of freeways. The intention of their study (Sinclair & Zuidgeest, 2016) was to understand the factors that contributed to pedestrian decision to cross high speed traffic at grade. Furthermore, their study looked in detail at how pedestrian made decision under extreme traffic conditions. The results from their study revealed the main factors leading to unsafe crossing were waiting time and crossing distance, many pedestrians preferred using the shortest route to minimise walking distance and delays.

Moreover, a study by Sisiopiku & Akin (2003) examined the pedestrian behaviours at pedestrian facilities and measured their perceptions towards various pedestrian facilities. This study revealed that properly designed and placed pedestrian facilities encourage users to cross at the allocated cross areas. The study also showed that the most important factor cited by pedestrians in making decision to cross at the designated crossing areas/facilities were distance of the crosswalk to desired destinations of pedestrians and convenience in using the crossing areas/facilities.

Another study by Räsänen *et al.* (2007) and Wu *et al.* (2014) reported on the factors that influence the use and non-use of pedestrian bridges and the pedestrian selective preference of overpass. The main findings of these studies revealed that factors that influence the use of pedestrian bridge were the frequent use of bridge, pedestrian perception of seeing the footbridge in use as a time saving and the perceived easiness of bridge use.

The above literature revealed that multiple factors influence the use and non-use of footbridge were availability of footbridge (and other street furniture), traffic environment, proximity of infrastructure, land use, traffic volumes, vehicular speed, number of pedestrians using the footbridge and their age, were important factors to consider.

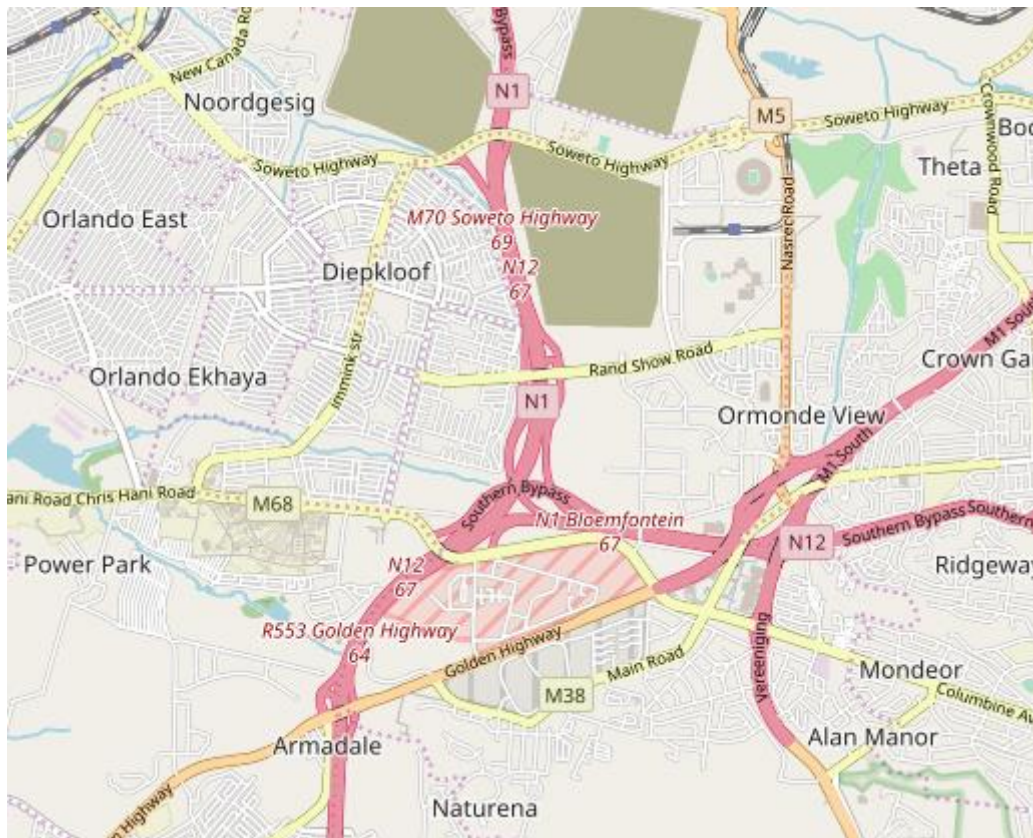


Figure 3.2 Study Area

Source: ArcGIS Desktop 10.6.1

According to Dada and Zuidgeest (2017) the freeway is considered to be on the highest scale for traffic-pedestrian impact due to the high travel speed associated with passing traffic and the number of lanes. Pedestrians crossing at-grade have high fatality probability. Therefore, these freeways present a major obstacle to pedestrians wanting to access economic opportunities across them.

The road classification in South Africa uses a route number classification made up of three route numbering systems for the public, namely: N for National, R for provincial and M for Metropolitan. Furthermore, the road classification in South Africa is closely related to the road functionality. Figure 3.3 shows the Road Functional Classification and is classified according to mobility and access. The mobility function roads are Class 1, 2 and 3 roads; while the access function roads are Class 4, 5 and 6 roads also shown in figure 3.3 (South Africa Committee of Transport Officials, 2012).

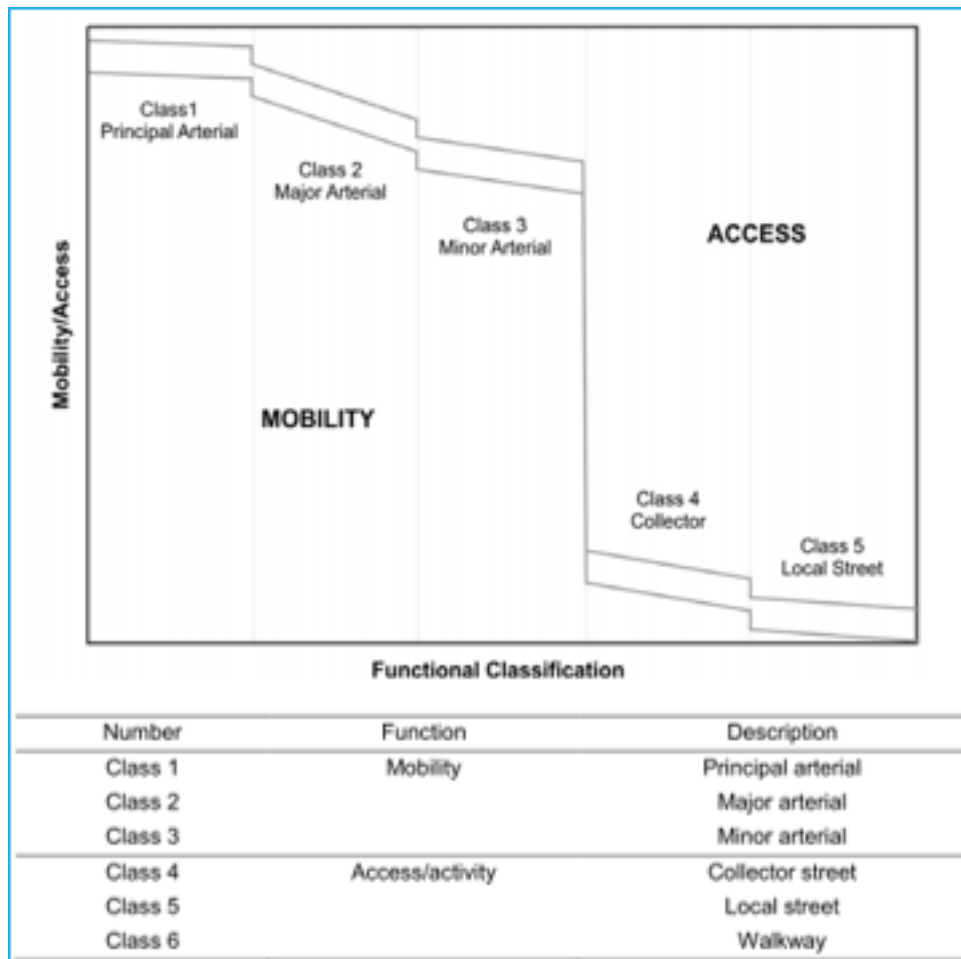


Figure 3.3 Road Functional Classification

Source: (South Africa Committee of Transport Officials, 2012)

The proposed study area has the National road N1 and N12 within the study zone and the functional classification of these roads is Class 1 principal arterial, mobility road with limited access and design speed of 120km/h as shown in Table 3.1. From literature it was shown that there is a direct relationship between vehicle speed and probability of death as shown in figure 2.4.

The average daily traffic on the study section area is more than 50 000 vehicles per day, the speed limit is 120km/hr and the average number of lanes is 5, as shown in Table 3.1. Therefore, the probability of death for road users crossing along the study area have a high risk of death.

Table 3.1 Study Area Traffic Information (Source: SANRAL ITIS, 2017)

| Name | LANES | ADT | % | | Speed (Km/hr) | | | Percentage vehicles in excess of speed limit |
|---------------------------|----------|--------------|-------------------|-------------|---------------|--------------------|--------------------|--|
| | | | Percentage Trucks | Speed Limit | Average Speed | 15th centile speed | 85th centile speed | |
| N1 Diepkloof IC SB | 5 | 46995 | 7.9 | 120 | 103.3 | 85.7 | 122 | 16.2 |
| Rand Show Rd SB On | 3 | 27458 | 4.8 | 120 | 96.8 | 77.8 | 115.9 | 6.3 |
| Rand Show Rd NB On Ramp | 5 | 55789 | 5.3 | 120 | 103.7 | 81.7 | 125.9 | 20.8 |
| Soweto Highway SB On Ramp | 5 | 54021 | 5.2 | 120 | 105.7 | 83.7 | 125.9 | 23.2 |
| Diepkloof WB | 5 | 66618 | 7 | 120 | 101 | 81.6 | 119.9 | 3.8 |
| Unclw Charlie EB Off Ramp | 6 | 68552 | 7 | 120 | 102.7 | 83.6 | 122 | 15.6 |
| Average | 5 | 53239 | 6 | 120 | 102 | 82 | 122 | 14 |

3.2 Freeway Management System

The chosen study area forms part of the SANRAL road safety strategy to improve mobility and accessibility for all road users, by reducing the exposure of vulnerable users. As part of the five pillars of the SANRAL's Strategy (2017), Road Safety forms part of pillars and the aim is to reduce vehicle crashes, deaths and injuries on SA roads by addressing: law enforcement, operator, vehicle and driver fitness, infrastructure, management and information systems and communication, public education and participation. Figure 3.4, shows the heat map for pedestrian incidents (the number pedestrian-vehicle crashes) recorded between June 2016 – June 2017. From the Freeway Management System (FMS) in Gauteng Province, it was shown that pedestrian at-grade crossing was the major cause of road incidents.

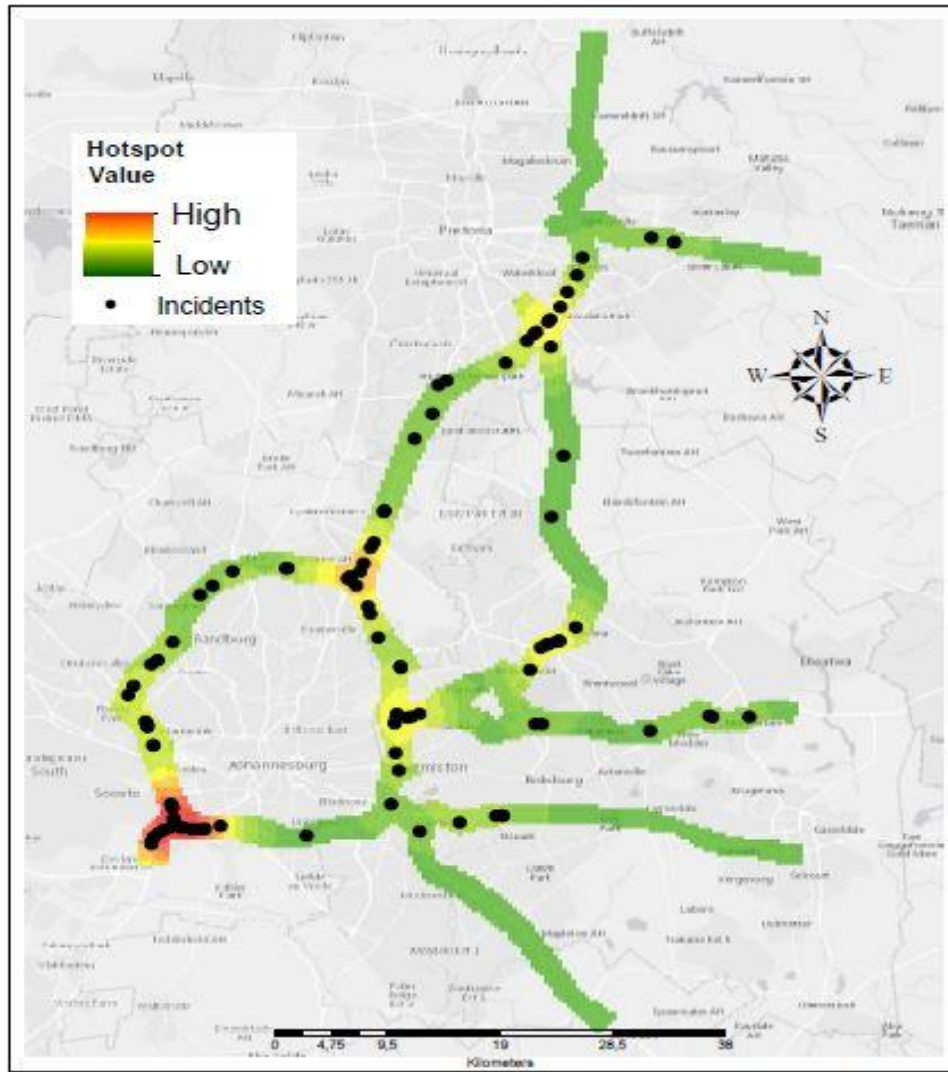


Figure 3.4 Pedestrian Incidents Heat Map for June 2016 – June 2017
Source: FMS Data (2017)

As shown in figure 3.5, majority of pedestrian incidents with high risk levels occurred mainly on the South West of Johannesburg, while the other sections presented low risk levels. This section of the road has routes that run through the Diepkloof Interchange and Uncle Charlie's Interchange and they stop on N1 Western Bypass (before the Soweto highway), N12 Southern Bypass (after the Southgate Mall) and Golden Highway as shown in Figure 3.6. Furthermore, the section of the road was recorded to have multiple challenges for pedestrians wanting to cross as shown in Table 3.1. The recorded pedestrian-vehicle crashes in the study area are also shown in Figure 3.6, with fatal crashes shown in red (total recorded = 16) and non-fatal crashes shown in purple (total recorded = 7).

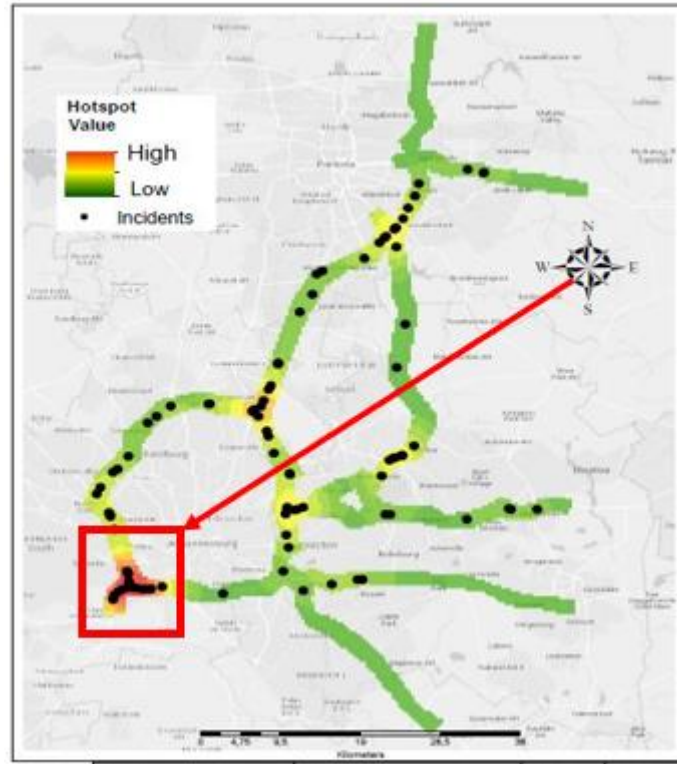


Figure 3.5 South West Johannesburg

Source: FMS Data (2017)

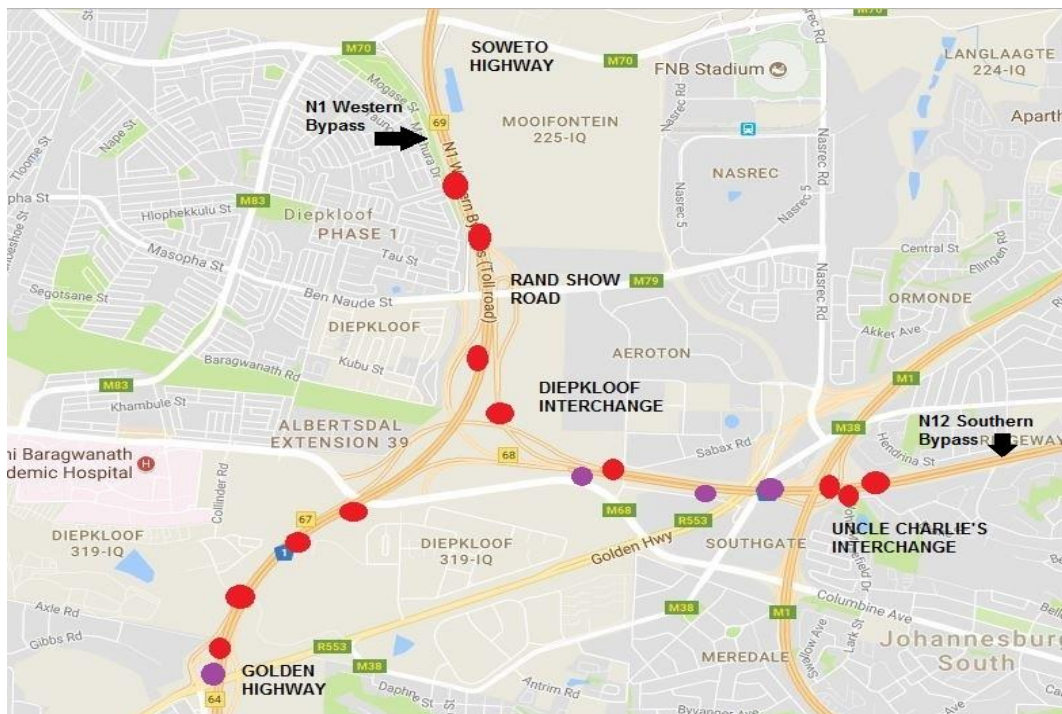


Figure 3.6 Pedestrian Incidents recorded June 2016 – June 2017

Source: TETI (2017)

3.3 Socio-Economic Status

The selected study area for the analyses of pedestrian footbridge location and allocation model is situated in the City of Johannesburg within a 500m radius (with exception of higher radius >800m for trip attractors) to the National roads N12 and N1, adjacent to Diepkloof in the South-western Township (Soweto) Johannesburg, shown in Figure 3.7 highlighted on the map in red, green and blue (National Department of Transport, 1998).



Figure 3.7 Diepkloof Pedestrian Study area

Source: Google Earth (2017)

The study area forms part of the Region D (Region D, nd). According to the Integrated Development Plan (IDP) for Gauteng Province and the Small Area statistics (2011), Region D has the second highest number of people living in poverty, unemployment and low to lowest income level as shown in Table 3.2 which shows the annual household income groups.

Table 3.2: Annual Household Income Groups

Source: Stats SA (2017)

| <i>Lowest Income Area</i> | <i>Low Income Area</i> | <i>Middle Income</i> | <i>High Income</i> | <i>Affluent Income</i> |
|---------------------------|------------------------|----------------------|--------------------|------------------------|
| R0_20500 | R20501_202500 | R202501_707000 | R707001_1512000 | R1512000_more |

According to Moeketsi (2002), in South Africa many low-income/ urban poor communities are living in the city fringes near high speeds roads (highways) as they have the “least access to private transport and for whom public transport is irregular, expensive and often unsafe”. Also, people migrate from the rural home lands into the urban areas in search of job opportunities and majority have low income

levels, due to this many end up living adjacent to high speed roads (many of which are National Roads), Moeketsi (2002) explains that the main factors causing majority of the low income level group is to improve their mobility and access to public transport, hitch-hiking, work and schools and many of these individuals are victims of road traffic collisions (pedestrian – vehicle crashes).

The following figure 3.8, 3.9, 3.10, 3.11 and 3.12 were derived using the Johannesburg, Region D Socio-Economic profile presented in the Joburg Integrated Development Plan. The single colour in each map shows the dominant category (e.g. employment status, income level, dominant gender, dwelling type and dominant race respectively) in each area for the different maps.

Figure 3.8 and 3.9, shows the employment status and income level in the study area respectively according to the City of Johannesburg Wards statistics. The study area is mainly residential areas with some industrial, economic and prison area. As shown by figure 3.8 most of the population are employed. Also, shown in figure 3.9 majority of the study areas have low income level followed by lowest income level and middle-income level (according to Table 3.2).



Figure 3.8 Employment Status for Study Area

Source: (Esri World Imagery, 2019 and City of Johannesburg Wards, 2011)

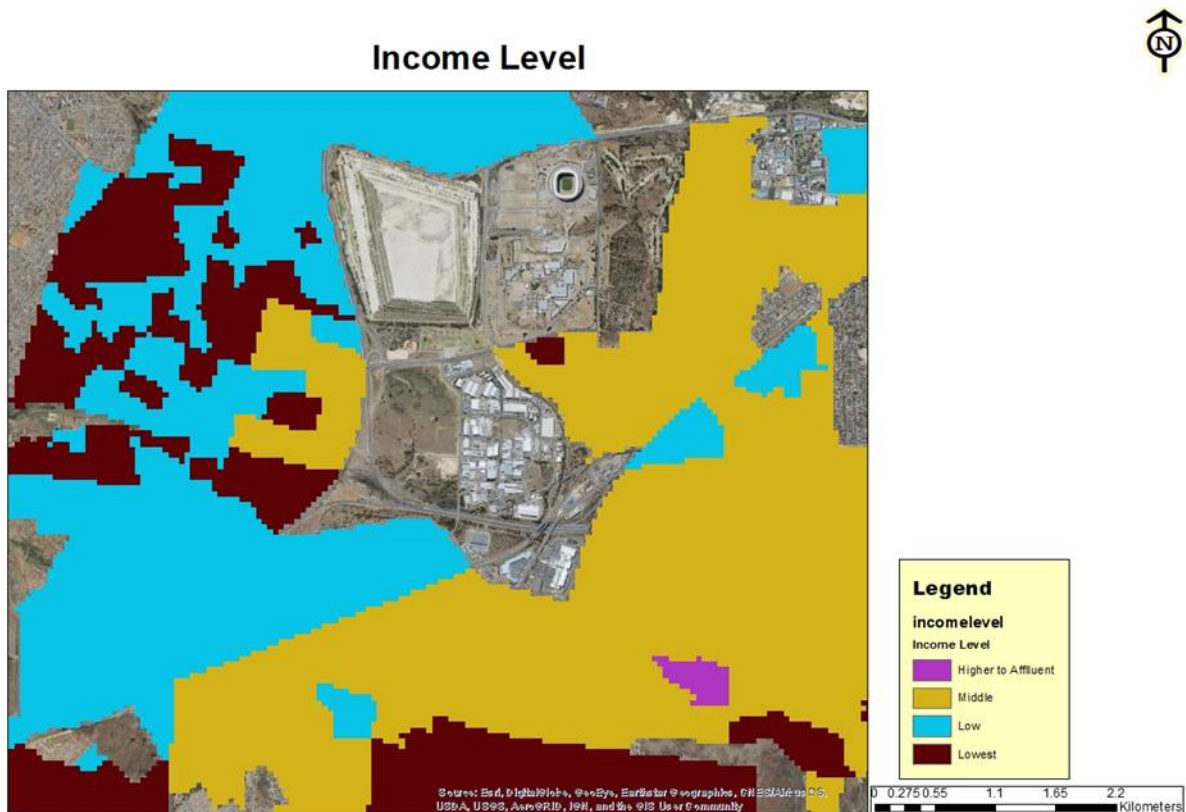


Figure 3.9 Income Level for Study Area

Source: (Esri World Imagery, 2019 and City of Johannesburg Wards, 2011)

Figure 3.10 shows the dominant gender in the study area as per the City of Johannesburg Wards statistics. According to literature individual characteristics such as gender influence pedestrian choice in choosing a suitable location to cross over the highway. According to the National Department of Transport (2011), road traffic deaths recorded in the year 2009 in South Africa were 76% Male and 24% Female. Moreover, studies by du Plessis, Hlaise and Blumenthal (2016) revealed that majority of fatalities involved males and majority of the males victim were often pedestrians with a positive BAC. The two studies show that males are the most VRUs, this shows that males are more inclined to take risky behaviour than females as more males are involved in road crashes than women as they are more aggressive.



Dominant Gender

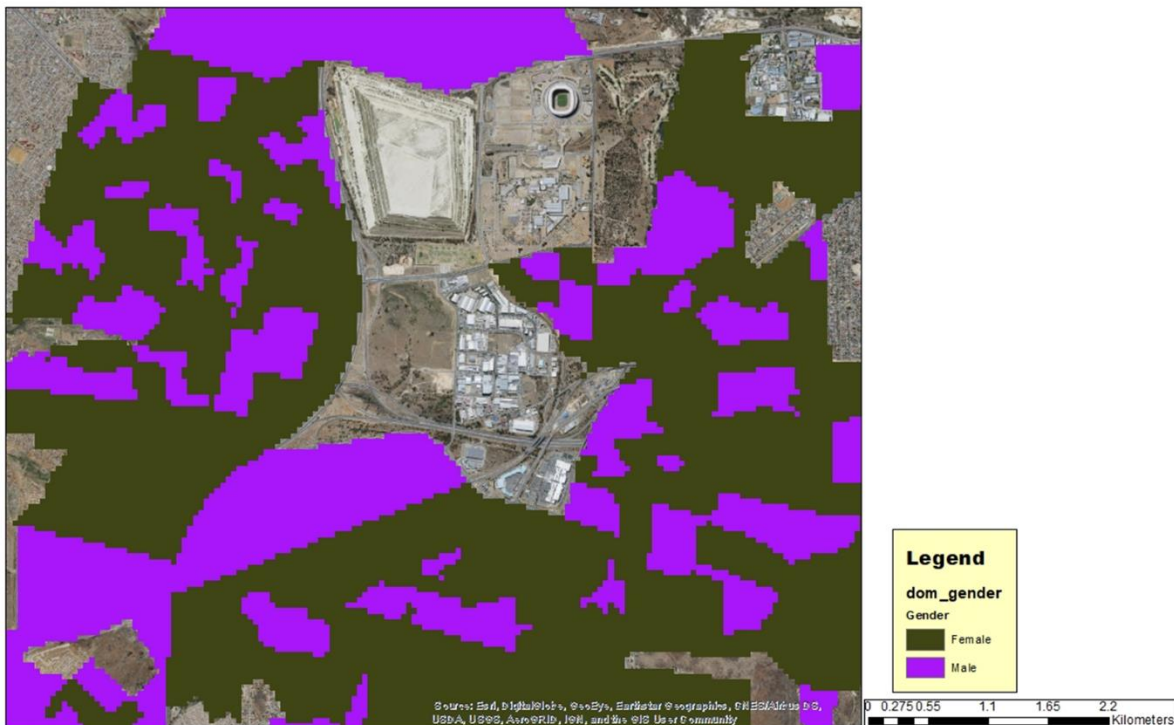


Figure 3.10 Dominant Gender in the Study Area

Source: (Esri World Imagery, 2019 and City of Johannesburg Wards, 2011)

Figure 3.11 show the dwelling type in the study area as per City of Johannesburg. According to the Stats SA, Region D's population is 1,058,978 many of whom live in informal settlements and the “established areas of Region D are largely composed of the old "matchbox" houses built to provide cheap accommodation for Joburg's workers during the apartheid era, but in some areas, such as Diepkloof Extension, prosperous Sowetans have built houses that can be compared to those in some of Johannesburg's most upmarket suburbs” (IDP, nd). Figure 3.12 shows the dominant race in the study area being Black African followed by Coloured or Asian. This shows the most affected race exists in the area.

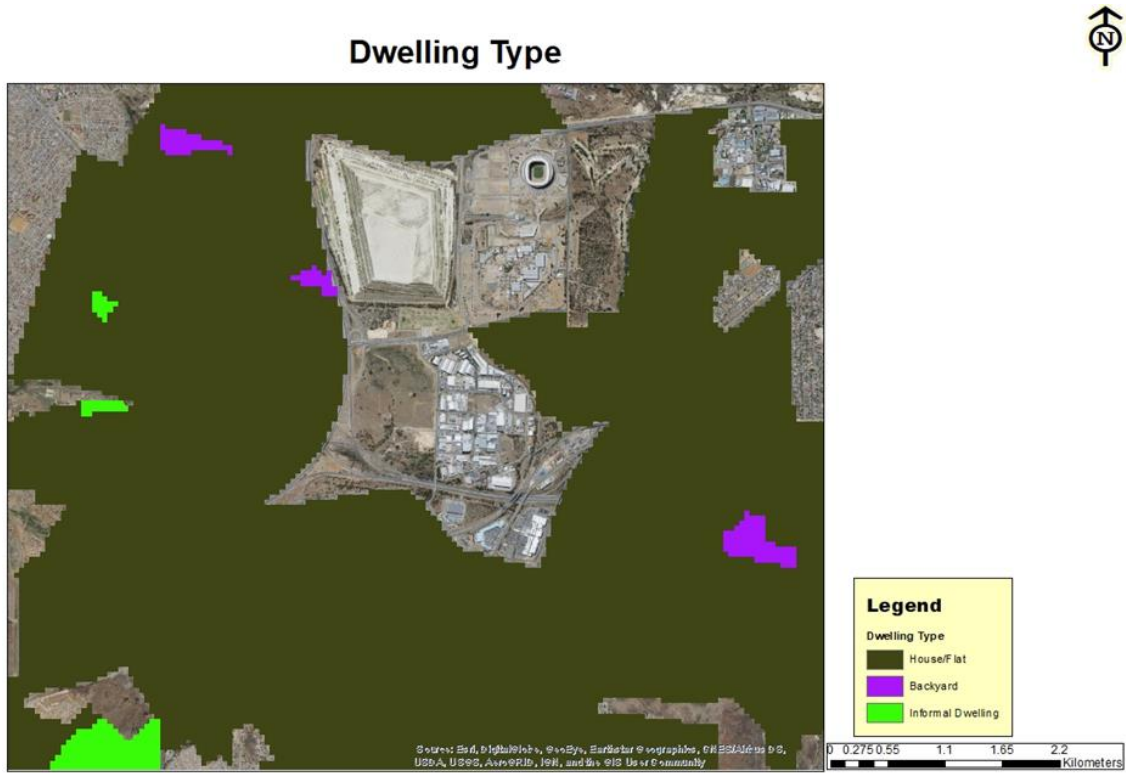


Figure 3.11 Dwelling Type in the Study Area

Source: (Esri World Imagery, 2019 and City of Johannesburg Wards, 2011)

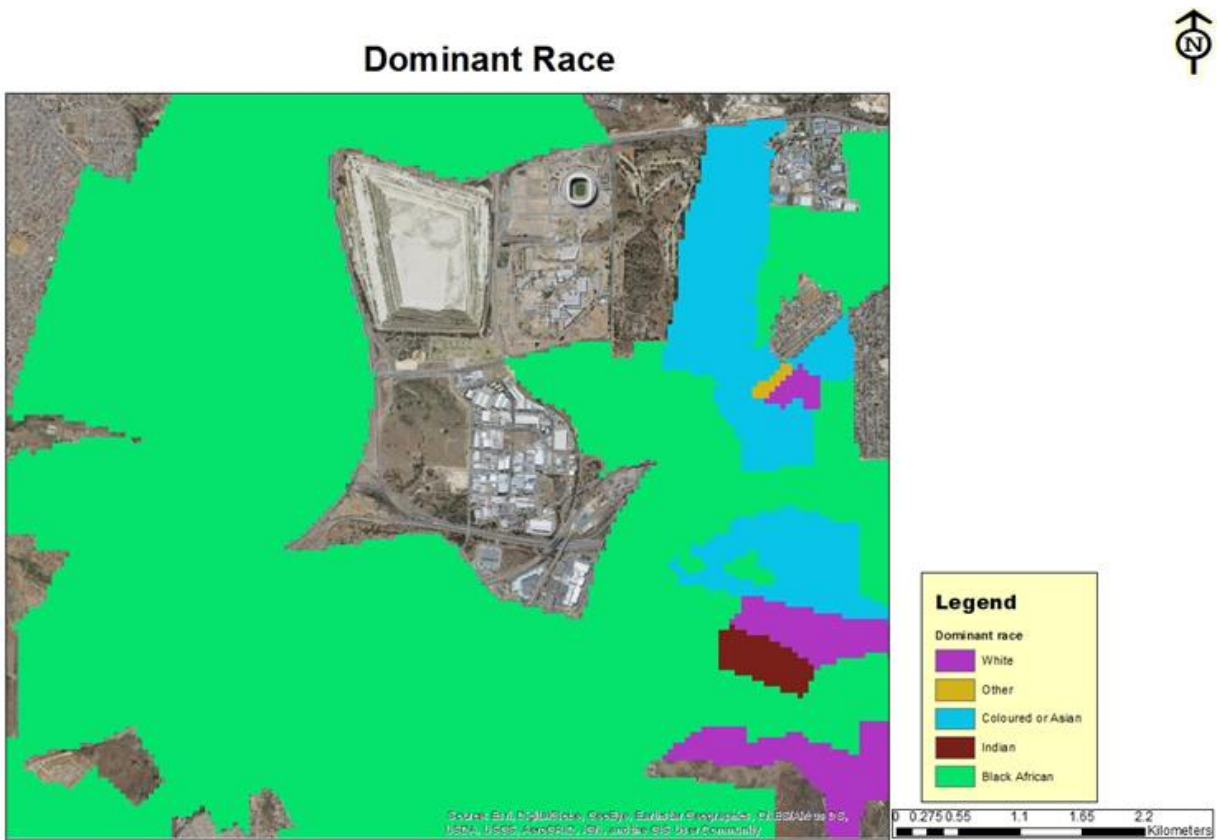


Figure 3.12 Dominant Race in the Study Area

Source: (Esri World Imagery, 2019 and City of Johannesburg Wards, 2011)

Moreover, poverty is recorded to be one of the major problems in Region D, with high unemployment and low educational levels (Census 2001, Stats SA). According to the Stats SA, the education levels in Soweto show that majority of the population in Soweto do not have higher education. Figure 3.13, shows that the Matric level followed by Some Secondary schooling, are the highest educational level in Soweto for all ages, while the Higher Education is at 9.8% for the entire population.

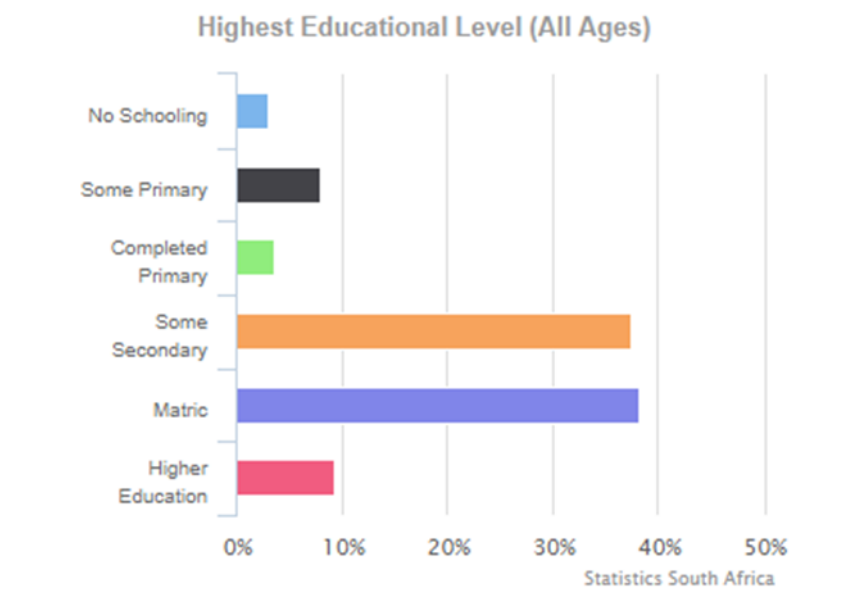


Figure 3.13 Highest Education level in Soweto

Source: (Statistics South Africa, 2011)

Figure 3.14 shows some of the key economic zones/areas in Region D, the following are the key economic areas: the world-renowned Chris Hani Baragwanath Hospital, Nasrec, Aeroton industrial Areas, FNB Stadium and South gate mall. Also, the study area has mixed land use, on one side there is the industrial hub and on another a mall, while on the other side is mainly highly dense residential area.

Sisiopiku & Akin (2003), argued that “traffic engineers should pay extra attention to land uses that may generate increased needs for pedestrian movement and consider these needs when making decisions on placement of pedestrian crosswalks at certain locations”. Moreover, the study done by Sinclair & Zuidgeest (2016) and Damsere-Derry, Palk and King (2017), show that there is a major link between poverty and transport; they argue that with restricted mobility among the urban poor there is generally high restrictions to escaping poverty as many of the urban poor are faced with long walking distances and exposure to high speed traffic, as a result majority of the urban poor use the highways for access to socio and economic facilities and services.



Economic Zones

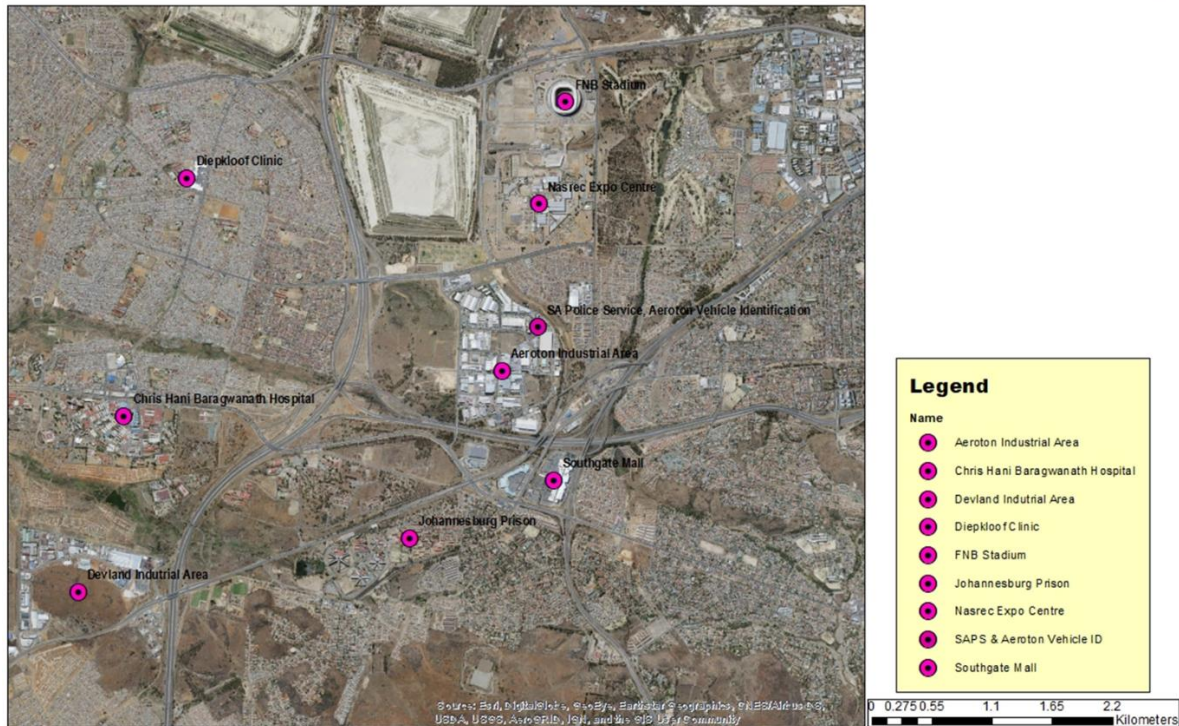


Figure 3.14 Economic Zones in the Study Area

Source: (Esri World Imagery, 2018)

The study area is mainly urban and industrial area. Furthermore, the proposed study area shows a relatively strong link between pedestrian fatalities and urbanisation is consistent with the heightened risk for pedestrians in urban environments reported by Petch and Henson (2000) in Priyantha Wedagama, Bird and Metcalfe (2006).

4 Research Method

As stated in the *Chapter 1 – Introduction*, the proposed research study aims to develop a geo-spatial model that optimises locations of pedestrian footbridge infrastructure along high-speed roads in Gauteng Province along the SANRAL network. The basic objective of this study is to use geo-spatial modelling techniques to analyse the most suitable location to allocate pedestrian footbridge. To achieve this the study explores the factors affecting the location of pedestrian footbridges from international literature. It has been established from the literature review the important causes of at-grade crossing along freeways are accessibility, convenience, comfort, safety, security, time delay, lack of infrastructure, unsafe human behaviour, lack of law enforcement and lack of road safety education.

A brief overview of the methodology was discussed in Chapter 1, this chapter presents the procedure followed in the research design (Platte, 2013)(Platte, 2013)(Platte, 2013)(Platte, 2013) The flow chart in figure 4.1, indicates the procedure followed starting from the:

- Literature review,
- Research proposal,
- Identification of the Case Study Area,
- Research problem
- Research design.

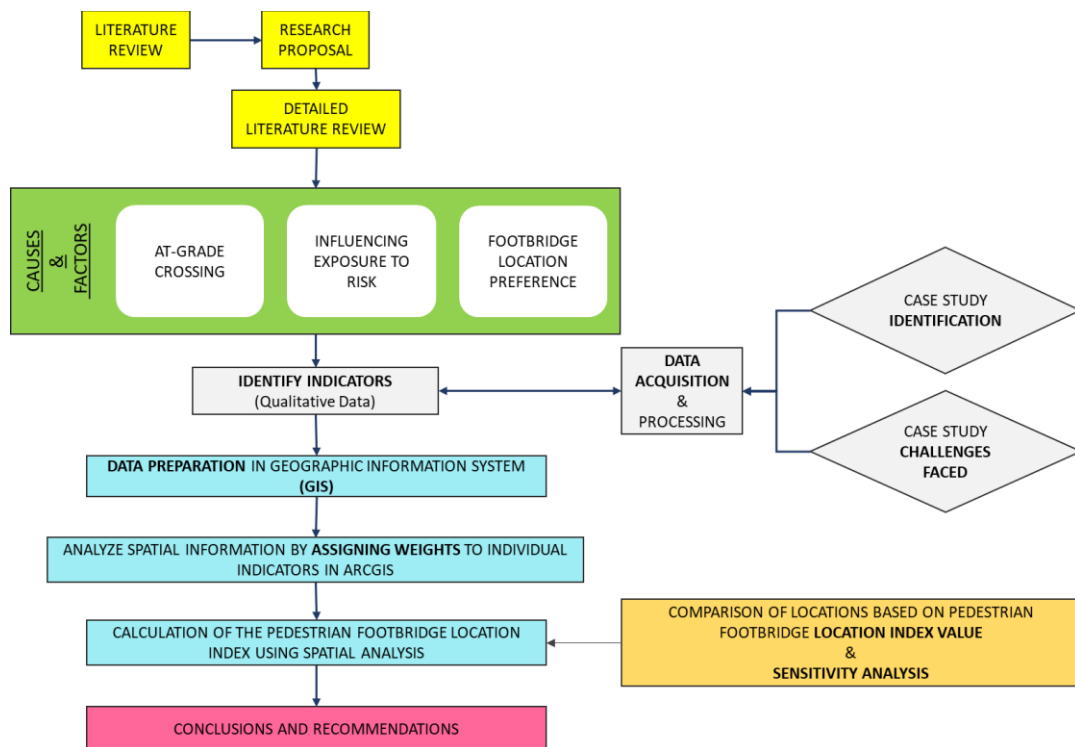


Figure 4.1: Flow chart depicting steps followed for the research

Most literature on pedestrian crossing has mainly focused on evaluating pedestrian crossing over minor roads and limited studies have been done to examine pedestrian crossing over freeways (major roads). The research effort made to date has been important to assist in understanding pedestrian crossing needs. Among the recent studies, a study on pedestrian crossing choices on Cape Town freeways by Sinclair & Zuidgeest (2016) examined factors that influence pedestrian crossing choices, these factors were discussed in detailed in Chapter 2. Moreover, it has been found that a complete study on the locating and allocating pedestrian footbridge has not been done.

The methodology followed to analyse the suitable location to allocate pedestrian footbridge has been depicted in Figure 4.2. As per the methodology, the research methodology involved the identification of key indicators that influence the location and allocation of pedestrian footbridge from literature review. Once the key indicators were identified qualitative data was gathered for these individual indicators.

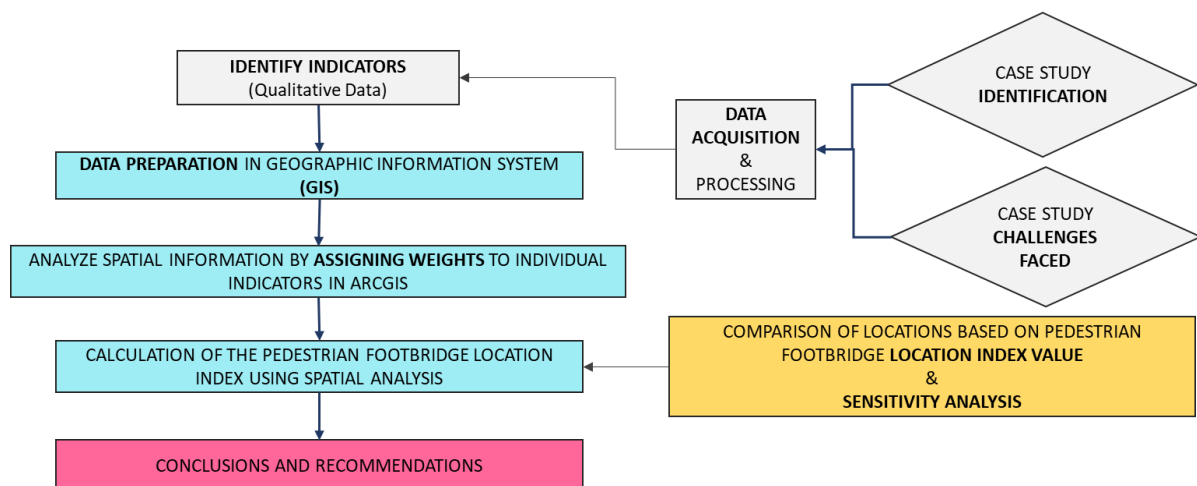


Figure 4.2: Research Methodology

The individual indicators were prepared and analysed spatially in ArcGIS by grouping them according to criteria and assigning weights to the indicators according to their importance. Thereafter, conducting spatial multi-criteria analyses (SMCA) using spatial analyst tool in Arcgis. The suitability map is prepared and the calculation on determining the pedestrian footbridge location index is conducted and the results of this SMCA analysis are mapped out. The pedestrian footbridge location index shows areas with pedestrian footbridge location demand. For instance, the *Higher the Pedestrian Footbridge location index therefore the higher the pedestrian footbridge location demand*, hence the recommendation to allocate in those locations. Once the pedestrian footbridge location index are identified a sensitivity analysis is conducted to verify and validate the results from the SMCA.

This chapter guides through the description of each components of the flow chart diagram and summarises the entire work flowchart method followed.

4.1 Identification of indicators

Literature review revealed the following as some factors most likely to affect pedestrian exposure to risk and pedestrian footbridge location preference, which is likely to consist of:

- Socio-economic characteristics of the population (eg. Population Density, Gender, employment, race, and income level)
- Engineering Shortcomings
- Vehicular Speed & traffic volume along the route
- Crash hotspots/statistics (along the route)
- Time Saving
- Acceptable Access Distance
- Aesthetics
- Land use planning

To improve safe crossing through freeways (high speed roads), literature also suggest that multiple factors should be considered when determining the best location to allocate pedestrian footbridge. Pedestrian crossing choice and occurrence along freeways is affected by various factors/indicators; and the influence of all factors is not the same for the entire study area and the influence of indicators are taken according to an area. As such the identification of indicators/criteria affecting the pedestrian crossing choice is key to determine data required and the extent. The following indicators were used as identified from literature review as identified as some key indicators, as shown in figure 4.3, these indicators were grouped according to the themes (criteria maps to be discussed in Section 4.5) for analyses purpose.

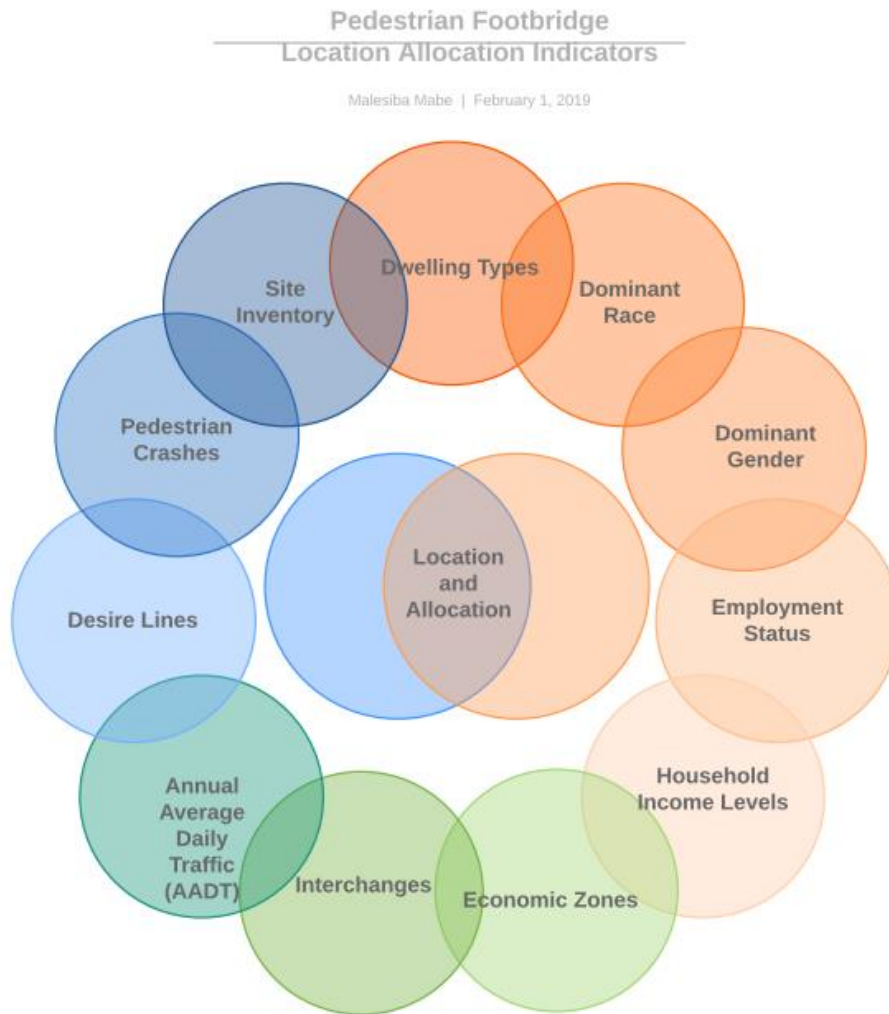


Figure 4.3: Location Indicators for allocating Pedestrian Footbridge
Source: (Author, 2019)

From the above factors, spatial multi-criteria analyses (SMCA) will be set-up and assigned suitability scores and used to derive suitability map. The suitability map will be used to identify locations with high pedestrian footbridge location index.

4.2 Data Sources and Description

Multiple data sources were used to access data, below is a brief description of the data source used. This research study forms part of the South African National Road Agency Limited (SANRAL) Freeway Management System (FMS) and Road Safety. The data used was gathered from SANRAL FMS and it showed the geographical location of pedestrian fatal and severe crashes. The traffic information data was gathered from the SANRAL ITIS System showing the number of lanes, average daily traffic (ADT), percentage of trucks and the speed. The traffic volume data was manually inserted into the study area road network map on Google Earth. The original data had coordinates points.

The following data for the proposed study area was gathered from the Statistics South Africa (2011) namely:

- Dwelling types
- Dominant Race
- Dominant Gender
- Employment Status
- Household Income Levels
- Education
- Population

This was used to determine the socio-economic status of the study area. The original data was in excel format and had coordinates. Another, data source used was Google Earth Pro - 7.3.2.5495 (64-bit), this was used to identify key economic zones, land constraints (mine residue and interchanges) and pedestrian desire lines within the study area. The desire lines were identified using the aerial satellite image of the study area by locating visible existing footpath from the identified economic zones and the residential areas. The footpaths were drawn using Google Earth Pro and named desire lines.

4.3 Data Analysis Tools

The following are tools used for data analysis:

- **Microsoft Excel** was used to prepare the Statistics South Africa 2011 data for use in ArcGIS.
- **ArcGIS Desktop 10.6.1** software package was used to map all the geographical data within the proposed study area. GIS is a user-friendly raster and vector analysis software and the Spatial analyst allows for suitability modelling. By mapping the geographical data allowed the identification of key indicators required in determining the location for allocation of pedestrian bridges. ArcGIS also assisted with the preparation of maps for further analysis.

- **Google Earth Pro - 7.3.2.5495 (64-bit)** - This is an open source component and it was used to gathered aerial information of the study area by assessing the land use and travel patterns

4.4 Data Processing

All data gathered was quantitative and in the following formats:

- Kml (for all google earth data)
- Excel (for all the Johannesburg small areas)
- Shapefile (for the Johannesburg areas)

This data was loaded onto ArcMap by either Add Data, Joins and relates (using the attribute table) or Kml to layer (using Conversion Tools in ArcToolbox). Table 4.1 shows the data source format and GIS data type used to develop criteria maps as per indicators to determine the pedestrian footbridge location-allocation.

Table 4.1 Pedestrian Footbridge Location-Allocation ArcMap Data Processing

| Indicators | Data Source Format | GIS Data Types | Raster | Reclassify |
|--------------------------|--------------------|-------------------------------|--------------------|--------------------|
| Traffic Volumes | KML | Lines | Line Density | Common Scale (1-5) |
| Desire Lines | KML | Lines | Line Density | Common Scale (1-5) |
| Economic Zones | KML | Polygons | Polygons to Raster | Common Scale (1-5) |
| Income level | Excel | Create feature with attribute | Polygons to Raster | Common Scale (1-5) |
| Dominating Race | Excel | Create feature with attribute | Polygons to Raster | Common Scale (1-5) |
| Dominating gender | Excel | Create feature with attribute | Polygons to Raster | Common Scale (1-5) |
| Employment status | Excel | Create feature with attribute | Polygons to Raster | Common Scale (1-5) |
| Dominating Dwelling type | Excel | Create feature with attribute | Polygons to Raster | Common Scale (1-5) |
| Incidents/Accidents | KML | Points | Kernel Density | Common Scale (1-5) |

The following steps were followed in data processing:

- The acquired data is processed and prepared for analyses in ArcMap.
- Data was imported into ArcMap to form shapefiles.
- Data frame Coordinate system by setting the projection to UTM 35s.
- Create a Mask which is a raster with dataset that defines the area of interest in the input rasters. Areas that had spatial constraint (unsuitable) within the study area were eliminated from the Mask.
- GIS data types were converted to Raster Maps.
- Reclassification of data (indicators) according to the scale required. Rescaling of indicator raster maps to bring all data to a common scale of 1 to 5, where 1 is low (less suitable to locate pedestrian footbridge) and 5 is very high (more suitable to locate a pedestrian footbridge).
- The reclassified data (indicators) is then grouped according to the criteria.

- Suitability analysis using arc-toolbox weighted sum and weighted overlay. The weighted sum multiplies the “designated field values for each input raster by the specified weight. It then sums all the input rasters together to create an output raster. Whereas weighted overlay (spatial analyst) “overlays several rasters using a common measurement scale and weights each according to its importance” (ArcGIS 10.7.1 Help, 2018).
- Sensitivity analysis.

4.5 Criteria/Themes Maps

From the above listed indicators, a spatial multi-criteria analyses (SMCA) will be conducted to analyse and determine the most suitable location to allocate pedestrian footbridge over freeways. This will be done by identifying key criteria themes to be used in analysing the suitable location to allocate pedestrian footbridge, as shown in Table 4.2. The criteria maps were built in GIS using the indicator raster maps as inputs. The following criteria themes were developed as adopted from Keshkamat (2007)’s study:

- **Social Deprivation** – The higher the social deprivation the more the need for safe crossing facilities and the closer the pedestrian footbridge ought to be for social convenience.
- **Economic** – The higher the economic zone is a trip attractor the more reasons to improve pedestrian access, mobility and interaction.
- **Transport Demand** – The higher the traffic volume, lane width and speed the more reason to consider pedestrian footbridge where there is high at-grade crossing. Moreover, the closer the proposed pedestrian footbridge location is to the desire lines the better accessible the pedestrian bridge.
- **Safety Risk** – The more prone the area is to crashes; the more benefit associated with providing the pedestrian bridge.

Table 4.2 Indicators and Criteria Influencing Location and Allocation of Pedestrian Footbridge

| Criteria/Theme | Indicators | Purpose |
|-----------------------|---------------------------------------|---|
| Social & Safety | Dominating dwelling type | Spatial benefit* High density of residential developments is an indication of high travel NMT use. The higher the dwelling type is backyard or informal type the more the need for safe crossing facilities |
| | Household (HH) Income levels | Spatial benefit* The more closer the pedestrian footbridge is to the low and middle income areas the greater the social convenience. |
| | Dominating Race | Spatial benefit* The closer the pedestrian footbridge the greater the social convenience. The influence of race on accidents was expected due to the role of social disadvantage. |
| | Dominating Gender | Spatial benefit* The more closer the pedestrian footbridge is to the female dominated areas the more use of the footbridge |
| | Employment Status | Spatial benefit* The more closer the pedestrian footbridge is to the unemployed zones the greater the access to the socio-economic zones. |
| Economic | Economic zones | Spatial benefit*. The more the economic activity (trip attractors) in the area, the more reasons to improve pedestrian mobility and interaction. |
| Transport | Annual Average Daily Traffic (AADT) . | The current traffic volumes along the national route. Spatial benefit* The higher the current |
| | Desire lines | Spatial benefit* The closer the pedestrian bridge is to the desire lines the more accessible the pedestrian bridge is. |
| Safety Risk | Accident/Crash hotspots | Spatial benefit* The more prone the area is to accidents, the more benefit associated with providing the pedestrian bridge. |

- Spatial benefit* - is defined as the criterion that contributes positively, the more you have the better.
- Spatial constraint* - is defined as a criterion that contributes to obstacle and are unsuitable.
- Spatial cost* - is defined as a criterion that contributes negatively; the less you have the better

4.5.1 Social-Deprivation Criteria Map

The social status/levels of the study area were discussed in Chapter 3 under Socio-Economic Status by describing the following indicators namely: Employment Status, Household Income Levels, Dominant Gender, Dwelling Type and Dominant Race shown in Figure 3.3, 3.4, 3.5, 3.6, & 3.7 respectively.. These indicators were assigned weights and used to form the Social-Deprivation Criteria Map using Weighted Sum. The weighted sum in ArcToolbox was used, by assigning each indicator map the same weight of 20%, as shown in table 4.3 below. The map was generated and standardised using the reclassifying tool in arcgis. Figure 4.4, shows the social-deprivation criteria map, most residential areas adjacent to the national roads within the study area have high to very high social deprivation level and the area with low social deprivation level are mainly economic zones with minimal to no residential areas.

Table 4.3 Social-Deprivation Criteria Weighted Sum

| <i>Weighted Sum</i> | | |
|---------------------------|-------------------|----------------|
| Criteria | Indicators | Weights |
| Social-Deprivation | Dwelling Type | 20 |
| | Dominant Race | 20 |
| | Dominant Gender | 20 |
| | Employment Status | 20 |
| | HH Income levels | 20 |

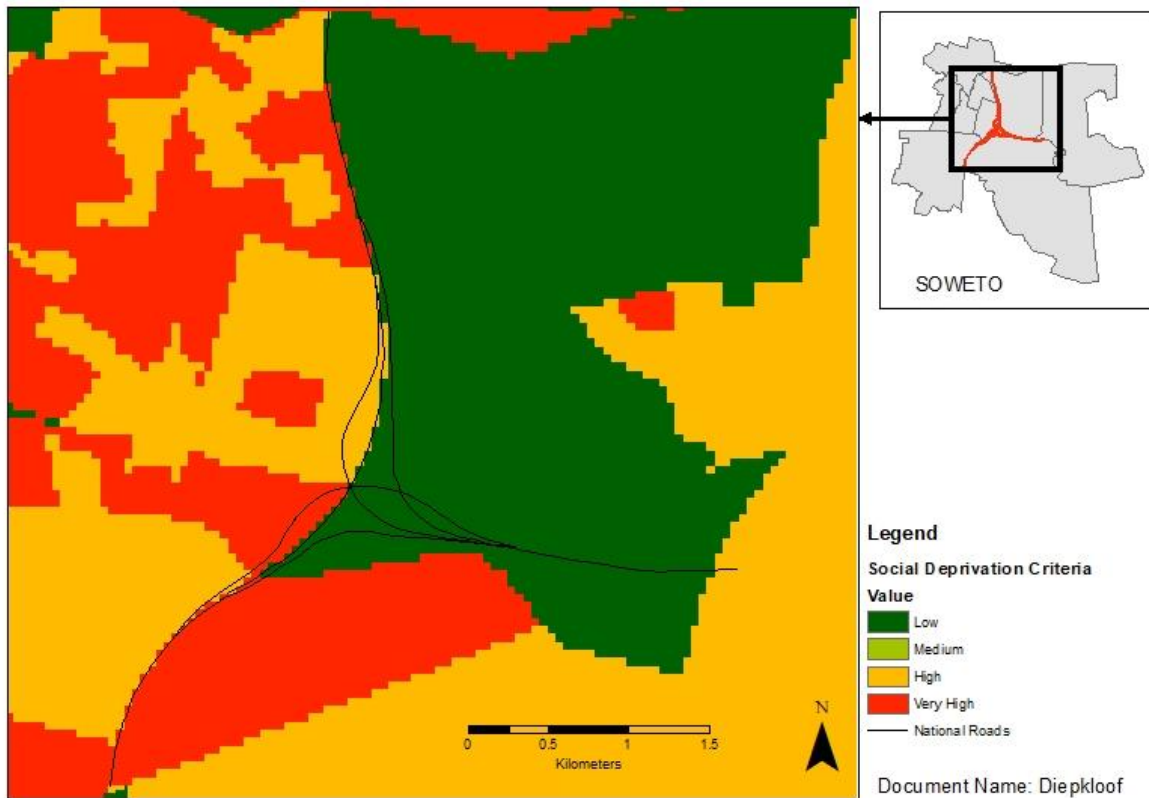


Figure 4.4 Social-Deprivation Criteria Map

4.5.2 Safety Risk Criteria

For the safety-risk criteria the pedestrian–vehicle crash stats were used as indicators to identify pedestrian hazard locations along a route. As discussed in detail in Chapter 3, the case study area was recorded to have the highest recorded pedestrian-vehicle crashes in the whole of the Gauteng Freeway Improvement Project (GIFP) as shown in figure 3.10. The pedestrian-vehicle crashes were processed using the Weighted Sum in ArcGIS by assigning weights as shown in table 4.4, to form the safety risk criteria map as shown in figure 4.5. The safety risk criteria map shows locations in the study area that have very low to extreme high risk for illegal grade pedestrian crossing. These locations have high suitability for locating a pedestrian footbridge so as to reduce the risk.

Table 4.4 Safety Risk Criteria Weighted Sum

| <i>Weighted Sum</i> | | |
|---------------------|-------------------|----------------|
| Criteria | Indicators | Weights |
| Safety Risk | Crash hotspots | 100 |

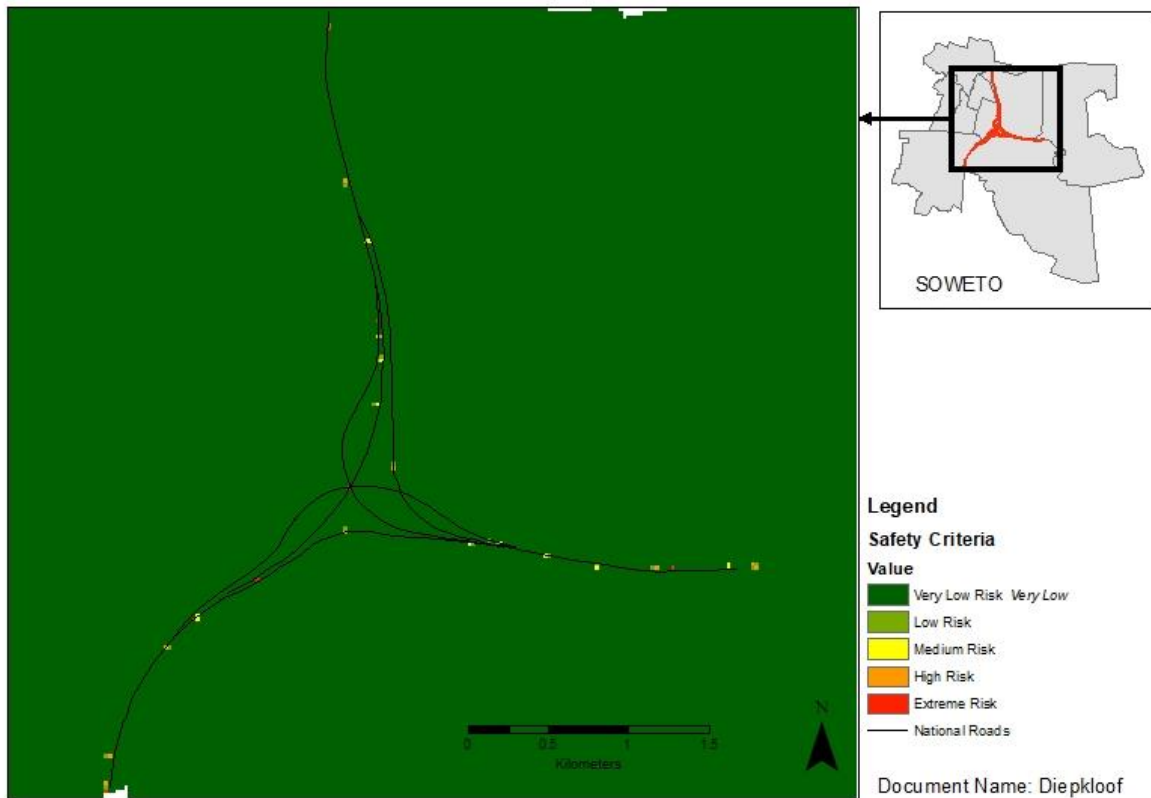


Figure 4.5 Safety-Risk Criteria Map

4.5.3 Transport Criteria

The term transport is used in the context of a digital representation of spatial data pertaining to the relationship among the Average Daily Traffic and the Desire lines. The Average Daily Traffic (ADT) discussed in Chapter 3, from the FMS showed that average daily traffic on the study section was approximately 52,300 vehicles for the year 2016 and the posted speed limit is 120km/h with the number of lanes ranging from 3, 5 and 6 per direction. Figure 4.6 which shows the average daily traffic (ADT) along the section of the road, while figure 4.7 shows the non-motorised transport (NMT) desire lines within the study area.

Average Daily Traffic

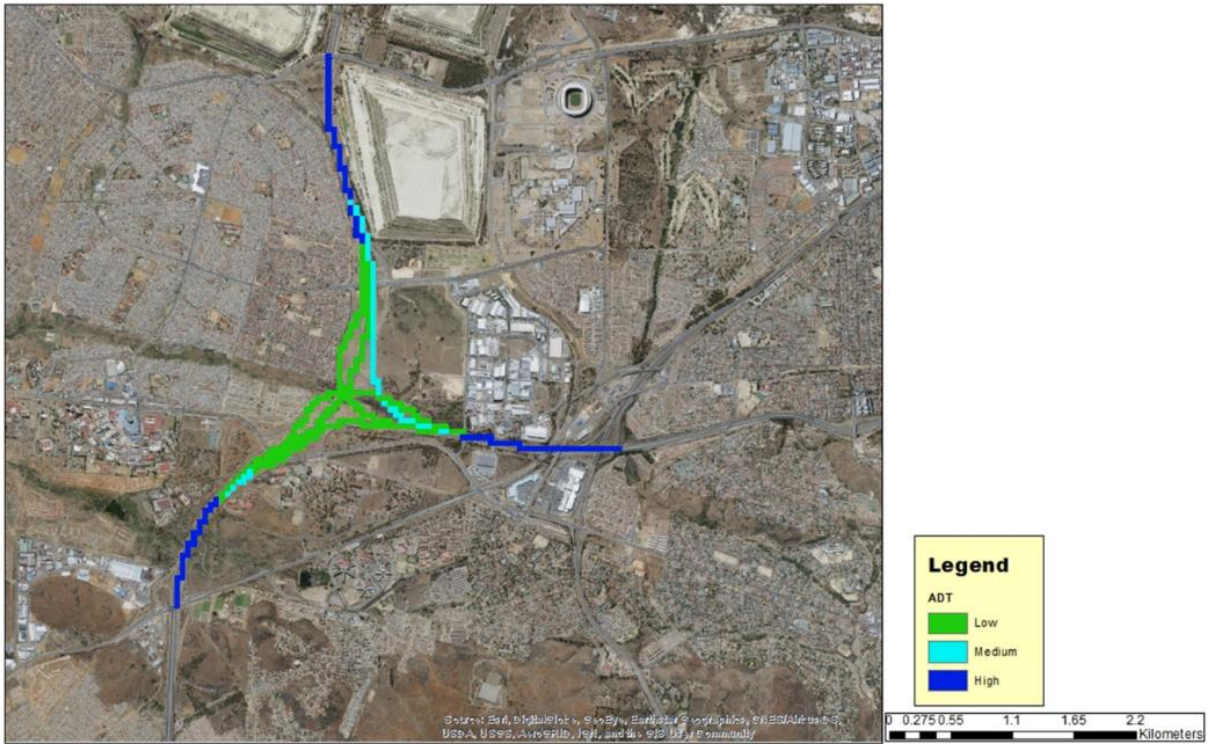


Figure 4.6 Average Daily Traffic in the Study Area

Desire Lines Indicator



Figure 4.7 Desire lines in the Study Area

The desire lines are the existing visible foot pathways that pedestrian in the area presently used for crossing at-grade as shown in figure 4.7. According to Behrens (2010), the positioning of the crossing facilities should be guided by the dominant presences of desire lines and the crosswalk locations. Moreover, the distance between crosswalk location and the desired location should be clear. The two indicator maps shown in Figure 4.6 and 4.7 are assigned weights as shown in table 4.5 and the Weighted Sum is used to develop the transport criteria map.

Table 4.5 Transport Criteria Weighted Sum

| <i>Weighted Sum</i> | | |
|---------------------|---|----------------|
| Criteria | Indicators | Weights |
| Transport | Current traffic density (ADT) volume along the route. | 40 |
| | Desire lines | 60 |

The output map is shown in Figure 4.8 Transport Criteria Map. High demand indicates locations in the study area where sections pedestrian's desire to cross and the traffic conflict are high, While the locations with very high demand show the very high pedestrian crossing demand and the very high conflicts movements that may occur between non-motorised transport users (pedestrians) and motorised traffic. The higher the transport demand the more need to create more walkable and safe crossing spaces. The suitability for locating a pedestrian footbridge is much stronger in areas where the non-motorised transport access and exposure to high traffic are highest, as shown in figure 48 were locations of very high demand for transport. Also, the transport criteria map, shows the NMT access demand and exposure to high traffic.

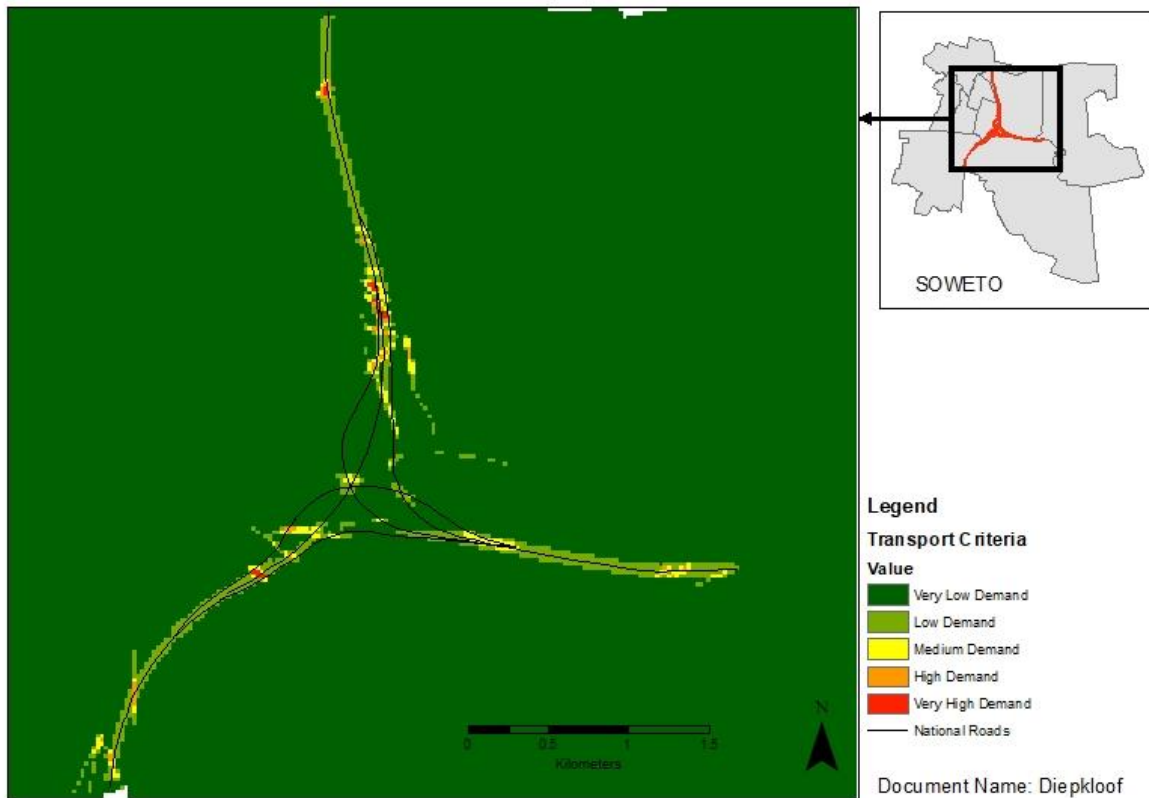


Figure 4.8 Transport Criteria Map

4.5.4 Economic Criteria

Economic zones in the study area are shown in figure 4.9 and have already been explained in Chapter 3. The economic Zones are areas of influence and trip attractors that may generate increased needs for pedestrian movement across highway for access using NMT. According to Dada and Zuidgeest (2017), “Employed persons constituted 91% of total respondent data and the bulk of trip purpose was home-based work trips. This confirms that pedestrians who use the freeways in Cape Town are captive to route choice patterns and have no alternative means of accessing their work locations”.

The access demands vary between the economic zone areas. For instance, the very high economic attractors, are economic zones that operate 7 days a week and offer employment or other economic activities (health care) and this type of economic zones are trip attractors as they attract high NMT use. The identified Economic zones were assigned weights and analysed using weighted sum (as shown in table 4.6) to produce the Economic Criteria Map

Table 4.6 Economic Criteria Weighted Sum

| <i>Weighted Sum</i> | | |
|---------------------|---|----------------|
| Criteria | Indicators | Weights |
| Economic | FNB Stadium (<i>Seasonal trips, opens 5days per week</i>) | 5 |
| | Nasrec Expo Centre (<i>Seasonal trips, opens 5days per week</i>) | 10 |
| | Aeroton Industrial Area (<i>operates 6-7days per week</i>) | 20 |
| | Southgate Mall (<i>operates 7days per week</i>) | 20 |
| | Devland Industrial Area (<i>operates 6-7days per week</i>) | 20 |
| | Chris Hani Baragwanath (<i>operates 7days per week</i>) | 20 |
| | Johannesburg Prison (<i>Seasonal trips, opens 7days per week</i>) | 5 |

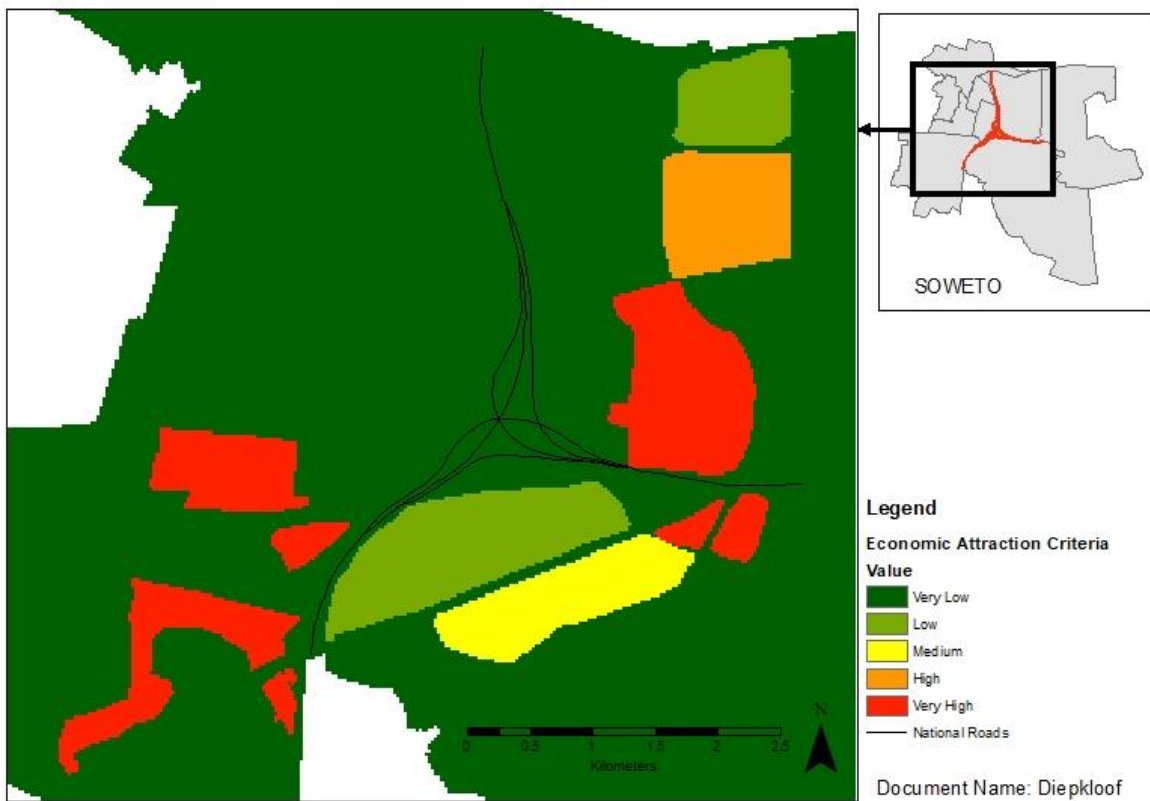


Figure 4.9 Economic Criteria Map

4.6 Policy Visions Weightings

The pedestrian crossing choice and occurrence along freeways is affected by various factors/indicators; and the influence of all factors is not the same for the entire study area and the influence of criteria map are taken according to the different policy visions.

The following policy visions were used to conduct spatial multi-criteria assessment (SMCA) also known as SMCE (Spatial Multi-criteria Evaluation), namely:

- Social Vision,
- Economic Vision,
- Equal Vision
- Transport Vision and
- Safety Vision

Multi-criteria analysis (MCA) is defined as a “technique used to consider many different criteria when making a decision” and it allows for suitability to be analysed by allowing different alternative solutions to be considered and ranked; while, spatial multi-criteria analyses (SMCA) “is used for decisions with a geographical element, most often in site selection processes where multiple factors need to be considered” (GIS People, 2019).

The spatial multi-criteria analysis was done using spatial analyst (weighted overlay), for the different visions. The weights given for the various visions were determined qualitatively using subjective rating system according to the “Expected Value Ranking method” as adopted from the study conducted by Keshkamat et al (2009) who used Integrated Land and Water Information System (ILWIS). According to Keshkamat et al (2009), the assignment of weights to the criteria maps is generally based on expert knowledge, as the expert determines the importance of criteria relative to others and this is normally supported by scientific knowledge. Therefore, each criteria map as shown in Table 4.7, is assigned a weightage depending on its influence on the location of pedestrian footbridge. The weighting used for the criteria maps were based on the “Expected Value Ranking method” from a free spatial tool Integrated Land and Water Information System (ILWIS) also used by Keshkamat (2007). The weightage shows the influence of the raster compared to the other criteria as a portion of the 100%. For instance, for the Social Vision the social criteria map in the area will have high weightage as compared to the other criteria map.

Table 4.7 Policy Visions Weighting

| Criteria/Vision | Transport Vision | Social Vision | Economy Vision | Safety Vision | Equal Vision |
|--|-------------------------|----------------------|-----------------------|----------------------|---------------------|
| Social-Deprivation Criteria Map | 15% | 52% | 6% | 15% | 25% |
| Economic Attractions Criteria Map | 6% | 6% | 52% | 6% | 25% |
| Transport Criteria Map | 52% | 27% | 27% | 27% | 25% |
| Safety Risk Criteria Map | 27% | 15% | 15% | 52% | 25% |

Transport Vision takes to account the sections of the roads with high ADT and high pedestrian crossing desire lines and aims to create a more walkable and safe crossing spaces. While the Social Vision takes to account the various factors that affect the deprivation level of a community, the higher the deprivation level the higher the at-crossing movements are expected. Whereas the Safety Vision takes to consideration the geographical locations where high pedestrian crashes occur. The Economy Vision takes to account locations along the national road network that are close to economic zones with high trip attractions and prioritises these locations more in locating a pedestrian footbridge. Lastly, the Equal Vision takes all the criteria maps to be equally important.

4.7 Data Analysis Methods

The Weighted Overlay Analysis in ArcMap Toolbox was used for data analysis to assess the best location to allocate a pedestrian footbridge. The weighted overlay is a method of modelling suitability in ArcGIS. To use this tool the following steps were applied:

- All raster data had to be reclassified and normalised to operate in the same range,
- Weights are assigned to each raster layer (criteria map) by *multiplying each raster cell's suitability value by its layer weight and totalling the values to derive a suitability value.* Assigning weights allows for the control of the influence of the different criteria.
- An output layer has values written to new cells with a symbology for these values.

Figure 4.10 shows the *Weighted Overlay* window in ArcMap with assigned weights to the percentage influence as stated in Table 4.7 above.

| Raster | % Influence | Field | Scale Value |
|------------------|-------------|--------|-------------|
| Scaled_Safety | 15 | Value | |
| | | 1 | 1 |
| | | 2 | 3 |
| | | 3 | 3 |
| | | 4 | 5 |
| | | 5 | 5 |
| | | NODATA | NODATA |
| Scaled_Social | 6 | Value | |
| | | 1 | 1 |
| | | 3 | 3 |
| | | 4 | 5 |
| | | 5 | 5 |
| | | NODATA | NODATA |
| Scaled_Transport | 27 | Value | |
| | | 1 | 1 |
| | | 2 | 3 |
| | | 3 | 3 |
| | | 4 | 5 |

Sum of influence: 100 Set Equal Influence

Evaluation scale: 1 to 9 by 1 From: To: By:

Figure 4.10 Weighted Overlay table

Using the weighted overlay (spatial analyst) five visions were analysed namely Social Vision, Safety Vision, Transport Vision, Economic Vision and Equal Vision respectively using the weights listed in Table 4.3 above. The results from the Weighted Overlay are shown below for Social Vision, Safety Vision, Transport Vision, Economic Vision and Equal Vision, respectively.

The Social Vision prioritises locations with high social-deprivation level. According to literature locations with higher social-deprivation level tend to have higher the illegal crossing actions. While the

Safety Vision prioritises locations with high safety risk, these are geographical locations where pedestrian crashes have been reported. Whereas Transport Vision prioritises locations with high transport demand. The Economic Vision prioritises locations with high economic demand. Lastly, the Equal Vision takes all the criteria to be equally important. Figure 4.11, 4.12, 4.13, 4.14 and 4.15 shows the suitable locations for pedestrian footbridge according to the various visions.

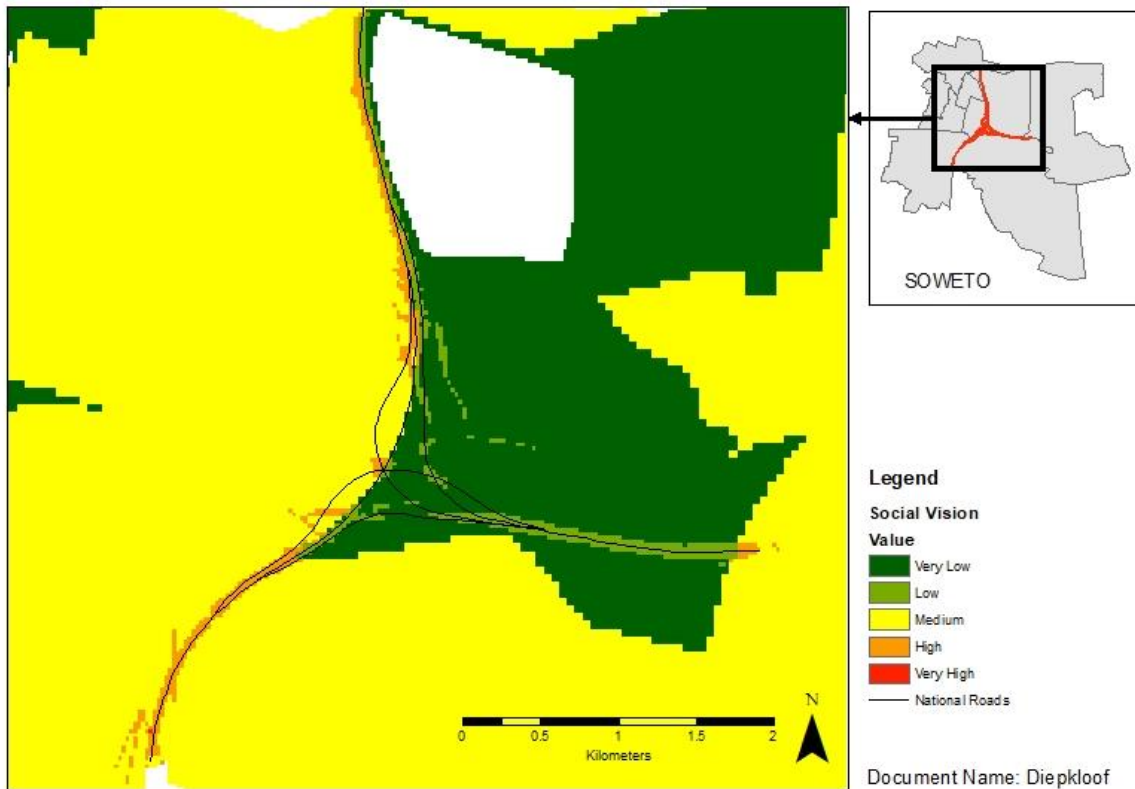


Figure 4.11 Weighted Overlay Social Vision

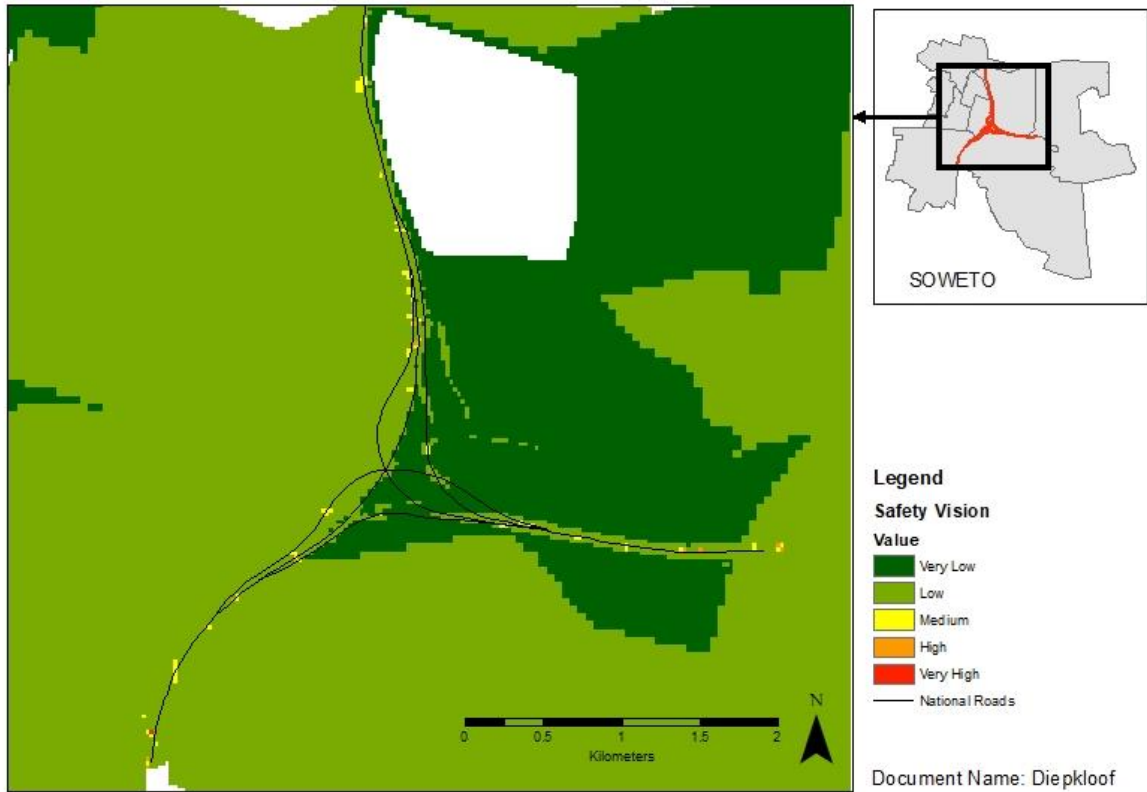


Figure 4.12 Weighted Overlay Safety Vision

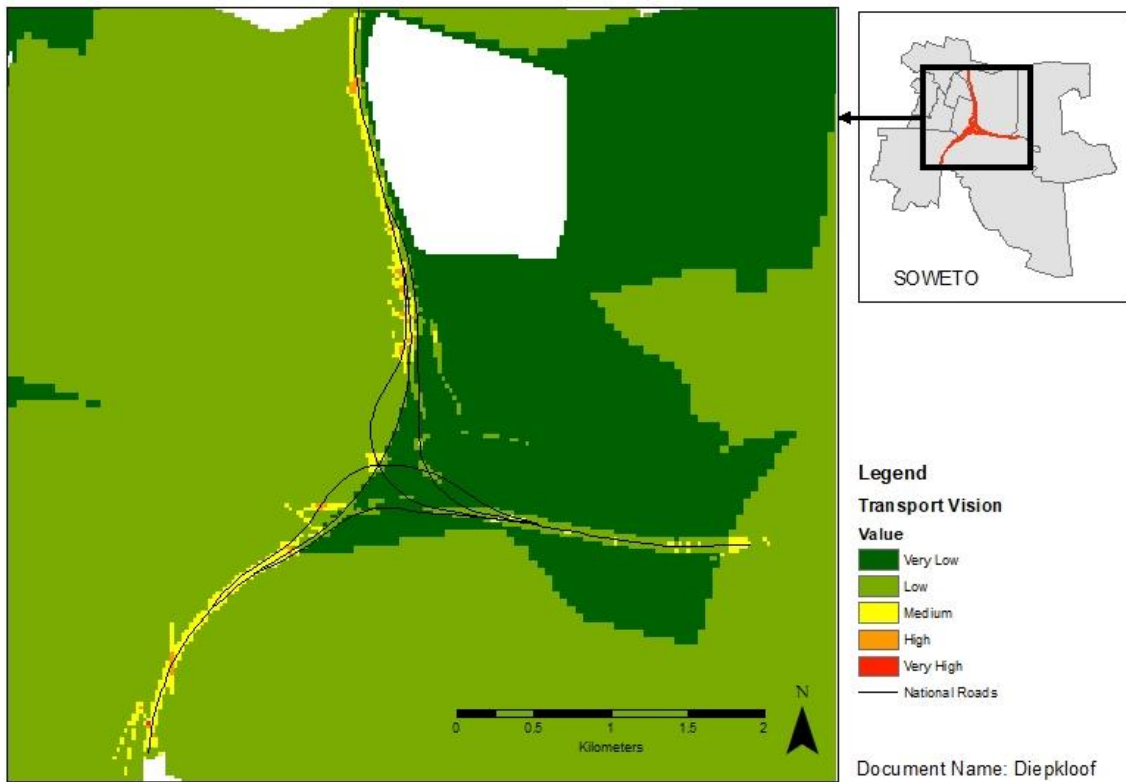


Figure 4.13 Weighted Overlay Transport Vision



Figure 4.14 Weighted Overlay Economic Vision

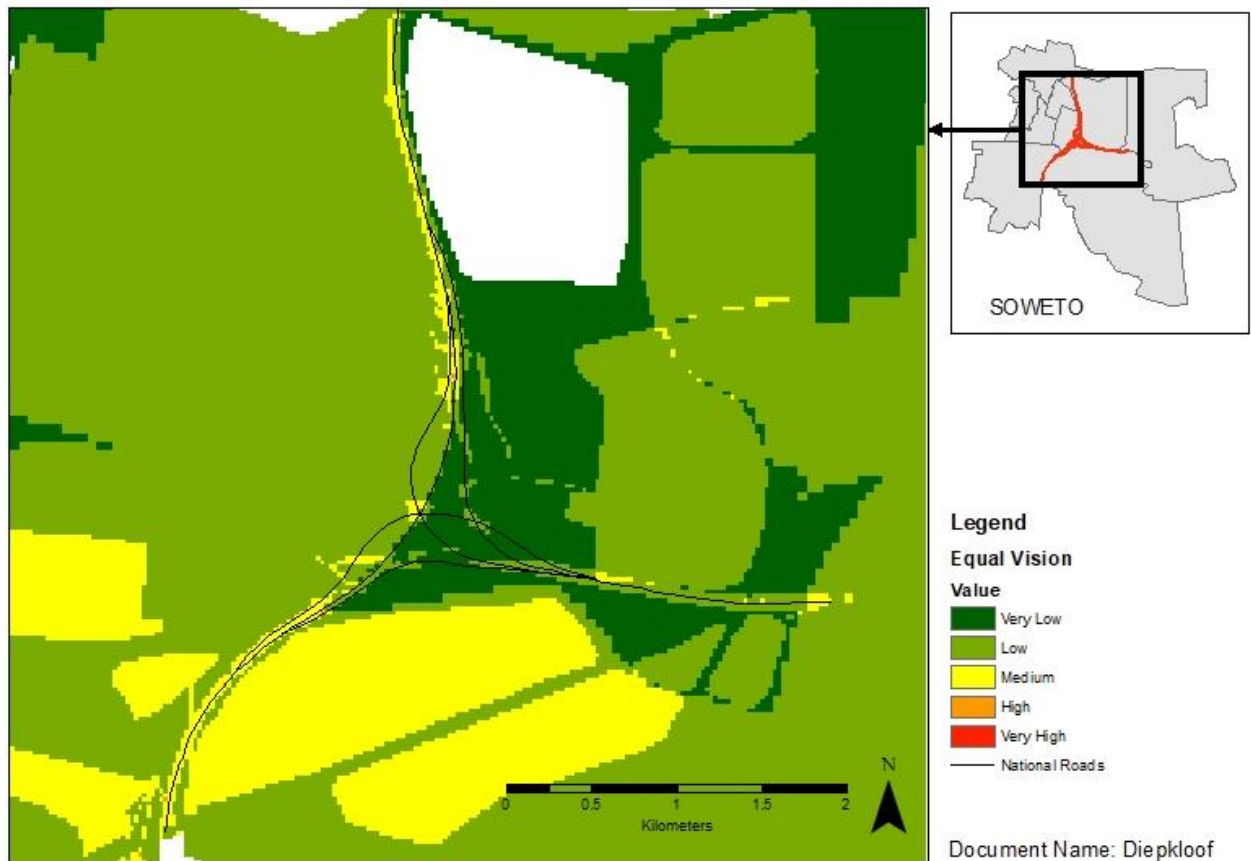


Figure 4.15 Weighted Overlay Equal Vision

4.8 Summary of Research Method

The main objective of this research is to analyse the most suitable location to allocate pedestrian footbridge along high speed roads in Northern South Africa. To achieve this a spatial multi-criteria analyses (SMCA) model is developed to analyse all indicators/factors important in the pedestrian's choice in the use and non-use of pedestrian footbridge.

SMCA promotes sustainable planning that involves an integrated analysis and avoids a narrow analysis which takes to account and focuses on limited inputs. Unlike other narrow analyses, SMCA takes to account various aspects such as the environment regulations and concerns, while integrating other equally important aspects such as transport system efficiency, safety, socio-economic demands, technical and financial viability, while also supporting stakeholder involvement (Keshkamat, 2007). Furthermore, according to Keshkamat et al (2009:55), SMCA “tools provide effective technique to assess cumulative impacts and to carry out a vulnerability or suitability analysis in order to evaluate alternative routes”. The SMCA gives priority to the path with the least impedance by differentiating between spatial benefit, cost and constraints for a given criteria. The spatial benefit defined as the criterion that contributes positively, the more you have the better it is. While spatial cost is defined as a

criterion that contributes negatively; the less you have the better it is. The spatial constraint is defined as a criterion that contributes to obstacle and are unsuitable and should be avoided, for this case study area the mine residue and interchanges were spatial constraints that needed to be avoided.

SMCA indicators are identified and analysed by allocating weights in geographic information system (GIS) to form the criteria maps. These criteria maps are used further in the data analyses to determine the suitable location. The SMCA is conducted using criteria maps developed in in ArcMap (GIS) spatial analyst for the policy visions. The policy vision maps show the most suitable location to allocate a pedestrian footbridge according to policy visions chosen.

5 Results and Discussion

Each criteria map was assigned a weight as shown in *Table 7 Policy Visions Weighting*, depending on its influence on the location of pedestrian footbridge. The results of the SMCA data analysis using weighted overlay (spatial analyst) in ArcMap toolbox are shown and discussed below.

5.1 Results of Weighted Overlay Analysis

5.1.1 Social Policy Vision

According to the weighting as per Table 6, the social policy vision accounts more weighting percentage for social-deprivation criteria map. The social deprivation takes to account the dominating dwelling type in the study area, for instance the high density of backyard or informal dwelling type the more the need for safer crossing facilities. It also takes to account the household income levels and employment status, the lower the income level and high unemployment levels the higher the need for access to improve socio-economic status

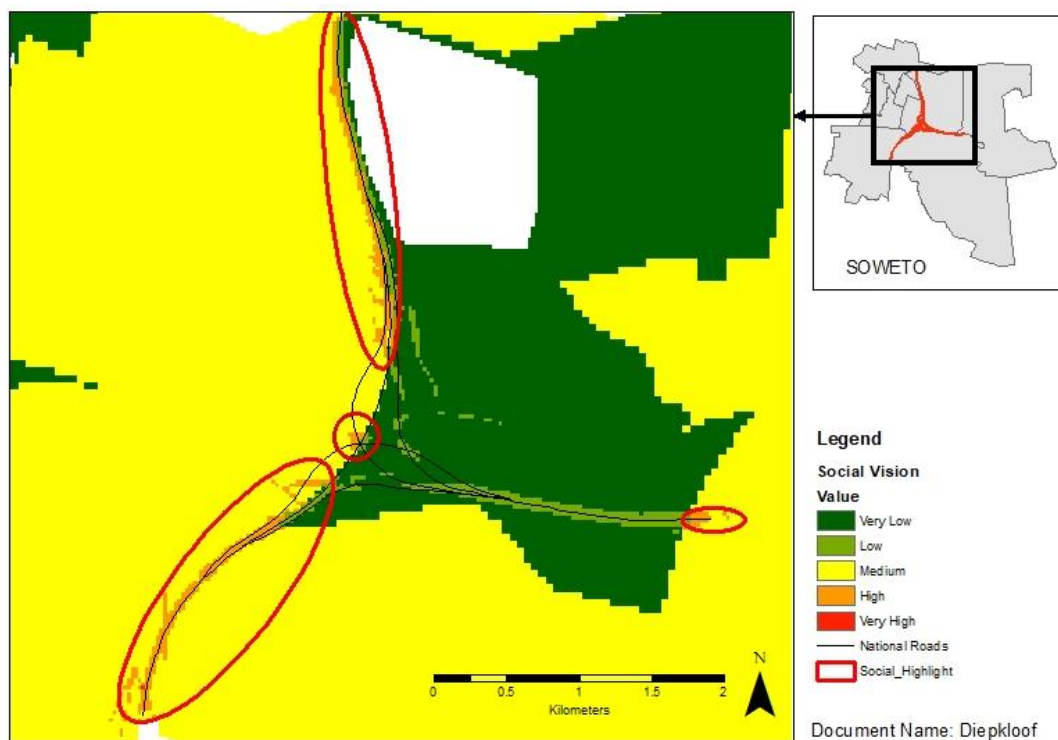


Figure 5.1 Results of Social Vision

The results for the Social Policy Vision, show that the location of pedestrian footbridge is high in the areas circled as shown in figure 5.1. These locations with high to very high values for Social Vision,

are areas where the social deprivation level and transport demand are high to very high as shown in figure 4.4 and 4.8.

5.1.2 Safety Policy Vision

According to the weighting as per Table 4.3, the safety policy vision accounts more weighting percentage for safety risk criteria map. The more prone the area is to crashes, the more risk associated with crossing illegal.

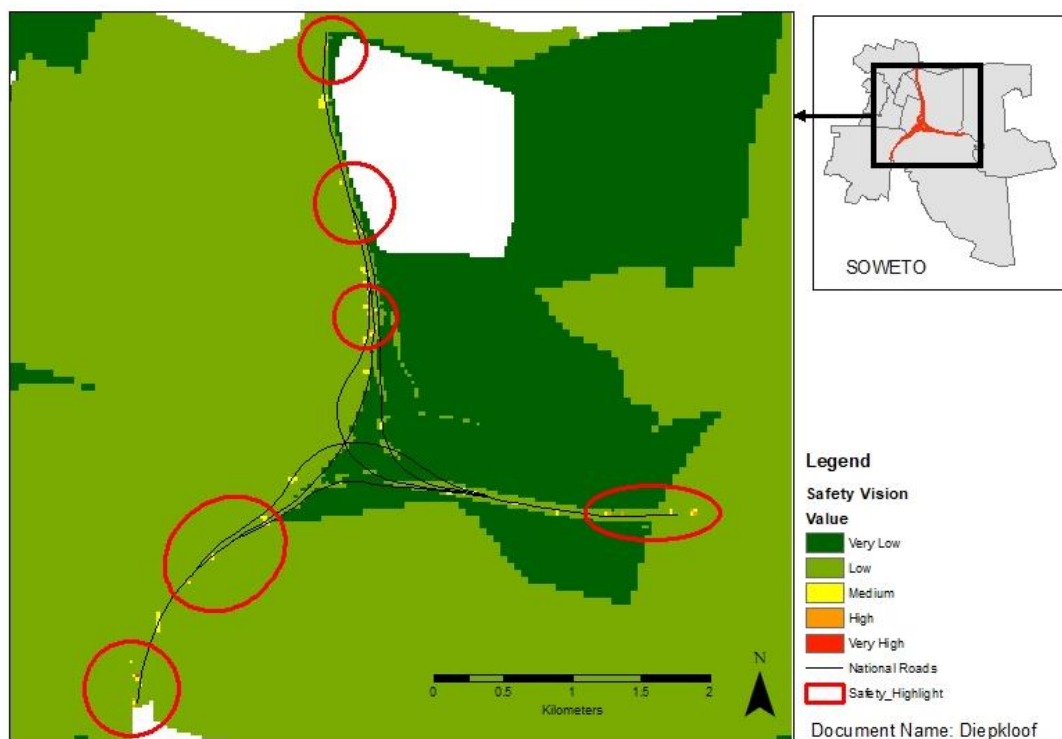


Figure 5.2 Results of Safety Policy Vision

The results for the Safety Policy Vision, show that the location of pedestrian footbridge is high in the areas circled as shown in figure 5.2. These locations with high to very high values for Safety Vision, are areas where the safety risk and transport demand criteria maps are high to very high as shown in figure 4.5 and 4.8.

5.1.3 Transport Policy Vision

According to the weighting as per Table 4.5, the transport policy vision accounts more weighting percentage for transport criteria map. The transport criteria map takes to account the current Average Daily Traffic (ADT) along the national road, all the sections of the national route within the study area

have high traffic volumes (on average 52300 vehicles per day), high traveling speed (120km/h) and number of lanes ranging from 3 – 5 per direction. Also, the transport criteria takes to account the existing pedestrian desire lines.

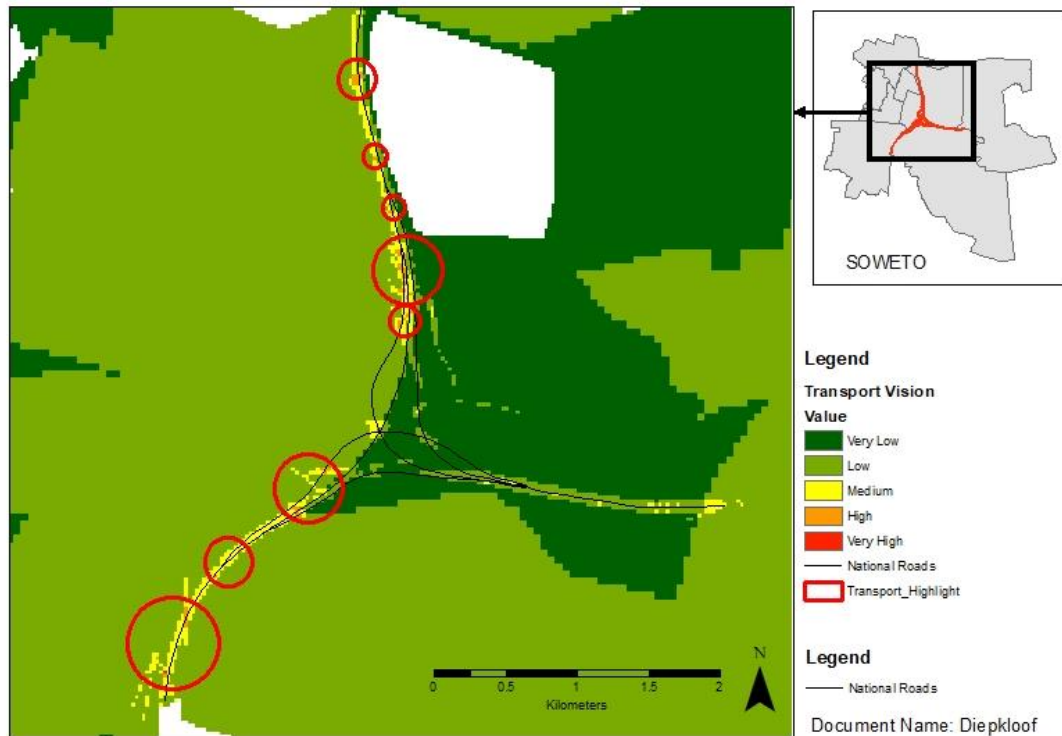


Figure 5.3 Results of Transport Vision

Figure 5.3 shows possible locations for pedestrian footbridge according to the Transport Policy Vision. The location of pedestrian footbridge is high in areas where there is non-motorised transport access demand, exposure to high traffic volumes and safety risk are high to very high as shown in figure 4.5, 4.6 & 4.7.

5.1.4 Economic Policy Vision

According to the weighting as per Table 4.3, the economic policy vision accounts more weighting percentage for economic attractions criteria map. The access demands vary between the economic zone areas. For instance, the very high economic attractors, are economic zones that operate 7 days a week

and offer employment or other economic activities (health care) and this type of economic zones will attract high NMT use.

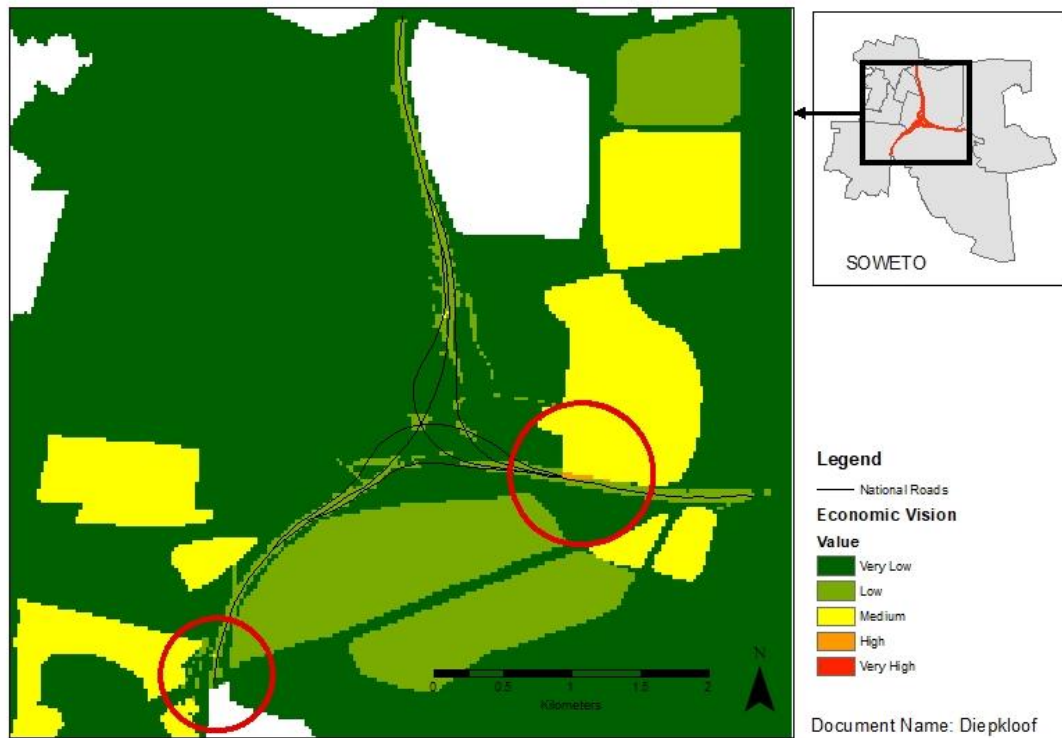


Figure 5.4 Results of the Economic Vision

Figure 5.4 shows possible locations for pedestrian footbridge according to the Economic Policy Vision. The location of pedestrian footbridge is high in areas where economic zones have high economic attraction (attract most trips as shown in figure 4.9) and transport demand (as shown in figure 4.8) are high to very high.

5.1.5 Equal Policy Vision

According to the weighting as per Table 4.3, the equal policy vision accounts for equal weighting percentage for all criteria maps (social deprivation, safety risk, economic attractions and the transport criteria maps).

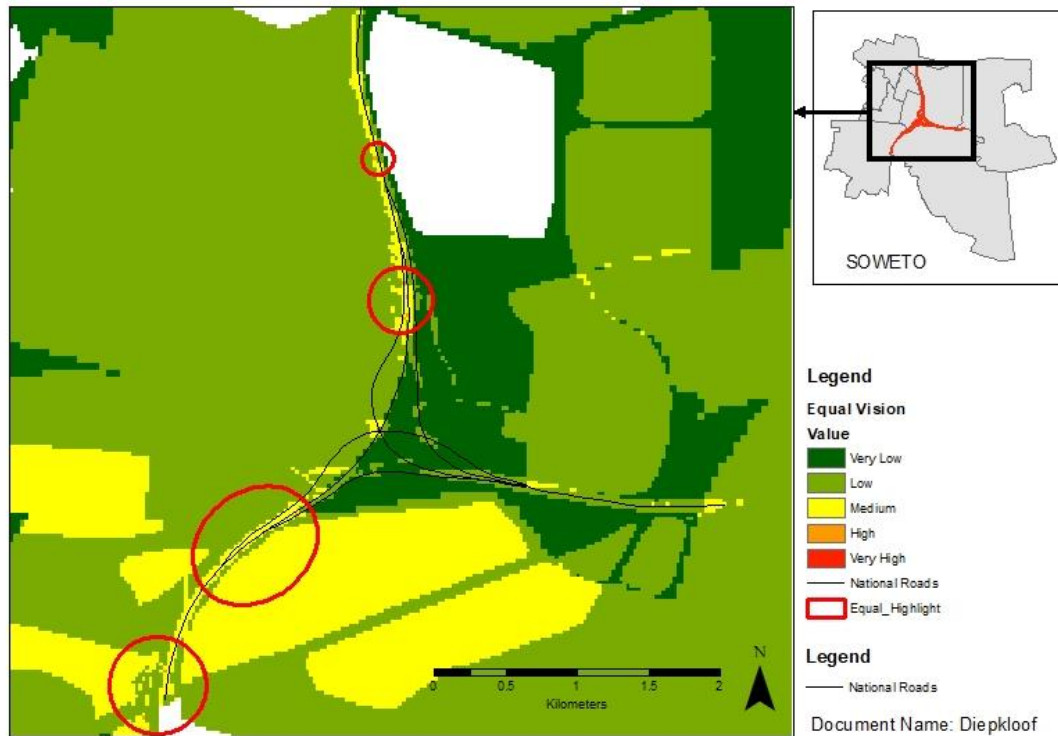


Figure 5.5 Results of Equal Policy Vision

Figure 5.5 shows possible locations for pedestrian footbridge according to the Equal Policy Vision. The locations of pedestrian footbridge are high to medium in areas where social, safety, transport and economic vision are weighed the same.

5.1.6 Weighted Overlay Results Summary

Table 5.1 shows the results of the weighted overlay analysis for all the visions, these results show the number of locations to allocate pedestrians footbridge according to the policy visions for each pedestrian footbridge location index. ranked from level five (5) to one (1) which denotes very high to very low respectively. The number of locations identified are also shown in table 5.1 with the pedestrian footbridge location index for medium (level 3) having the highest number of pedestrian locations followed by low (level 2) and high (level 4) at multiple locations within the study area. From these results the Social, Safety and Transport visions are the policy visions that have a very high pedestrian footbridge location index, (mainly located at the Devland Industrial Area).

Table 5.1 Weighted Overlay - Pedestrian Footbridge Location Index

| Pedestrian Footbridge Location Index | Number of Locations | | | | | Number of Locations |
|--------------------------------------|---------------------|---------------|---------------|--------------|------------------|---------------------|
| | Economic Vision | Social Vision | Safety Vision | Equal Vision | Transport Vision | |
| Very High (level 5) | 0 | 1 | 1 | 0 | 1 | 3 |
| High (level 4) | 3 | 31 | 17 | 10 | 22 | 83 |
| Medium (level 3) | 4 | 4 | 37 | 34 | 55 | 134 |
| Low (level 2) | 29 | 23 | 8 | 25 | 24 | 109 |
| Very Low (level 1) | 19 | 10 | 10 | 11 | 10 | 60 |
| Number of Locations | 55 | 69 | 73 | 80 | 112 | |

Table 5.2, shows the pedestrian footbridge provision. The Social, Safety and Transport visions are the policy visions that have pedestrian footbridge provision for the level 5 (very high) pedestrian footbridge location index. While all visions have pedestrian footbridge provision for level 1 – 4 pedestrian footbridge location index.

Table 5.2 Pedestrian Footbridge Provision - Weighted Overlay

| Pedestrian Footbridge Location Index | Pedestrian Footbridge Provision | | | | |
|--------------------------------------|---------------------------------|---------------|---------------|--------------|------------------|
| | Economic Vision | Social Vision | Safety Vision | Equal Vision | Transport Vision |
| Very High (level 5) | 0 | 1 | 1 | 0 | 1 |
| High (level 4) | 1 | 1 | 1 | 1 | 1 |
| Medium (level 3) | 1 | 1 | 1 | 1 | 1 |
| Low (level 2) | 1 | 1 | 1 | 1 | 1 |
| Very Low (level 1) | 1 | 1 | 1 | 1 | 1 |

5.2 Sensitivity Analysis

The results of the weighted overlay were assessed for any sensitivity using sensitivity analysis. A sensitivity analysis was carried out using the vision maps described in Section 5.1 above. According to (Hamby, no date), “sensitivity analysis only addresses parameter sensitivity relative to the point estimates chosen for the parameters held constant”. The sensitivity analysis takes account of the vision maps variability and the associated influence on model output. The sensitivity analysis was done to check for the vision maps sensitivity relative to the point estimates chosen for the locations (perspective zones/areas) held constant.

The sensitivity analysis was conducted by first identifying locations with very high, high to medium pedestrian footbridge location index for all the visions. These locations were identified using the summary results of the weighted overlay analysis. Moreover, these locations were named according to

the perspective zones/areas labelled A (A1 – A3), B (B1 – B3) and C (C1 – C3). Once these locations were identified the sensitivity analysis was conducted. To do this, all the identified perspective zones/areas were fixed while the visions maps were repeatedly varied one at a time as shown in figure 5.6, 5.7, 5.8, 5.9 & 5.10.

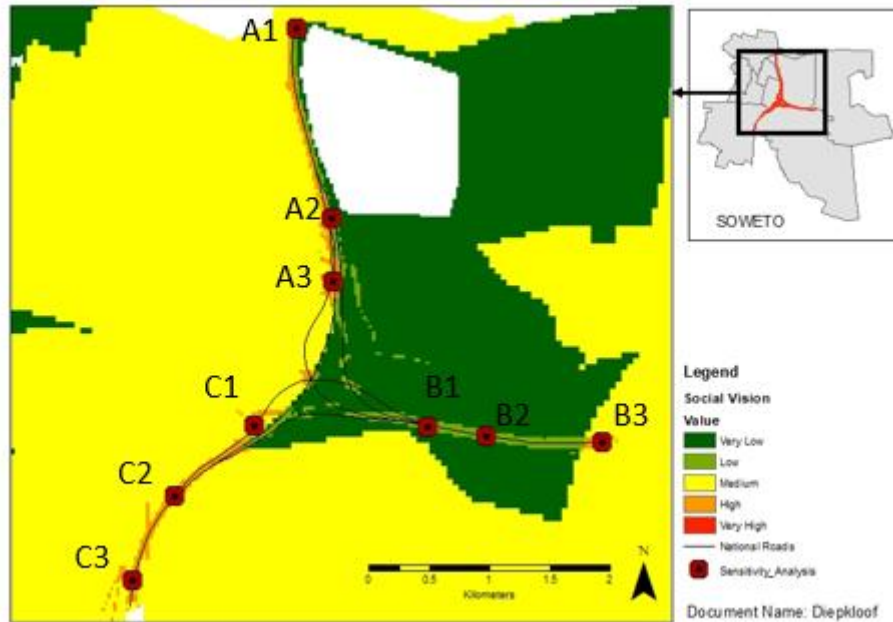


Figure 5.6 Social Vision – Sensitivity Analysis (Index)

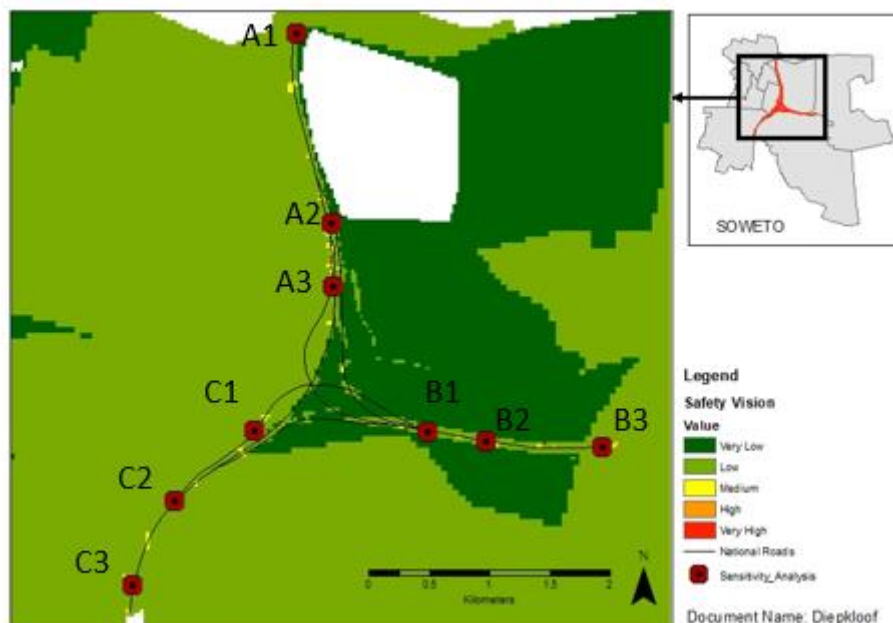


Figure 5.7 Safety Vision – Sensitivity Analysis (Index)

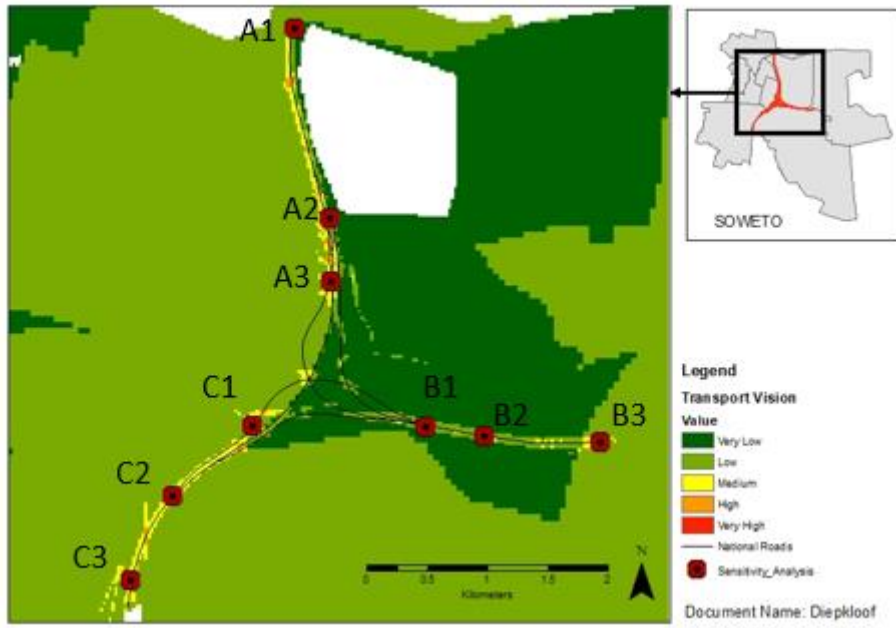


Figure 5.8 Transport Vision – Sensitivity Analysis (Index)

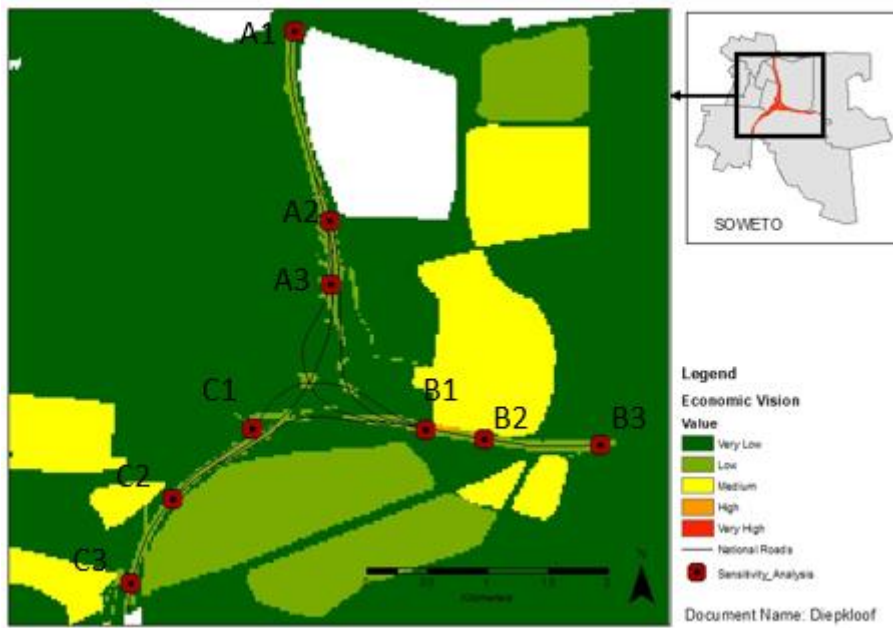


Figure 5.9 Economic Vision – Sensitivity Analysis (Index)

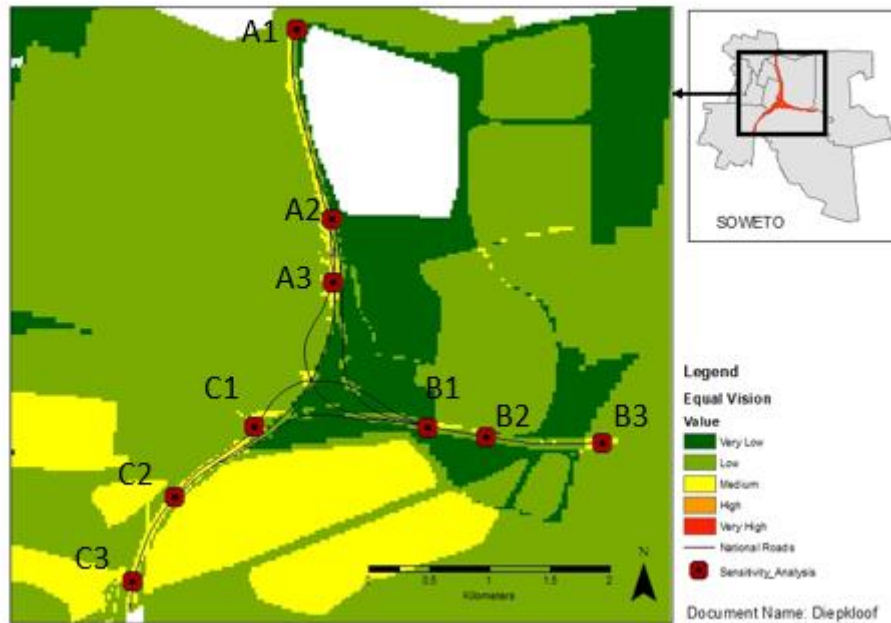


Figure 5.10 Equal Vision – Sensitivity Analysis (Index)

Table 5.3 shows the summary of results from the sensitivity analysis and pedestrian footbridge location index levels for the Economic, Social, Safety, Equal and Transport Policy Visions respectively.

Table 5.3 Pedestrian Footbridge Location Index for Sensitivity Analysis

| Sensitivity_Analysis | | | | | | | | |
|----------------------|-----------|--------|------|----------|--------|--------|-------|-----------|
| | OBJECTID* | SHAPE* | Name | Economic | Social | Safety | Equal | Transport |
| ▶ | 1 | Point | A1 | 2 | 2 | 2 | 2 | 2 |
| | 2 | Point | A2 | 2 | 2 | 2 | 2 | 2 |
| | 3 | Point | A3 | 3 | 4 | 4 | 4 | 4 |
| | 4 | Point | B1 | 2 | 2 | 2 | 2 | 2 |
| | 5 | Point | B2 | 2 | 2 | 2 | 2 | 2 |
| | 6 | Point | B3 | 2 | 4 | 2 | 3 | 3 |
| | 7 | Point | C1 | 2 | 4 | 2 | 3 | 3 |
| | 8 | Point | C2 | 2 | 4 | 2 | 3 | 3 |
| | 9 | Point | C3 | 2 | 4 | 2 | 3 | 3 |

The results from Table 5.3 are further analysed and classified using the pedestrian footbridge location index shown. Table 5.4, shows the pedestrian footbridge provision results summary of the Sensitivity Analysis..

Table 5.4 Pedestrian Footbridge Provision Results from Sensitivity Analysis

| Pedestrian Footbridge Location Index | Pedestrian Footbridge Provision | | | | |
|--------------------------------------|---------------------------------|---------------|---------------|--------------|------------------|
| | Economic Vision | Social Vision | Safety Vision | Equal Vision | Transport Vision |
| Very High (level 5) | 0 | 0 | 0 | 0 | 0 |
| High (level 4) | 0 | 1 | 1 | 1 | 1 |
| Medium (level 3) | 1 | 0 | 0 | 1 | 1 |
| Low (level 2) | 1 | 1 | 1 | 1 | 1 |
| Very Low (level 1) | 0 | 0 | 0 | 0 | 0 |

Unlike the results shown in table 5.2 (Pedestrian Footbridge Provision from Weighted Overlay), the results from the sensitivity analysis shown in table 5.4 show zero pedestrian footbridge provision for level 5 (very high) and level 1 (very low) pedestrian footbridge location index for all policy visions. While the Social, Safety, Equal, and Transport have pedestrian footbridge provision for level 4 (high) pedestrian footbridge location index.

Table 5.5 Summary of the Sensitivity Analysis Pedestrian Footbridge Location Index

| SENSITIVITY ANALYSIS Pedestrian Footbridge Location Index | | | | |
|--|----------------|------------------|---------------|--------------------|
| Very High (level 5) | High (level 4) | Medium (level 3) | Low (level 2) | Very Low (level 1) |
| | | | A1 | |
| | | | A2 | |
| | A3 | A3 | | |
| | | | B1 | |
| | | | B2 | |
| | B3 | B3 | B3 | |
| | C1 | C1 | C1 | |
| | C2 | C2 | C2 | |
| | C3 | C3 | C3 | |

High (level 4) Pedestrian Footbridge Location Index

Five locations were recorded to have high pedestrian footbridge location index, as shown in Table 5.5:

- Location A3 - is located on the South – East of the edges of the mine residue and connects to one of the key economic zones Aeroton Industrial area, SA Police Service Aeroton Vehicle Identification.
- Location B3 – is located on the East of the edges of the study area and connects to one of the key economic zones South Gate Mall.

- Location C1 – is located on the West side along multiple freeway interchanges adjacent to informal settlements (Highest deprivation level) that were not incorporated in the Stats SA 2011 data used. It connects one of the socio – economic zones Chris Hani Baragwanath Hospital and gives way to access Aeroton Industrial area, SA Police Service Aeroton Vehicle Identification.
- Location C2 - is located on the West side adjacent to informal settlements with the highest deprivation level, that were not incorporated in the Stats SA 2011 data used It connects to the following socio - economic zones: Johannesburg Prison and gives indirect access to South Gate Mall.
- Location C3 - is located on the West side at Devland Industrial Area adjacent to informal settlements. The perspective zone/area for pedestrian footbridge location also connects to the following socio - economic zones: Johannesburg Prison and gives indirect access to South Gate Mall.

Medium Pedestrian Footbridge Location Index

There are five (5) locations with medium pedestrian footbridge location index the following was deduced, as shown in Table 5.5, these locations are the same as High (level 4) pedestrian footbridge location index discussed above, namely:

- Location A3
- Location B3
- Location C1
- Location C2
- Location C3

Low Pedestrian Footbridge Location Index

There are eight (8) locations with low pedestrian footbridge location index, namely: location A1, A2, B1, B2, B3, C1, C2 and C3 as shown in Table 5.5:

- Location A1 – is located on the North edges of the mine residue and connects to key economic zones Diepkloof Clinic and FNB Stadium.
- Location A2 – is located on the South edges of the mine residue and connects to key economic zones Nasrec area, FNB stadium, Aeroton Industrial area, SA Police Service Aeroton Vehicle Identification.

- Location B1 – is located on the East and connects to key economic zones Aero-ton Industrial area and the Johannesburg Prison
- Location B2 – is located on the East and connects to key economic zones Aero-ton Industrial area, SA Police Service Aero-ton Vehicle Identification and Johannesburg Prison.

The results from the sensitivity analysis show that location A3 is not sensitive to changes in policy visions should be given first prioritisation in locating pedestrian footbridge. This should be followed by locations B3, C1, C2 and C3 and these should be given second prioritisation in allocating pedestrian footbridge.

5.3 Summary of Data Analysis

The location and allocation of pedestrian footbridge along highways is influenced by various indicators as stated in section 2.4. Some of the most important factors are high population densities adjacent to the highway, accessibility, and land-use. These indicators can influence the need for improved accessibility for the vulnerable roads users (VRUs) when accessing key socio-economic areas, public transport modes and work opportunities.

Having high pedestrian densities wanting to cross over highways may support the location and allocation of pedestrian footbridge. Also, higher economic development leads to higher travel activity.

While the land-use may determine the location for the pedestrian footbridge, the location should allow for the consistent user flow throughout the day and this will create a balanced and conducive infrastructure provision as this would meet the user needs.

The results show that there is a strong correlation between the sensitivity analysis and the weighted overlay results for locating pedestrian footbridge, as both the results show the high to medium demand in locating pedestrian footbridge adjacent to industrial (Aeroton & Devland), healthcare (Chris Hani Baragwanath Hospital) and shopping mall (Southgate Mall). The results from the sensitivity analysis show that A3 (Aeroton) should be given first prioritisation in locating pedestrian footbridge. This should be followed by locations B3 (South gate mall), C1 (Chris Hani Baragwanath Hospital), C2 (informal settlement area) and C3 (Devland) and these should be given second prioritisation in allocating pedestrian footbridge.

6 Conclusions and Recommendations

6.1 Study Objective

This study aimed at developing a pedestrian footbridge location allocation model given a set of spatial and non-spatial built-environment and socio-economic indicators. Also, the study sought to identify the factors affecting the location and allocation of pedestrian footbridge on high speed roads (freeways) with potential hazardous locations where pedestrians cross at-grade. A practical geo-spatial model was developed and used to analyse the most suitable location to allocate pedestrian footbridge. A spatial multi-criteria model has been developed by accounting for all factors important in the choice of user. Once the factors are identified the weights are allocated to form criteria maps using a Geographic Information System (GIS) to show the most suitable location to allocate a pedestrian footbridge.

This chapter serves to summarise the main points that can be concluded from the literature review and data analysis. Recommendations for further areas of study in this field, which were beyond the scope of this paper, are also discussed.

6.2 Conclusions from Literature

The following conclusions have been drawn from the literature presented:

- High urban densities have an important effect to the effective use of the pedestrian footbridge.
- Land use diversity creates a more balanced and consistent flow of user flow throughout the day.
- The higher the economic development and land use diversity across the high-speed roads this will lead to higher travel activity and could result in at-grade crossings. According to Sinclair & Zuidgeest (2016), not so much choice is given to pedestrians. As such there needs to be multiple pedestrian footbridges in proximity to the communities, they serve to offer pedestrians with alternatives and to allow pedestrians the choice to choose, to avoid confining and restricting pedestrians.
- Pedestrian footbridge should allow easy access to public transport modes and work opportunities.
- Pedestrian footbridge should be attractive, comfortable, and user-friendly system (safe to use). According to Handy (1996) and Shiver (1997) in Sisiopiku & Akin (2003), the design of pedestrian facilities should encourage walking without compromising the safety and convenience. Safety is defined in two ways, one being how safe one feels crossing on the bridge (fear of criminals) and the other being how safe one feels crossing at-grade, the safety from traffic. The pedestrian footbridge should offer the following:

- Pedestrian footbridge should be offered to the user at high frequency service with multiple alternatives along fixed lines.
- Pedestrian footbridge should allow easy access to public transport modes and work opportunities.
- Pedestrian footbridge should be attractive, comfortable, and user-friendly system (safe to use).

6.3 Conclusions from Spatial Analysis

The following conclusions can be drawn from the research problem and analyses that was conducted for the case study:

- This research supports the literature that males are more inclined to take risky behaviour than females as more males are involved in road crashes more than women in all age groups as they are more aggressive. According to Sandovic and Juozapaitis (2012) in Wu *et al.* (2014) females were found to be more likely to use the overpass, mainly because most females feel securer by using the overpass/ footbridge than crossing at-grade. The research study showed dominant gender as part of the indicators influencing the location and allocation of pedestrian footbridge for the data analysis.
- The results revealed multiple locations to allocate pedestrian footbridge along the study area.
- The results show that there is a strong correlation between:
 - land use diversity,
 - socio-economic,
 - crash hotspots/statistics (along the route),
 - vehicle traffic volume along the route and
 - population density (serviced by the pedestrian footbridge).
- The higher an area has these factors, the *Higher the Pedestrian Footbridge location index*
- Land use diversity creates a more balanced and consistent flow of users across the day to use the pedestrian footbridge, for instance the higher the economic development leads to higher travel activity.

6.4 Recommendations

Limited studies on the location and allocation of the pedestrian footbridge for pedestrians are reported in the literature, further research in this field should be considered, especially in built-up areas along the SANRAL network where there are high number of residential areas along high-speed roads, this behaviour is unique and common in South Africa.

Also, in areas where the land-use is growing linearly with the road, traffic engineers and planners through statutory policy or the road Act, should prohibit further linear growth of the township or villages along the freeways. Furthermore, where the land use is linear to the freeway, the crossing areas for pedestrians should be provided through universal accessible facilities and the location and allocation of these pedestrian footbridge should always allow the pedestrians to have more than one alternative to choose from.

It is further recommended for an improved NMT user safety future studies to improve bridge safety should be explored this should be explored for future studies.

Further, studies should be conducted to assess the location-allocation model presented in areas where there is existing pedestrian footbridge allocated. These analyses will check the location presented by the model against the existing location.

It is also recommended that future studies should assess the effects of stakeholder involvement in the location and allocating of pedestrian footbridge using the model presented in this research.

It is further recommended that future studies should use the presented model to assess areas with low traffic volumes but severe crashes statistics (hazard locations).

This research aims to add new knowledge in the limited research undertaken on at-grade crossing behaviour across high-speed roads. Further analyses are required to incorporate additional details, the distance to the nearest pedestrian crossing. For example, the lack of pedestrian crossing facilities may cause people to jaywalk. It is imperative to have research studies dedicated to address and improve pedestrian safety.

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