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IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

**Modelling freeway pedestrian crossing behaviour in
Cape Town.**

By

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Abstract

South Africa's Freeway Management System (FMS) in Cape Town has recorded an alarming increase in pedestrian activity on its freeways in recent years, with a similar trend in (fatal) freeway pedestrian crashes. Both South African and international studies have demonstrated the relevant factors that account for the choices of pedestrians to cross roadways, while few studies have looked at freeway crossing. This study was undertaken to identify and estimate the factors that influence illegal freeway crossing using a discrete choice experiment in Cape Town. It is hypothesized that freeway pedestrian crossing is driven by personal factors and the perceived contribution thereof to the risks associated with the crossing using a footbridge or (illegally) at-grade. Using a stated choice survey including a perceived crossing risk assessment to estimate a series of choice models and based on a 300 participants survey, intercepted along three Cape Town freeways, ordered-responses logit models were developed to estimate risk perception thresholds for both general risk perception (prior to the choice experiment) as well as choice – task specific risk perception. Furthermore, basic and mixed logit models were estimated for freeway crossing choice. Correlations between risk perception and the crossing choices using a Cholesky transformation matrix were established. Finally, the implied relative sensitivities, or trade-offs, between at-grade and footbridge crossing alternatives were estimated. The findings of this study confirm that, as expected, crossing choice is largely influenced by a combination of built environment, vehicular and pedestrian traffic, as well as socio-demographic characteristics. Among the 8 selected factors, traffic, walking distance and law enforcement presence were observed to be most vital in influencing the risk perception of pedestrians. Results show that younger pedestrians were more risk seeking than their older counterparts and that tenure - the length of time that a pedestrian has lived in Cape Town reduces the risk perception levels of traffic safety. Moreover, pedestrians were more likely to cross with the footbridge rather than directly under normal circumstances. As pedestrian safety is a part of policy interventions in transport, this thesis also suggests an approach to solve the problem of illegal freeway crossing. The results of this study can inform opportunities to counter the upward trend of fatalities and provide suggestions for policy-making, interventions and campaigns that would lead to improved freeway crossing safety.

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Abbreviations

MLM – Mixed logit model

BNL – Binary Logit

OLM – Ordered Logit Model

PCB – Pedestrian crossing behaviour

FMS – Freeway Management system

DCE – Discrete Choice experiment

SC – Stated Choice

RP – Revealed preference

CAPI – Computer Aided Personal interview

CASI – Computer aided Self interview

MRS – Marginal rate of Substitution

LMIC – Low and Middle-income countries

HIC – High income countries

Glossary of terms

CONTROLLED-ACCESS – A highway type that is designed for free flow high speed vehicular traffic.

LOCAL ROADS - A Class 5 road (rural) or street (urban) carrying traffic with origins or destinations in the immediate (local) area with the main purpose of giving access to individual properties.

ARTERIAL ROADS – The purpose of the arterial roadway is to connect the local roads to the limited access roads.

LIMITED ACCESS ROADS – A controlled- access way consisting of limited or no access to adjacent property, using grade separated interchanges and prohibits regular modes of transport.

MEDIAN OR JERSEY WALLS – Medians are separators that divide between two opposing directional flow of traffic to reduce crossing distance between safe points. Jersey walls are concrete structures as medians, set up to prevent impact of vehicles moving in opposite directions. The walls or curbs also provide a safe pause for pedestrian crossers.

FENCES – Pedestrian fences also referred to as guard rails are physical separation structures used at the sides of the travelled – way to restrict pedestrian access to the roads.

PEDESTRIAN – A pedestrian is any person walking on foot or using a wheelchair.

PEDESTRIAN OVERPASS OR UNDERPASS: A grade-separated pedestrian facility, typically a bridge or tunnel structure, over or under a major highway or railroad, that allows pedestrians to cross at a different level.

ROADWAY – The portion of a highway designed and improved for use of vehicular travel. A wide space between places accessible by traffic.

SIDEPATH – A shared path located immediately parallel and adjacent to a roadway.

ROAD SAFETY INDEX – A context indicator that facilitates comparisons between road safety conditions in different countries.

GRADE SEPARATED CROSSING – A facility that allows pedestrians and non-motorized transport users to safely cross a roadway. Vehicles and pedestrians intercept at different heights in a grade-separated crossing.

Chapter One

Introduction

1.1 Background

Pedestrian crossing has been a global concern in road safety for many decades. Prior to the 21st century, transport engineering and urban planning strategies that involved road safety practices for vehicle-pedestrian collisions have been applied to drivers and passengers while ignoring the needs of the more vulnerable road users i.e. pedestrians, cyclists, etc (Tiwari, 2002). Little has been done to tackle the problem of pedestrian crash on the freeways (Sinclair & Zuidgeest, 2015). This is because freeway pedestrian crossing appears to be a minor problem in many (advanced) countries as opposed to African cities where land use policies are not strictly laid out to prevent pedestrians from accessing the freeways.

Several studies (Papadimitriou et al, 2016; Cantillo et al, 2015; Jain et al, 2014; Nteziyaremye & Sinclair 2013; Thompson et al, 2013) have analysed the interaction between independent physical factors and pedestrian behaviour on local and arterial roadways. These interventions are being applied to real time transport designs to create a safer crossing environment. However, the improvement of Road Safety Index (RSI) – defined as a composed indicator that combines the road safety outcome or output of a country – remains a focal point of global cities (Leur & Sayed, 2002) and more recently, countries have placed increased emphasis on the safety of vulnerable road users (Wegman et al, 2008).

Road casualties are the outcomes of traffic crashes in the form of severe injuries, death or minor bruises that occur from the collision of vehicles with other vehicles, a pedestrian or stationary obstacle while road fatality occurs for any person who is killed immediately or dies within the duration of 30 days following a road accident (Organization for Economic Co-operation and Development, 2012).

In South Africa, an average of 32 people among every 100,000 people are killed annually in traffic crashes (World Health Organisation, 2014). This figure is far above the global average of 17 and regional (African) average of 23 fatalities per 100,000 inhabitants. Of the 32 fatalities, vulnerable road users like pedestrians, cyclists and riders of motorized two – and three wheelers represent more than half (52%) of those killed, with pedestrians alone accounting for 37% (Peden et al, 2014).

Over a 12-month period in 2011, a total of 13,932 fatal crashes have been recorded in South Africa (Road Traffic Management Corporation, 2011). Also in South Africa, pedestrians represent the highest percentage of road users that are associated with traffic crashes (RTMC, 2011). Among the estimated 5,154 pedestrians who died in 2011, around 2,000 are killed on freeways, particularly those in the Global North, as pedestrians and freeways are not expected to coexist in any proximity to each other, while traffic legislation internationally makes it clear that freeways are designed and intended for vehicular

traffic only (Sinclair and Zuidgeest, 2015). As seen from figure 1.1, between May 2010 and September 2016 freeway pedestrian fatality figures have increased steadily from 3 to 20 in Cape Town (Cable, 2016).

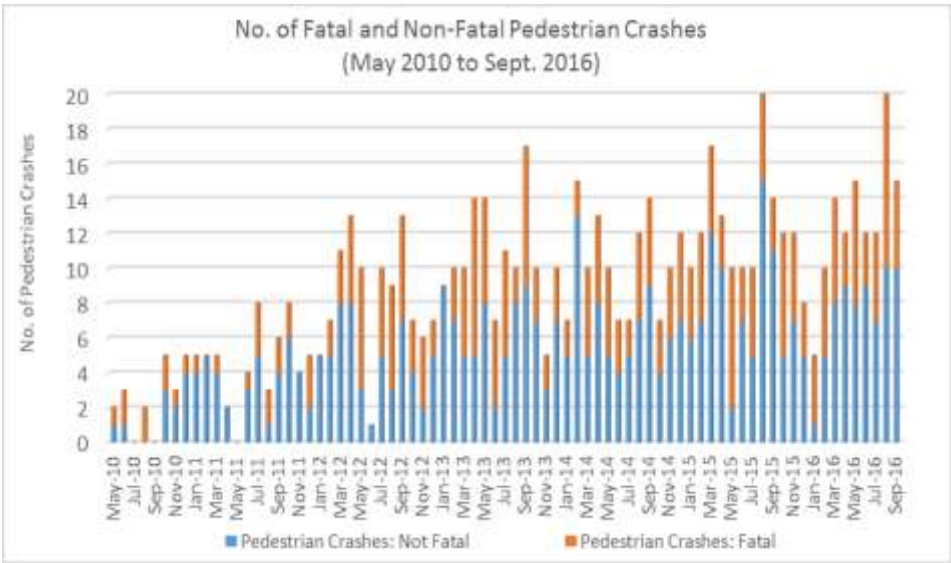


Figure 1.1 Trend of pedestrian crashes on freeways in Cape Town (Cable, 2016)

At-grade pedestrian crossing behaviour on freeways, even though illegal, cannot be looked at in isolation from a historical and contemporary context of poverty, inequality, spatial and social segregation and crime. The legacy of apartheid, where between 1960 and 1983, an estimated 3.5 million people in Cape Town were forcibly removed from ‘white’ neighbourhoods and relocated to the less desirable townships many kilometres away from the city centres without proper infrastructure and services, until today, creates a situation of spatial and transport injustice whereby workers, job seekers, students and more, are highly reliant on walking long distances (inevitably having to cross a road) and/or using paratransit modes that frequently drop and pick-up passengers in the freeway road reserve in an attempt to access opportunities that are mostly not located in the townships (Behrens et al, 2016). This combined with world-class infrastructure where speeds are high and where crime (harassment, mugging and even rape) are prevalent in and around available formal grade-separated crossing infrastructure (Sinclair and Zuidgeest, 2015) creates a context where many have to make a very inconvenient and uncomfortable choice between crossing at grade and (where available) use grade-separated footbridges.

Whilst the vast majority of pedestrians uses grade-separated infrastructure (footbridges and viaducts) to cross the freeway there is a significant minority group that can be identified as ‘choice-crossers’ choosing between at-grade and grade-separated crossing options. It goes without saying that the freeway can be placed on the highest scale for traffic – pedestrian crash impact (Tiwari, 2002), resulting in the local governments’ and roads agency ambition to develop policies for improved freeway crossing conditions.

Earlier research by Sinclair and Zuidgeest (2015) revealed that risk perception plays a role in the decision to cross at-grade or not. It is therefore that the research presented here seeks to investigate pedestrian crossing choice and the role of risk perception in a context of an highly fragile freeway crossing environment.

Since 2010, the South African National Road Agency (SANRAL) conducted surveys on the freeway to capture pedestrian activity at hourly and weekly intervals. With the help of this data, a geographic information system analysis has been carried out to identify fatality hotspots for pedestrian-vehicle collisions in terms of severity and frequency. Anticipating the use of choice modelling theory, we postulate that individuals presented with two freeway crossing alternatives consider the risks, cost and overall benefits of the alternatives before responding with a visible action in the form of a choice. This research holds out hope for effective interventions that incorporate freeway crossing behaviours and the possibility of an improvement in freeway safety if these issues are addressed adequately and systematically. Based on data received from SANRAL we extract features that are relevant to survey methods and choice modelling.

1.2 Research goals

This research analyses pedestrian crossing choices on freeways in Cape Town to obtain a better understanding of the role that the built environment and perception of risk plays in reducing illegal crossings on the freeways. Using a discrete choice approach, we determine the variable factors that influence these crossing decisions. Heterogeneity around the mean of the random parameters contained within the experiment is related to pedestrian individual attributes and risk perceptions of safety across the freeway and security on the footbridge. A framework is proposed that models the trade-offs that pedestrians make when deciding to cross either to use the footbridge or not. Understanding freeway crossing behaviour provides opportunities to counter upward trend of fatalities and provides suggestions for improved safety for roadways. Adequate information for policy-making, interventions and campaigns would lead to improved safety which has social and economic implications.

Aim of research

This study proposes to understand crossing choice behaviour of pedestrians on Cape Town freeways and the role of risk perception towards safe and unsafe modes of crossing. By developing a choice experiment and estimating a discrete choice model that delineates the trade-offs that captive pedestrians make when deciding to cross the freeways, we investigate the decision-making behaviour of pedestrians crossing freeways in Cape Town.

Objectives of study

The main objective is to conduct a stated choice experiment and develop choice models that critically examines pedestrian crossing behaviour on Cape Town freeways

Sub-objectives to this research are:

1. To determine the key factors of pedestrian choice behaviour in general and specifically in a freeway environment. To understand the risk perception connected to these factors.
2. Design and conduct a (stated) choice experiment to elicit preferences about crossing interventions for the freeway.
3. Estimate choice models of pedestrian crossing choice to forecast freeway pedestrian crossing behaviour using:
 - a. Ordered logit, taking into account the ordinal nature of responses to reveal coefficients of socio-demographics and the built-environment levels of risk perception.
 - b. Multinomial logit (MNL) to reveal coefficients of freeway choice attributes.
 - c. Mixed logit to reveal coefficients of freeway choice attribute by incorporating taste variations of socio-demographic and risk levels of traffic safety and footbridge security.
4. Identify correlation coefficients among risk perception and freeway choice.
5. Propose effective countermeasures to reduce the frequency and severity of pedestrian accidents in Cape Town based on the model outcomes.

The overall goal is to investigate factors that contribute to a person's decision to cross the freeway, and to look more closely into how these decisions are made. Understanding such decision – making processes could assist transport planners and engineers to better accommodate the needs of pedestrians, and to develop alternative and sustainable ways of accessing the city.

Research questions

Here we present questions that motivate the research.

1. Formulating the pedestrian crossing decision problem

- What factors influence the decision of pedestrians to cross illegally?
- Can the factors of high relevance be identified through literature reviews, observations and interviews?
- Based on concluded studies and interaction with experts, how do pedestrians rate the relevance of these factors?
- How are these factors related, in terms of pedestrian crossing risk perceptions?
- Do these variables correlate/interact with each other? And if so, what impact does this have on the

response ability of pedestrians?

3. Designing survey tools

- Can we understand choice behaviour by presenting hypothetical situations and observing pedestrian crossers' responses?
- How can questionnaires be constructed for optimal efficiency?
- How long does it take to complete an effective interview session?
- In what part of the day is the greatest amount of responses recorded?
- Can the survey process be optimised for increased accuracy of information?
- Will the regular way of administering choice questions be suitable for the intending market segment?
- What is the literacy level of the target populace? Are there language barriers?

4. Conducting a stated choice experiment

- How do we determine the choice pattern of pedestrian crossers on Cape Town freeways?
- What are the attributes that define the dominant factors in pedestrian crossing choice on freeways? Do these attributes adequately reflect the essential characteristics of the illegal crossing problem?
- Are these attributes subject to non-attendance (AN-A)? Can we test for systematic AN-A?
- What are the main effects and possible interactions in the experiment and how much information can be obtained from pre-tested stated preference survey?

5. Estimating binary choice models for illegal crossing choices.

- Can standard coefficients for behavioural attributes be estimated from pedestrian crossing choices?
- How do the attributes affect the decision to use the footbridge or not to use?
- Under what circumstances are pedestrians *more likely* to cross legally or not?
- What is the likelihood rate of pedestrian crossing legally? Or how likely is it that pedestrians who cross the freeways will make use of the footbridge?

6. Determining correlation of random variables

- Are the risk indicators of safety and security for mainstream and choice, correlated?
- If so, how strongly do they impact the coefficients?
- Are there significant interpretations for the correlated random variables? In other words, are the variables positively, negatively correlated or uncorrelated?

7. Accounting for heterogeneity around the mean of distribution

- Are respondents sensitive to the observed variables in the experiment?
- What changes may be observed from incorporating taste differences among respondents?
- What are the values of changing coefficients? Does this model pass goodness-of-fit tests?

8. Recommending counter-measures for freeway safety improvement policies.

- Can a realistic representation of pedestrian crossing situation be implemented in present-day policing

decisions?

- How can previously unapproachable transportation issues relating to crossing illegally be addressed through model result interpretation?
- What factors of priority can be estimated from the marginal utilities of the attributes?

9. Conclusions

- What conclusion(s) may be deduced from the wide range of model results?
- What are the limitations to research methods and experimental design observed?
- How can future research be improved for better performance?

Hypothesis statement

Predictions → if traffic causes a change in behaviour, pedestrians would most probably cross with the freeway when vehicular flow is lower. Factors such as traffic, distance, convenience, group dynamics, lighting, etc. affect the change of behaviour in freeway crossing. High traffic would mean legal crossing. This implies that, in theory, interventions relating to traffic would take priority in encouraging safe crossing attitude.

Summarily, we develop crossing choice models that speaks to modelling perception and behaviour and may be applied to freeway networks within the context of a developing country. Assumptions that inform the study and proffered solutions are highlighted below:

1. Pedestrians cross the freeway illegally

Solution: Review of existing pedestrian data for freeway crossing in Cape Town (Public dataset).

2. Certain factors influence the behaviour of pedestrian crossers on the freeway:

Solution: Identifying factors through literature review and expert opinions: Papers listed in the reference section of this thesis were used extensively to furnish information on the effectiveness of various elements of pedestrian crossing behaviour. Persons with expertise in traffic and transportation engineering were contacted and information was gathered through face-to-face discussions and via e-mail.

3. Risk perceptions play a significant role in assessing crossing choice behaviour.

Solution: Inclusion of latent variables in choice task and modelling risk perception as a function of socio-demographic and built environment variables.

4. Individual pedestrians behave differently under underlying factors of importance.

Solution: Estimating a multinomial choice model and obtaining beta values for freeway crossing choice.

5. More precise judgement can be made from responses in the freeway crossing behavior study.

Solution: Analysis of disaggregate crossing behaviours accounting for taste variation among

respondents and the correlation between risk indicators and choice.

6. A shift to safer modes of crossing is possible:

Solution: Application of model result to real life situation and recommendation for interventions and estimation of marginal utilities for choice attributes.

We aim to prove or disprove these points using tested methods in this research.

1.3 Thesis outline

Chapter 1 – Introduction. Background into the concept of freeway crossing behaviour, research aims, objectives, design and hypothesis statement.

Chapter 2 – Review of research in pedestrian crossing. What previous studies fail to address. Pedestrian crossing behaviour, Theory of planned behaviour, Survey methods, experimental design. description of case study, Random utility theory, Choice modelling, contribution to transport modelling.

Chapter 3 – Design of Stated Choice experiment, Experimental set-up. Methods of data collection, cognitive loading, Sampling, Pilot testing, Site information.

Chapter 4 – Description of data obtained in chapter 3. Freeway crossing choice as a discrete model, discrete choice models, application of crossing choice model, mathematical representation of binary and ordered logit choice model; Model results: Random effects model, covariance and significance tests. Research method

Chapter 5 – Discussion and implication of research. Interpretation of model results, risk effect on choice.

Chapter 6 – Policy recommendations, interventions, suggestions for further research, summary & conclusions.

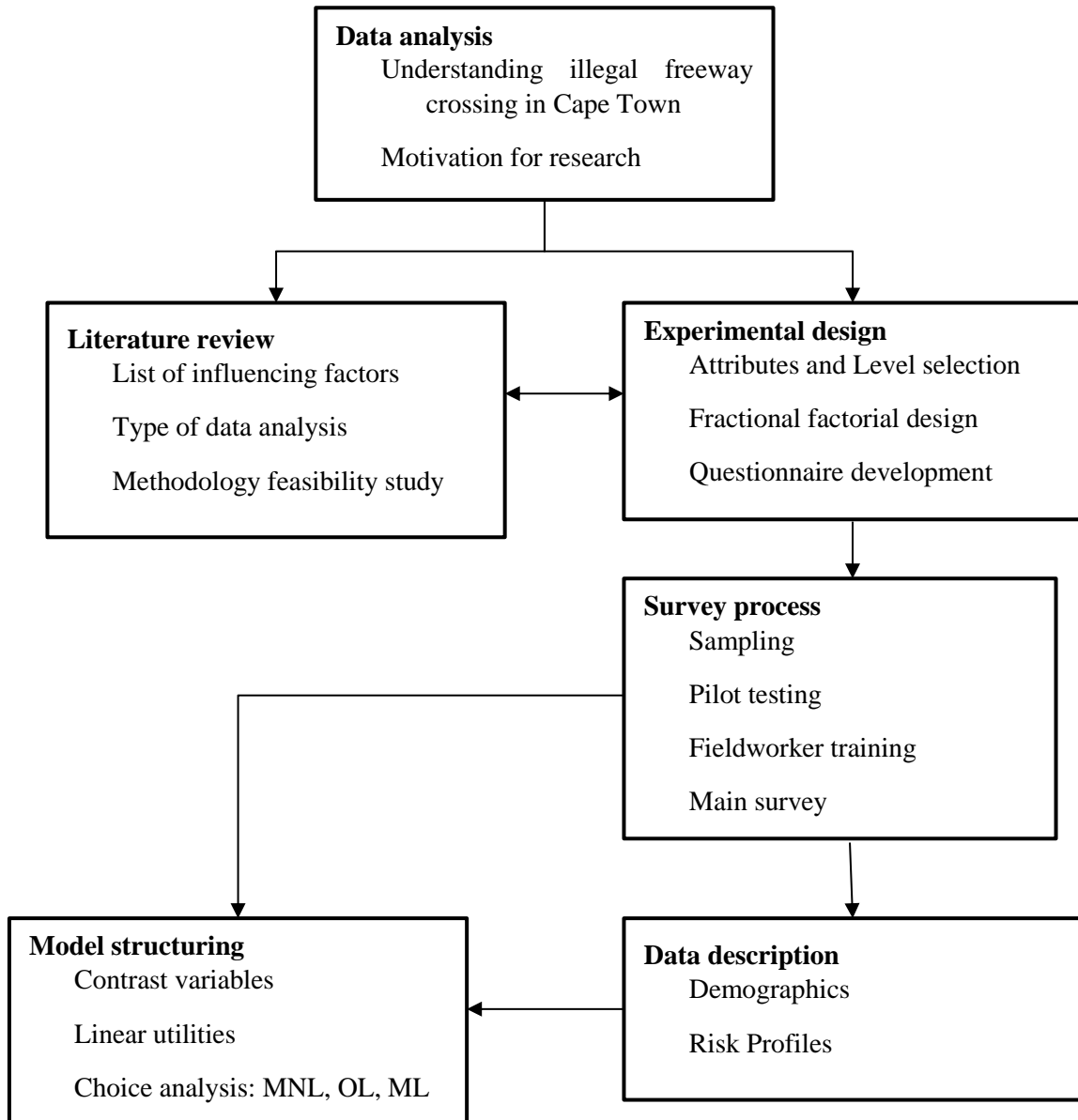


Figure 1.2 Steps in Research methodology

Chapter Two

Literature Review

As discussed in the first chapter, this research aims to investigate the relationship between factors of human and environmental influence that affect pedestrian behaviour towards legal freeway crossing. To achieve this, a choice experiment for binary crossing is developed. In this chapter, we document on a literature review into walking, pedestrian crossing on roadways, attitude towards legal crossing, traffic safety, pedestrian crossing environment, barriers to safe crossing, crossing choice behaviour, and pedestrian crossing infrastructure, as well as the theory of planned behaviour as it relates to risk perception. Finally, we conclude with a description of the key research methods used in this study and how heterogeneous methods employed in the later sections of the research.

2.1 Walking as a mode of transport

The most common activity known to man, walking has been established for centuries as a physical and social activity influenced by street patterns, infrastructure, amenities, a mixture of land use and nearness of destinations (Forsyth et al, 2008). For the majority of journeys globally, travel by foot constitute 20 – 40 % of total transport (The Organisation for Economic Co-operation and Development, OECD, 1998) and makes up about 80% of transportation for short trips. A clear distinction exists between walking for commuting in the low and middle-income countries (LMICs) and leisure walking in more advanced countries. In the high income countries (HICs), road users are inclined to use non-motorised means of transportation due to education, pedestrian-friendly roadways and awareness. However, in LMICs, walking is often more of a necessity than choice. Hallal et al (2005) investigated the purpose of walking among residents of a low and middle country and concluded that the low-income, uneducated earners have a lower likelihood of walking for leisure purposes than the higher income educated people.

This study does not focus on pedestrians who walk for healthy purposes, we rather investigate the behaviour of captive walkers in a LMIC city. This category of people are often in danger of traffic collisions and criminal attacks from crossing roadways. Traffic accidents involving pedestrians have been reported by World Health Organization (2012) to be among the top 5 main causes of unnatural deaths especially among younger people between the ages of 15 and 29 years and since safe walking is being encouraged to increase the benefits of the non-motorised transit (NMT), it is necessary to eliminate the dangers accrued to walking and crossing.

2.2 Freeway crossing environment

The standard freeway consists of limited safe crossing choices for the pedestrian (Sinclair & Zuidgeest, 2015). Urban freeways have been designed to provide full access control to vehicles but limit access to other road users. Although pedestrians are by law prohibited from walking alongside the carriageway or

running across, the condition of land use and restricted mobility options makes it impossible for pedestrians to stay off the freeway in Cape Town. For this reason, footbridges are constructed at conflict points on the freeway for safe crossing. As such, pedestrians observing oncoming vehicles may choose either of two ways to get across the freeway which is by crossing at-grade or using the footbridge. When vehicles move at a high speed, like on freeways, there is an increased probability that a crash occurs compared to pedestrian friendly roadways that are designed for local and arterial road networks.

The Freeway

Under the functional classification of the Road Access Guidelines in South Africa, freeways are high order roads and primary distributors designed to maintain separation of opposing traffic with the use of central refuge or medians (South African Road Classification and Access management Manual - SARCAM, 2012). The freeway has at least four lanes and varies by location and volume of traffic along corridors. Its primary function is to enable full-fledged mobility, high operating speed of traffic and level of service while limiting access to land use (SARCAM, 2012). Ramps and grade separated interchanges are used for entrance and exit of motorised vehicles. Figure 1.2 shows the elements of a typical freeway. The features have been highlighted below:

- **Roadside:** This feature is characterised by limited land use and may sometimes include other transport amenities along its corridors. Utility and landscape fall within these areas.
- **Travelled Way:** This represents the portion of the freeway accessed by vehicles at free flow speed.
- **Right and Left Shoulders for both Travelled Ways:** The shoulders represent an emergency stopping area at the sides of the freeway. Widths of freeway shoulders are less than 3m for urban routes.
- **Median:** Divided roadways are separated by physical barriers in form of concrete medians. The barriers separate between vehicular and pedestrian traffic and are sometimes replaced with curbs and landscaping elements.
- **Traffic Lanes:** This is the part of a roadway that is designed for use by a single line of vehicles. Traffic lanes are constructed in multiples depending on the width of carriageway/roadway.
- **Fence:** Fences are provided as guard rails for the reduction of car head-on collisions. They serve as crash prevention elements and are built to maintain stability for car movement along steep slopes. Fences provide pedestrians a safe enforcement against crossing
- **Side Slope (cut):** The gradient of a traversing slope cut between the travelled way and the roadside. A relationship between the side slope and traffic collision has emerged (Allaire, C., et al, 1996) showing that off-the-road collisions with pedestrians and roadside obstacles are heightened by inadequate flattening of side slopes. Improvising slope gradients caused a decrease in the frequency and severity of collisions.

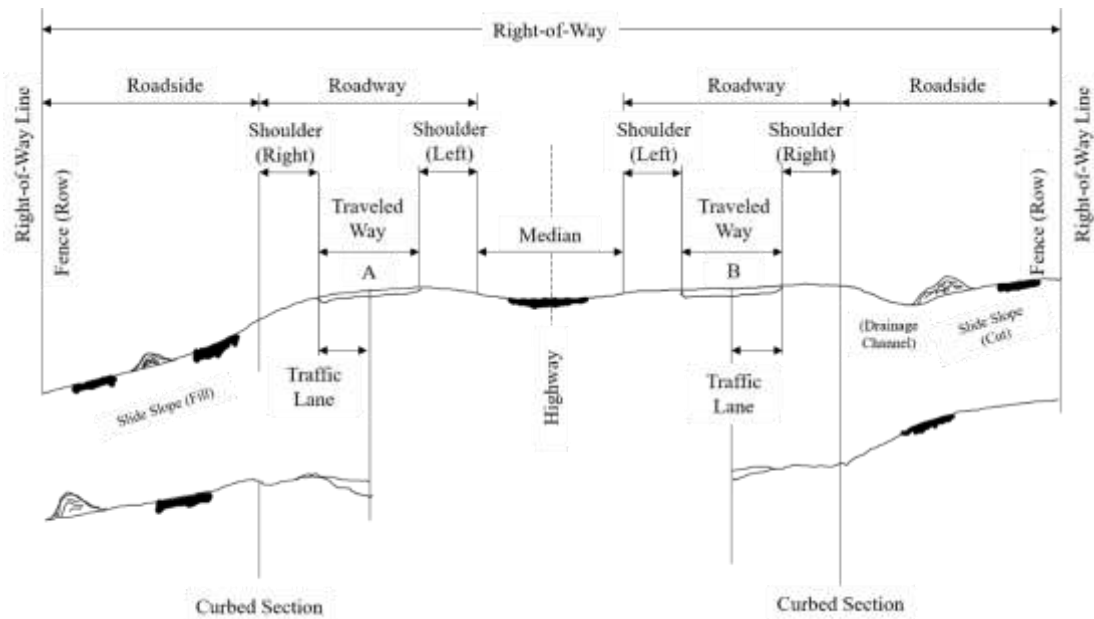


Figure 2.1 Cross-section of a freeway (Source: Federal Highway Administration, USA)

Access by pedestrians into and across the freeway is by right-of-way on the shoulders and sidewalks of carriageway. The medians and fences barriers increase pedestrian and vehicular safety and are occasionally represented as concrete jersey walls and guardrails to curtail direct access to the roadway. Hamed (2001) suggest that pedestrians tend to want to cross where it is convenient for them, and with as little delay as possible, leading to increased exposure to road casualties.

For Cape Town freeways, three de-facto ways of crossing exist: **Direct or at-grade crossing, grade-separated intersection** and **footbridge crossing**. At-grade crossing holds similar consequences for pedestrians as the violation of traffic laws on local and arterial roadways. On secondary and tertiary roads, safe crossing includes the appropriate use of crosswalks, signalised intersections and grade separated crossings. However, for freeways, the only other means of legal crossing is the use of the footbridge. Decisions for illegal roadway crossing take root in the theory of planned behaviour.

Footbridges

Footbridges are pedestrian assisted overpasses that are built to accommodate pedestrian traffic over roadways. To facilitate safe crossing for pedestrians on local and arterial roads, traffic calming devices and pedestrian assisted facilities are usually constructed. However, on controlled access roads such as freeways, the use of these devices is not possible as it would create obstructions to vehicular traffic thus negating the full use of the freeway. To resolve this challenge, pedestrian footbridges are built where grade-separated overpasses don't exist, to enable safe movement of pedestrians across the freeway while maintaining free flow of traffic.

In South Africa, construction and siting of pedestrian footbridges on the freeway is the responsibility of the South African National Road Agency Ltd (SANRAL). The process of deciding where a footbridge is placed depends on several factors which includes, but is not limited to:

1. Desire lines – usually of highest priority as it defines the coordinates of highest pedestrian activity
2. High traffic volumes.
3. Level of pedestrian activity around adjacent land use areas.
4. Sociological and cultural factors
5. Age group of expected users of the facility.

Other considerations are the location of power poles, streetlights and drainage facilities. Design of the footbridge is carefully assessed to ensure an unrestrained movement of both pedestrian and vehicular traffic. Policies and rules are set out in SANRAL's Procedures for Road Planning & geometric Design (2003) and notes that additional footbridges are erected at locations where pedestrian volumes are higher and the bridges are inadequate.

2.3 Theory of planned behaviour

The theory of planned behaviour (TPB) posits that intention is the immediate antecedent of behaviour and that TPB is a function of attitude towards behaviour, subjective norm and perceived behavioural control. These determinants follow respectively from beliefs about the behaviour's likely consequences, normative expectations of important others and the presence of factors that control behavioural performance (Ajzen, 1991). The theory suggests that people hold certain beliefs that influence a behaviour and these beliefs are most often linked to a certain outcome. The cumulative effect of these outcomes across repeated individuals lead to the formation of attitude that have subjective values.

TPB demonstrates attitudes that predict spontaneous unplanned behaviour but not deliberate actions. In other words, attitudes when combined with perceived control and subjective norms will predict actual intention that leads to deliberate behaviours.

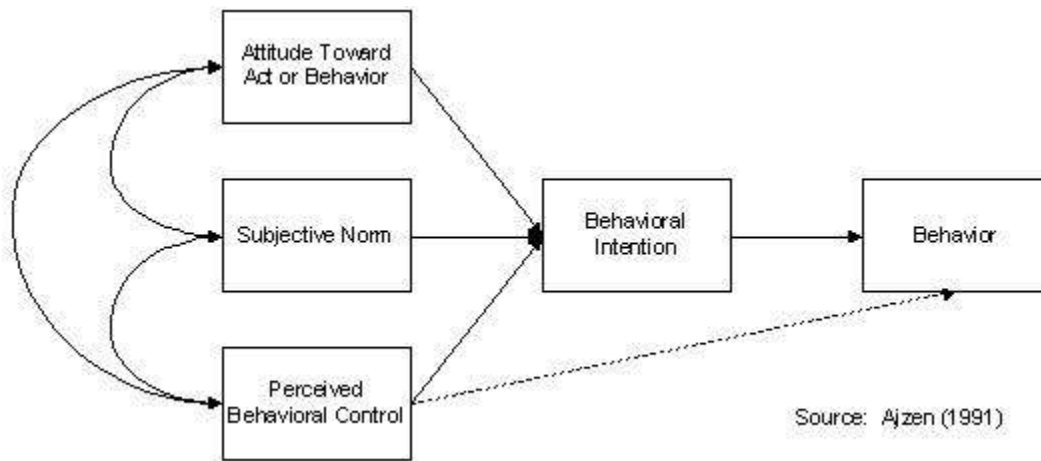


Figure 2.2 Theory of planned behaviour (TPB)

In road safety studies analysing crossing behaviours, TPB is considered a major determinant for decision-making when crossing a roadway (Evans & Norman 1998). Behavioural beliefs could either deter or favour outcomes and normative beliefs stem from peer/subjective norms. According to Diaz (2002), young people who exhibit increased traffic violations tend to possess subjective norms that are less inhibitory than adults.

2.4 Previous research on pedestrian crossing behaviour

Most literature on pedestrian crossing starts from the premise that pedestrians confine themselves to types of infrastructure where pedestrians (in general) are welcome (even though situational and behavioural factors may instigate illegal behaviour in this otherwise legal environment, for example when running red-light (Zhang et al, 2016; Tom and Granić, 2011; Rosenbloom, 2009; Cambon de Lavalette, 2009), and for which the road design anticipates and accommodates pedestrians (even when design and control issues may instigate illegal behaviour in this otherwise legal environment, see for example (Osama and Sayed, 2017; Iasmin et al 2016). Some research looks into the type of users and their habitual behaviour. Kitaori and Yoshida (2004) for example find that first time crossers are more likely to cross legally than routine crossers implying that the behaviour of surrounding people strongly predicts pedestrian crossing behaviour. Rankavat et al (2013), in a study carried out in Delhi, India, observed that the use of footbridges, subways and other pedestrian structures decreases with increase in age.

This is all true for legal, pedestrian controlled environments. The reality is however that in many developing countries pedestrians walk along and cross freeways at-grade as a matter of course, because (Sinclair and Zuidgeest, 2015):

- freeways provide the shortest, most efficient and most direct routes between suburbs and the city;
- freeways are obstacles to the free movement of pedestrians wanting to access locations beyond them;

- most pedestrians are captive walkers or want to access informal public transport vehicles that board and alight in the freeway road reserve;
- some pedestrians fear using footbridges because of crime.

Literature on pedestrian crossing on freeways is very limited, and indeed appears to be exclusive to a developing country/emerging economy context (with known research in Turkey, Colombia, Greece and China). Notably Oviedo-Trespalacios and Scott-Parker (2017) explored factors of pedestrians' decisions, including attitudinal factors that influence high-volume highway crossing choice in the vicinity of footbridges in Barranquilla, Colombia. Also in Colombia, Bogotá, Cantillo et al (2015) looked at latent variables around security/safety and attractiveness of the crossing facility in the choice to cross illegally or not. Räsänen et al (2007) looked at habitual behaviour of pedestrians in the use and non-use of pedestrian facilities in Ankara, Turkey. Also in Turkey, Demiroz et al (2015) looked specifically at gap acceptance and crossing times versus socio-demographics, such as age, in the decision to cross illegally in Izmir, Turkey. In Xi'an, China, Wu et al. (2014) looked at design and personal factors for crossing preferences over a major arterial in Xi'an.

Methods of analysing pedestrian crossing behaviour from previous studies

Most papers on illegal pedestrian crossing on higher-order roads use some kind of choice modelling in their approach and also all consider human factors (including risk attitudes). Papadimitriou et al (2016) developed a mixed logit model for crossing choice in Athens, Greece, and used principal component analysis to distinguish different pedestrian profiles; Cantillo et al (2015) developed a hybrid crossing choice model for Bogotá, to show time taken to arrive at a safe crossing was critical factor in pedestrian crossing behaviour. The other Colombian study by Oviedo-Trespalacios and Scott-Parker (2017) developed a logistic-regression model that includes perceptions around security and crime and distance to the footbridge. Both Demiroz et al (2015) and Räsänen et al (2007) used general statistical techniques to conclude on the road crossing choice in Turkey, while Wu et al (2014) use a binary logit model to reveal that gender, age, career, education level, license, detour wishes, detour distance, and crossing time are major contributors to crossing choice decisions.

Whilst acknowledging some of the factors that may influence crossing behaviour of pedestrians on freeways globally, the Michigan Department of Transport (MDoT, 2006) observed that the more important needs of pedestrians include:

1. Secure facilities free from criminal elements and safety hazards such as slippery surfaces.
2. Protection from traffic, accessibility of facilities to all users.
3. Convenience – direct fast route.
4. Comfortable gradients and an attractive environment.

Ribbens (2008), in the context of South Africa, adds to this that footbridges, unless properly designed may actually prove disadvantageous to the lesser population that includes the sick, pregnant women, physically disabled, aged and even those with a fear of heights. They must have appropriate ramps, smooth ground level access and hand railways.

In this context we hypothesize that freeway pedestrian crossing is driven by factors of location, design, safety, crime and the perceived contribution thereof to the risks associated with the crossing, either at-grade or grade-separated in particular footbridges.

2.5 Risk perception

Risk is the likelihood that an individual will experience the effect of danger (Short Jr, 1984). The inclusion of known risk is a concept that has been repeatedly implemented in risk studies across diverse research fields. Slovic et al (1986) discussed risk perception of individuals who were opposed to technological advancements. It was discovered that the perception of risk towards technology was irrelevant to the true nature of the hazard and may or may not be particularly harmful. This confirms risk perception to be relative in cognitive experiments. Risk has been discovered to be determined by experiences, emotional factors and information (Slovic et al, 1986) hence, the concepts by which risk is characterised and the accuracy of public perception is required to understand the factors underlying such perceptions. This will enable the development of more accurate management strategies. Evaluation of hazardous activities becomes necessary in determining a right approach to solving problems in the future.

Decision-making under risk has been researched extensively in literature across various fields of study including finance. When individuals are faced with risky situations, there is a tendency to lean towards the alternative that represents reduced risk. Gardner & Steinberg (2005) observed that risky decision-making behaviours decreased with age and focus is placed on the benefits rather than cost of a risky action. As posited by Wright (2013), risky decision-making is invariant across task environments and depends on the estimated levels of the alternatives. The lack of invariance subjectively reduces the validity of the result in analysis.

Therefore, risk analysis requires considerations for cognitive behaviour, previous experiences and researched theories. The risk ladder is one way to explain the levels of exposure and associated risk estimates in line with the research objectives in question (Sandman et al, 1994). The risk ladder represents risk magnitude as a degree of individual perception. As earlier mentioned, Sandman et al. (1994) used the risk ladder to emphasize risk characteristics as a means of determining how individuals perceive threat in health-related matters. Representations of risk were done by using different layers of risk on the respective ranks of the ladder. In doing this, perception at upper ranks proved to be higher

than at lower ranks regardless of the level of risk being represented. We modify this suggestion for pedestrian crossing by employing real time statistic values in the allocation of levels for risk.

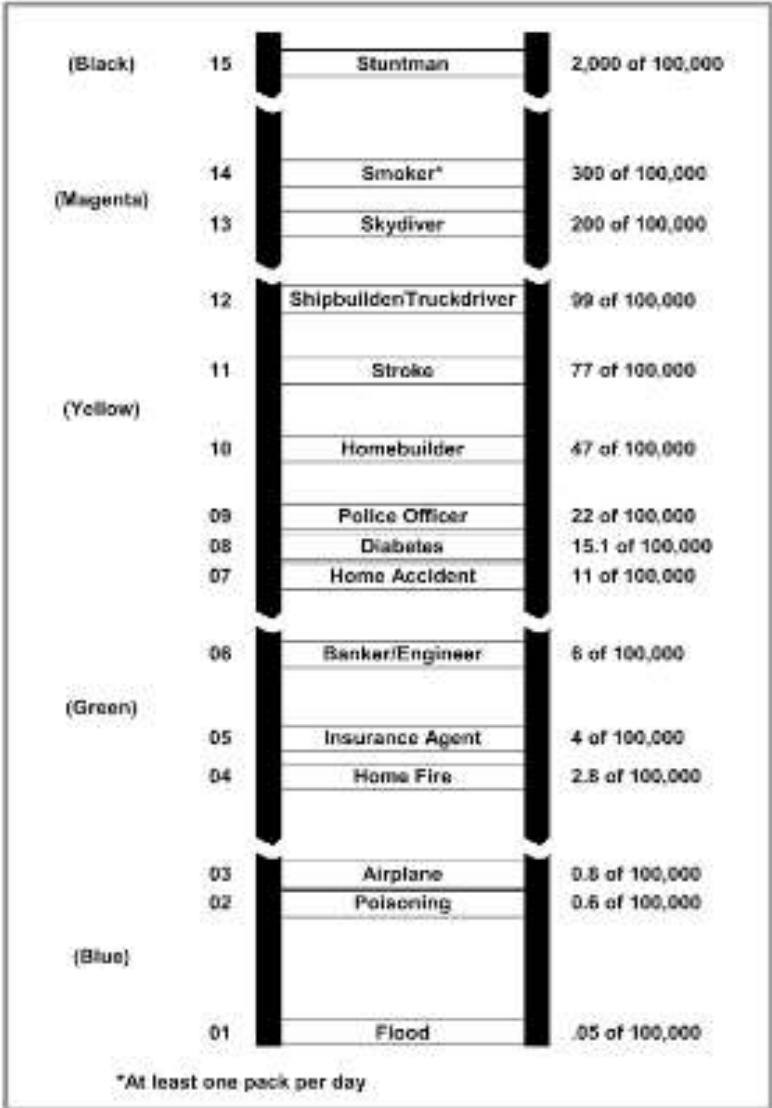


Figure 2.3 A risk ladder (Matthews, Freeman and Desvousges, 2007)

Figure 2.3 shows sequential ranks of probabilities as they relate to environmental risk. Several factors account for risk perception among individuals. Some of these factors include technical estimates which are measured from media, third party information, cultural theory, heuristics and biases. Technical risk estimates are provided by research and are the real risks that are useful for well-advised, expert and assessed risk valuation. Subjective probabilities account for heuristic risk and varies by the amount of information made available regarding the risk. A combination of real and subjective bias then form a person’s risk perception.

In selecting the statistics (as in 1 in X) that represent the level of ranking, global and local records have been used. The World Health Organization (WHO) provides ratings for health-related incidents around the world and especially in African countries. From these reports (Statistics South Africa, 2015; World Health Organization, 2013), the occurrence of events is applied and implemented for risk perception analysis.

Visual aids have been researched to reduce cognitive burden on respondents in qualitative surveys (Lindsay, 2009). This is implemented in risk ladders by the pictorial representation of levels of risk in a perception exercise. The use of known risk is relevant in eliciting accurate perception information for useful practice. Persoskie, & Down (2015) established the concept of consistency, reliability and validity in the use of ladders for estimating perceived likelihood.

2.6 Modelling freeway Pedestrian crossing behaviour (PCB)

The concept of choice in behavioural modelling stems from the theory of utility maximization which postulates that an individual would choose an alternative that provides the highest form of satisfaction. This is known as the random utility theory (RUT). RUT leads to the development of random utility models otherwise known as RUMs. Discrete choice models are derived from RUMs which implies that every decision – maker obtains a certain level of utility from the alternatives in an experiment. This decision is only known to the decision -maker. If the decision -maker chooses an alternative among the several alternatives in the task, it is assumed that that alternative holds the highest utility for him/her. A function can then be specified that expresses the observed utility of the respondent. This utility for any such respondent is given as U_{ij} where the single individual, i , chooses an alternative, j among a set of alternatives, 1, 2, 3, ... J .

2.6.1 Random utility theory

The choice of any individual within a sample set is probabilistic and may be explained by the utility theory. According to rational choice theory, individuals would choose whichever option will maximize their interests and provide them with the greatest utility, or benefit. In deciding to cross legally or not, it is assumed that the pedestrian considers alternatives in a choice process as random variable consisting of observable and unobservable parts. The observable part consists of the physical attributes of the crossing alternative. It is measurable and well defined. There are also individual attributes that account for the choices that respondents make during the choice process. These individual attributes make allowance for taste variation among heterogeneous populations. All respondents in a survey task exercise different characteristics which influence their choices individually and it's important that this is taken into consideration when estimating the utility for each person. To completely identify the utility functions in each dependent variable, there is also the need to consider uncertainties that may arise from

inadequate information about the choice process. Error components are inevitable during any experimental procedure.

The utility function for alternative grade-level in a binary choice is given by:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (2.1)$$

Where:

V_{ij} = observed part of the utility for respondent i , choosing alternative j .

ε_{ij} = unobserved part of the utility

The observed part of utility, V_{ij} is further split into the explanatory (or generic) variables and individual attributes.

$$V_{ij} = V(X_{ij}, S_{ij}) \quad (2.2)$$

Assuming a linear function for independent and dependent variables,

$$V_{ij} = V(X_{ij}) = \sum \beta X_{ij} \quad (2.3)$$

X_{ij} is the function of the deterministic explanatory variables of the alternative.

S_{ij} implies the individual characteristics of the respondents.

β is a vector of coefficients for generic attributes or marginal utilities obtained from stated data. It is assumed that the pedestrian will choose an alternative in which utility is well presented as seen from Bhatta (2011).

In a normal data where the distribution of the random variables is symmetrical and its elements are evenly spaced, the probability that an individual will select j as a subset of J alternatives in an experiment, as earlier mentioned, is given as the difference in the utilities of each alternative (Bhatta, 2011) i.e., $\forall j \neq m$ where j and m are subsets,

$$\begin{aligned} P_{ik} &= Prob[U_i(x_{ij}) > U_i(x_{im})] \\ &= Prob[V_i(x_{ij}) + \varepsilon_{ij} > V_i(x_{im}) + \varepsilon_{im}] \end{aligned}$$

$$= Prob[V_i(x_{ij}) - V_i(x_{im}) > \varepsilon_{im} - \varepsilon_{ij}]$$

therefore:

$$Prob[\varepsilon_{im} - \varepsilon_{ij} < V_i(x_{ij}) - V_i(x_{im})] \quad (2.4)$$

This is the cumulative probability of the random variable effect. Discrete choice models (DCMs) are based on a theory of choice that focuses on the interaction of several behavioural factors linked to each other. As opposed to conjoint analysis, it explains the intention towards a required action and aims to provide an understanding of how behavioural processes may lead to choice using definite and exhaustive attributes.

2.6.2 Multinomial logit model

Multinomial logit models analyse the relationship between a polytomous response variable and a set of independent variables. The logit model as a type of DCM is derived under the assumption that the unobserved error components are drawn from a multivariate generalized extreme value (GEV) distribution.

GEV or Block Maximum is culled from extreme value theory applied in risk assessment, risk value, income distribution analysis (Friederichs, 2007) and focuses on extreme or rare events. It consists of three parameters – Location (μ), scale (σ) and shape (κ). These parameters are used in describing the shape and underlying properties of the distribution. Their values determines the type of distribution. The Gumbel (Type 1 GEV), Weibull (Type 3 GEV) and Frechet (Type 2 GEV) are the different types of GEV and are defined on the basis of the distribution shape parameter. The logit model is derived under the assumption that unobserved effects are drawn from a Type 1 GEV or Gumbel distribution (Hensher et al, 2015)

For a sample distribution, $M_n = \max\{X_1 \dots X_n\}$ converging to $n \rightarrow \infty$, the shape parameter for the Gumbel distribution is set to $\kappa = 0$ while the Weibull has an upper finite endpoint (Friederichs, 2007). The implication of these lie in the estimation of parameters for any given sample set. For an estimation to take place, the random variables must be independently and identically distributed (i.i.d).

“IID conditions states that the unobserved components of utility of all alternatives in a choice task are uncorrelated with the unobserved components of utility for all other alternatives, combined with the assumption that each of the error terms has an exact same distribution.”
(Hensher et al, 2015)

The binary logit model shows the behavioural capabilities of a binary response choice outcome. In a binary choice, from equation (2.4), we have the probabilities of the respondent, i represented as:

$$P_{i1} = Prob[\varepsilon_{i2} - \varepsilon_{i1} < v_{i1} - v_{i2}]$$

$$\text{And } P_{i2} = Prob[\varepsilon_{i1} - \varepsilon_{i2} < v_{i2} - v_{i1}]$$

And we assume that the random variables, ε_1 and ε_2 are IID random variables with type -1-extreme-value (Gumbell, Weibull). It follows then that the probability

$$P_{i1} = \frac{e^{v_{i1}}}{e^{v_{i1}} - e^{v_{i2}}} \text{ or } P_{i1} = \frac{e^{v_{i1}}}{1 + e^{v_{i2} - v_{i1}}}$$

Hence,

$$P_{i1} = \frac{1}{e^{\beta'(x_{i2} - x_{i1})}} \quad (2.5)$$

And

$$P_{i2} = \frac{1}{e^{\beta'(x_{i1} - x_{i2})}} \quad (2.6)$$

In transport, policies that assist transport planners improve on existing travel systems and increase efficiency and effectiveness are being developed through choice analysis and utility maximization. MNLs have been used in the analysis of driver and pedestrian route choice (Hoogendoorn & Bovy 2004; Abdel-Aty et al, 1997; Teodorović & Kalić, 1995), Consumer behaviour (Talluri & Van Ryzin, 2004; Kamakura and Russell, 1989), risk assessment (Mehdizadeh et al, 2017; Sönmez & Graefe, 1998; Tversky and Kahneman, 1991) and pedestrian safety (Aziz et al, 2017; Lovreglio et al, 2014)

Modelling variables determine how factors need to be weighed and assessed because they are of comparable order of magnitude – in terms of overall importance – to each other. Individuals presented with alternatives tend to consider the risks, cost and overall benefit of the alternatives before responding with a visible action in form of choice. Discrete choice modelling has been used in several studies for estimating preferences among a set of consumers, commuters, patients.

2.6.3 Heterogeneity as an extension of the multinomial logit model

Mixed logit is one way of measuring probabilities for unobserved heterogeneous data. It analyses fixed and random effects of variables & takes into account the heterogeneity of parameter values among respondents allowing for a distribution in sensitivities across decision makers (Hess & Daly, 2014). It is

flexible and provides information about heterogeneity in the data while estimating unbiased parameter estimates (Greiner et al, 2014). An example is a decision maker who chooses to consistently take the bus as opposed to owning a private car but does so due to social and environmental benefits. Another decision maker under the same expectation chooses to use the bus as a result of economic restrictions. In the model, both respondents have decided to use the bus albeit motivated by different circumstances. These circumstances are not immediately observed in the experimental process and as such are tagged unobserved variables. However, they are important in estimating behaviours because a change in one or more of the conditions would lead to a change in choice. Ignoring unobserved heterogeneity omits relevant variation in the effect of observed variables. It inadvertently restricts the results to be the outcome consequent upon same rationale across all observations. In doing so, the model will be “misspecified and the estimated parameters, biased leading to erroneous inferences and prediction” (Mannering et al, 2016)

The discrete distribution among pedestrian crossers allows for individual latent classes of the respondents with the weights given by the density $f(\beta)$ of the log-normal distribution. Monte Carlo simulation, which is employed here, uses the maximum likelihood technique to estimate the probabilities of choice. It is a model whose choice probabilities can be expressed as a function of vector β following a random distribution – as opposed to a normal distribution as in MNL, with parameters Ω , and is given as:

$$P_{ni}(\Omega) = \int P_{ni}(\beta) f\left(\frac{\beta}{\Omega}\right) d\beta$$

where $P_{ni}(\beta)$ is the choice probability evaluated from the standard logit equation and $f(\beta/\Omega)$ is a density function of β given distributional parameters Ω . A generalisation is adopted by transforming the probability expression such that a new distribution is created in the form of multivariate correlation of random parameters. This correlation is made possible with the application of *Cholesky decomposition* for ordinal response models in this case. We assume separate univariate distribution for each parameter to allow for the mixing of different distributions within the same model for different random parameters (Hensher, Rose & Greene, 2015). This allowance for taste differences incorporates fixed effects and correlation between random elements.

Quasi-Monte Carlo simulations of risk choice parameters and choice probabilities are evaluated by taking draws of each of the random parameters, calculating the choice probabilities for each of the draws and averaging the probabilities over the draws (Hensher, Rose & Greene, 2015). The simulated *log-likelihood function* is then calculated using the estimations from each of the draws and maximized based on the expected likelihood.

The steps in estimating maximum likelihood simulation are as follows:

1. For the choice situation of at-grade crossing, draws are taken for each of general risk perception, choice risk and choice probabilities.
2. For each draw, the utility is calculated as normal in relation to the probability of choice in the standard logit model.
3. The simulation process is run to produce expected choice probabilities
4. Based on the parameters under consideration, the variations in collinearity are obtained

The linear form of mixed logit utility function is given as

$$U = \beta \cdot X + \alpha \cdot W + \varepsilon$$

Where β is obtained from estimation of coefficient of observed variables. X is the explanatory variable fixed parameter. α is estimated in the mixed logit as a function of individual and latent characteristics. W is the taste variation parameters for each sub category of sample distribution. It incorporates biases or preferences that permits the error component ε to be zero as reflected in the Alternative Specific constant (ASCs) which is the mean effect of all unobserved utility.

In the ML model, observations for alternative decisions are categorized into latent classes (Hess et al, 2013). The probability of observing a ranking for an individual i may be expressed as

$$\prod \Pr[y_i; \beta, p]$$

Where p represents the value of mixing proportions: risk perceptions, demographic and generic variables as a function of the alternatives' respective utilities.

The utility of choosing to cross at at-grade under mixed conditions is given as

$$U_{at-grade} = \alpha_c + \beta' X_{at-grade} + \gamma'_{at-grade} Z_{at-grade} + \varepsilon \quad (2.8)$$

$\gamma'_{at-grade} Z_{at-grade}$ represents common effects associated with the heterogenous variables. The success factor of choosing at-grade crossing over footbridge crossing remains

$$U_{at-grade} > U_{footbridge}$$

$$\beta' = \beta + \vartheta h_{at-grade}$$

$\vartheta h_{at-grade}$ is the random variation linked with parameter estimates. This random variation applies scaling and individual effects. Hence,

$$\vartheta h_{at-grade} = \exp -\tau^2 / (2 + \tau w + \delta' z)$$

τ is the scaling coefficient

$\delta' z$ represents the individual variables/random variation.

MNL as a means of identifying variations in the behaviour of a group of persons has seen development of extended models incorporating taste and individual differences in both observed and unobserved utilities. One of these advanced models is the inclusion of scale in the estimation of choice parameters. Scale heterogeneity has been researched in literature (Hess & Rose 2012; Fiebig et al, 2010; Deshazo and Fermo, 2002) and broadly covers the topic of preference heterogeneity (Hensher et al, 2015). In preference heterogeneity, random parameters are estimated alongside the standard MNL to form a generalized mixed logit model that includes variations in conditions that are associated with the random component. Hensher et al (2015) modelled the relationship between voting preferences and perceptions for mode choice in Australian cities. The inclusion of perception is observed to influence the differences in the use and non-use of public transport. Lee et al (2016) modelled risk perception and choice in a qualitative study regarding place of birth for expecting mothers. Weber and Milliman (1997) provides evidence of risk aversion and risk seeking behaviour to be prominent in preference options perceived to be more or less risky respectively. The study notes that changes in individual preferences corresponded with the changes in risk perception concluding that differences in choice and risk perceptions are systematically related.

In standard choice analysis, the number of choice situations and the characteristics of each alternative are assumed to be the same for all persons in the population. However, each person differs in unobserved utility across a weighted density $f(b)$. Hensher (2012), incorporates scale differences in scale heterogeneity using a pooled revealed and stated choice dataset to include correlations caused by repeated observations for each sampled respondent. Using a generalized mixed logit model, the variations in the variance of unobserved effect for scale and preference heterogeneity can be identified and taken into consideration.

2.6.4 Ordered-responses logit

When estimating coefficients of a standard multinomial logit model, the assumption is that all observations have equal magnitude and are in no order of sequence (Hensher et al, 2015). However, in cases where a dependent variable has more than two categories, and the value of each category has a sequential order where one value is higher than the initial one, an ordered logit model may be used (Bhatta, 2011). Ordered logit models (OLM) are employed in research that seek to measure perceptions and attitudes towards certain indicators on a response scale. The numerical values attached on a ranking order provide magnitude for lower and upper limits.

The ordered probit and logit models have a dependent variable that are in ordered categories. Examples include rating systems of poor, fair, good, very good, excellent; and opinion surveys from strongly disagree to strongly agree. Feelings of satisfaction and comfort are likewise measured using an ordered and conditional logit model. The use of OLM produces an accurate representation of data for linear functions.

In this research, as attitude towards at-grade and footbridge crossing risk were captured on a near-Likert scale using the risk ladders (the responses are ordered in the ten queried risk perception levels, varying from *not risky at all* to *extremely risky*), for each crossing alternative j , an ordered-responses logit model is estimated since the dependent choice variable (risk perception level) is of an ordinal nature. Following Train (2003) it is depicted that the risk perception level Y_j as an observed ordinal variable, which is function of the unmeasured latent variable model Y_j^* . The variable Y_j^* incorporates the socio-demographic effects, the choice scenario as well as some random variation. The effects of the latent variable model vector Y_j^* is estimated with k taste preferences β_{kj} for alternative j , in addition to the estimation of threshold points φ_i in the ordered-responses logit for $i \in [1 \dots 9]$ corresponding to the 10 (minus 1) near-Likert levels, as seen in equations 3.1 and 3.2.

$$\begin{cases} Y_j = 1 \text{ if } Y_j^* \leq \varphi_1 \\ Y_j = 2 \text{ if } \varphi_1 \leq Y_j^* \leq \varphi_2 \\ Y_j = 3 \text{ if } \varphi_2 \leq Y_j^* \leq \varphi_3 \\ \vdots \\ Y_j = 10 \text{ if } Y_j^* \geq \varphi_9 \end{cases} \text{ for } j = 1, 2 \quad (2.9)$$

and:

$$Y_j^* = \sum_{k=1}^K \beta_{knj} X_{knj} + \varepsilon_j \text{ for } j = \{1, 2\}; \forall n. \quad (2.10)$$

with β_{knj} the vector of taste preferences fixed across respondents n , X_{knj} the vector of attributes $X_{knj} = \langle X_{1nj}, \dots, X_{Knj} \rangle$ and ε_j the unobserved utility for risk perception level Y_j . Now the probability that a respondent is perceiving a risk perception level greater than l is:

$$P(Y_{nj} > l) = \frac{\exp(\sum_k \beta_{knj} X_{knj} - \varphi_l)}{1 + \exp(\sum_k \beta_{knj} X_{knj} - \varphi_l)} \text{ for } j = \{1, 2\}; \forall n. \quad (2.11)$$

Assuming that the unobserved utility terms for the crossing choice are Gumbel distributed the binary logit model that describes the modelled part of the utility V_{nj} between pedestrian utilisation and non-utilisation of the footbridge is:

$$P_{nj} = \frac{\exp(V_{n,j})}{\sum_j \exp(V_{n,j})} \text{ for } j = \{1,2\}; \forall n. \quad (2.12)$$

As the vector of taste preferences β_{knj} changes, the probability of each alternative increases depending on the sign attached to the outcome of the choice.

Goodness-of-fit

Several tests are conducted to ascertain the goodness of fit of choice models. Goodness of fit is used to compare the observed sample distribution with the expected probability distribution. In choice models, the values compare how well the statistical methods and analysis fit the data. Interdependence between observations is validated by the repetition of choice tasks across respondents. High correlation in stated preference data suggests that variance makes up for the unobserved error distribution. Akaike (AIC) and Bayesian information criterion (BIC) are the statistical tests often used in determining the goodness-of-fit for higher order models. BIC is used in a set of finite models and is best preferred at its lowest values. The AIC is closely related to BIC and is dependent on the data. It is given as:

$$AIC = 2 \log L(\hat{\theta}|y) + 2k \quad (2.13)$$

where $\hat{\theta}$ = the set (vector) of model parameters, L = the likelihood of the candidate model given the data when evaluated at the maximum likelihood estimate of θ , and k = the number of estimated parameters in the candidate model. Akaike weights are used in model averaging by representing the relative likelihood of a model. To evaluate, the relative likelihood for each of the models is calculated, i.e. $\exp(-0.5 * \Delta AIC \text{ score for that model})$. The Akaike weight for the model is this value divided by the sum of these values across all models (Burnham & Anderson, 2002)

2.6.5 Cholesky's transformation

Correlation of random parameters from the simulation of maximum likelihood has implications for interpreting model results (Hensher et al, 2015). Correlations are invoked upon increasing the number of draws in a Halton sequence - a deterministic sequence of numbers in a uniform distribution formed from simulated probabilities for individuals. Correlation is assumed to exist when simulation takes place. Hence, random parameters are independent only in the absence of a simulation of choice probabilities. However, upon including latent variables (e.g convenience, comfort, safety, security or risk), correlation is increased, and is based on the number of draws taken. Correlation is observed to exist even among attributes for decision-makers in a choice experiment (Hensher et al, 2015) hence a respondent might demonstrate trade-off between time and effort when accessing a grade-separated

crossing. This means that respondents who are less sensitive to travel time can be more sensitive to convenience and those who are less sensitive to effort are more sensitive to travel time, indicating a negative correlation between the two attributes of time & effort.

To understand the degree of correlation between estimates, a process called the Cholesky factorization or transformation is employed. Here the vector coefficient,

$$\beta_n \sim N(\beta, \varphi_r)$$

Where φ_r represents the covariance matrix of random parameters, β_n and β_n is itself a vector of normally distributed elements. All the estimates of φ_r are estimated from the model and thereafter factorized by constructing a lower triangular matrix, C, such that $\varphi_r = CC'$ where C' is the transform of the matrix C where all the upper off-diagonal elements of the matrix are zero. The number of draws for simulation is decided and multiplied through by the element of the matrix which forms a new simulated draw that shows the predicted correlation structure. The correlation structure is assessed by decomposing the standard deviation parameters into their attribute-specific and attribute-interaction standard deviations (Hensher et al, 2015). The correlation coefficient used to produce the correlation is given as:

$$\rho = \frac{cov(X1, X2)}{\sigma_{x1}\sigma_{x2}} \quad (2.14)$$

Where X1 and X2 are the independent random parameters and σ_{x1} & σ_{x2} are the standard deviations of the two parameters considered.

To obtain the correlated values between the risk perception levels, as estimated for the two risk perceptions (road or bridge) using the ordered-responses Logit, and the actual choices as modelled using the mixed binary Logit, a Choleski transformation is used for multivariate Normals to transform the set of uncorrelated variables into variables with given covariances.

The Cholesky transformation is used to show how general and task-specific risk perceptions are correlated with the actual choice making behaviour for the covariance factors.

2.7 Marginal utilities and rate of substitution

The marginal rate of substitution (MRS) in transport demand is used to measure the rate at which a commuter is willing to substitute one transport service for another (Varian, (ed.), 2010). The utility for the transport service/crossing choice often represent a group of characteristics that define each alternative e.g. travel time, convenience, cost, etc. Commuters view these characteristics by assigning priorities to each one, differently.

MRS is implemented in this research to describe the rate at which a respondent is willing to give up at-grade crossing for footbridge crossing. The utilities represented are the coefficients of independent variables of the model. Assuming k kinds of crossing means in analysis and x independent variables,

$$MRS_{ij} = -\frac{dJ}{dI} = \frac{MU_i}{MU_j} \quad (2.15)$$

Where MRS_{ij} = Marginal rate of substitution of alternative i for alternative j .

MU_i = marginal utilities of i

MU_j = Marginal utilities of j

$$\frac{MU_i}{MU_j} = \frac{\frac{\partial U(x)}{\partial x_i}}{\frac{\partial U(x)}{\partial x_j}}$$

$$\therefore MRS_{ij} = \frac{\frac{\partial U(x)}{\partial x_i}}{\frac{\partial U(x)}{\partial x_j}} = \frac{\partial x_j}{\partial x_i} \quad (2.16)$$

2.8 Design of Discrete Choice Experiments

Discrete choice models contain a definite, exhaustive number of alternatives which are mutually exclusive and contains all possible alternatives in a choice experiment (Train, 2009). The DCE is effective in providing a range of feasible and affordable policy interventions that addresses issues in the society through analysis of DCE data by indicating the effect of individual characteristics on preferences. The process of DCE involves repeated choices from choice subset and details on the number of times an alternative is chosen over the others.

In a binary choice, the individual makes a choice between two alternatives that provides a greater utility. This mostly takes place as an experiment that determines whether the individual would choose an action or not. Multinomial choices involve more than two alternatives and allows for a more elaborate specification of individual preferences.

2.9 The implementation of Stated Choice experiments over Revealed Preference surveys.

In economics, it is a usual practice to analyse preferences based on actual behaviour. This is known as the revealed preference (RP). RP is a method of measuring preferences by analysing choices made by individuals. It is completely dependent upon the observable behaviour characterised by individuals and is most often limited in variation of the choice attributes whereas stated choice (SC) experiments are quantitative techniques that are used to obtain preferences of individuals under hypothetical scenarios by representing choices that can be imagined easily in experiment. The application of revealed choice in experimental designs is known to reduce errors associated with hypothetical statements that stem from behavioural constraints (Hicks, 2002). However, RP is restricted in experimental scope, structure and measurement. There also exist a high collinearity between independent variables. For this reason, and for the fact that revealed data in this study is constrained, the stated choice method has been implemented in this study.

Stated choice experiments (SC)

SC preference methods were first introduced into marketing research in the early 1970s, and have successfully been implemented in diverse fields of study. In more recent times, emphasis has shifted to the application of preference measurement for both market and non-market goods (Hicks, 2002).

Previously, SC experiments were designed to understand behaviours in situations that made the use of revealed qualitative techniques impossible. This implies that a behaviour/attitude could be studied under conditions where the attributes do not exist yet. Analysis of qualitative attributes can be conducted when actual behaviour is unavailable or unmeasurable. Choice experiments are also employed to measure social responsiveness to these products which are yet to be made available in the market.

SC designs are created from the understanding that each product or alternative in the design possesses a unique utility that is characteristic of choice and respondents are expected to compare alternatives in a choice set. A zero difference in utility between two alternatives in a choice experiment annuls the validity/viability of that choice task. In stated choice, respondents are presented with a variety of options and asked to select the alternative that best describes their preference. This process is repeated severally in the case of panel data. SCEs use an attribute-based approach to collect data (Ryan, Gerard & Amaya-Amaya (Eds.). 2007). The hypothetical scenarios are generated from a combination of attribute levels which is assumed to define the utility of each alternative. The responses to the stated scenarios make it possible for analysis to be carried out eventually. This ascertains the probability of an alternative being chosen as a function of the independent – generic and individual attributes.

Three experimental designs in stated choice are defined. They include Orthogonal, D-efficient and S-efficient designs (Hensher, Rose & Greene 2015). The d-efficient and s-efficient designs assume prior knowledge of parameter estimates. Discrete choice studies make use of experimental designs to create

subsets of services, goods or product where a respondent, presented with a set of options chooses the most preferred alternative. The choice model is linear in nature and is be designed to provide a visual representative structure of the choice instrument.

In a conjoint analysis, all possible combinations of treatment are produced using a full factorial design. The full factorial method uses all the approved attribute levels and presents both the main effects and interactions. Main effects depict the same characteristics for each attribute in the model while the interaction effect combine two or more attributes. The full factorial design optimizes the experiment for all main, two-way and higher – order interactions that are estimable and uncorrelated (Kuhfeld et al, 1994).

Factorial design

A choice set consist of constructed subsets of all possible profiles which could either be the main effects or with interaction effects (Golek, 2005). As earlier described, a design with all possible combination of input factors is known as a full factorial design. The full factorial design for any given set of fixed attribute and attribute levels is given as L^J^K where L is the number of levels; J is the number of alternative crossing choices – binary, and K represents the number of attributes. (Hensher, Rose & Greene 2015)

Full factorial designs are not cost-effective and are highly demanding of cognition, i.e. presenting high cognitive loading on respondents during the experimental exercise. As such, it is deemed impractical. A design consisting of three attributes at four levels each will produce $4^3 = 4 \times 4 \times 4 = 64$ combinations for a full factorial design which is clearly tasking for any one individual. To solve this problem, main effects of the variables producing fewer runs are estimated in a fractional factorial design. For fractional factorial designs, which is balanced and orthogonal, each attribute level occurs equally across all factors and is orthogonal to each effect (Kuhfeld 2010). Orthogonal designs are used when the number of attributes and attribute level is minimal and where there are instances of zero priors in the experiment.

Efficient designs are used when orthogonality in the experimental design cannot be achieved. The efficient designs are flexible, superior and the d-error is lower than in the orthogonal design. Steps in generating d-efficient combinations include choosing the number of runs as decided by the analyst. D-efficient design aims to minimise all covariance of the parameter estimates while the S-efficient or Sample Size efficient design minimises the sample size required for the experiment to produce statistically significant parameter estimates. To design the D and S -efficient, assumption of priors is necessary (Hensher et al, 2015)

The steps involved in conducting a stated choice experiment according to Ryan, Gerard & Amaya-Amaya (2007) are set out below:

Characterising the choice problem

There is need to devote time and resources to understanding the problem. This forms the basis of any experiment. An experiment is the observation of the changes made to a response variable under the manipulative, scientifically guided conditions of the levels of one or more independent variable (Hensher et al, 2015). It is required that respondents be tasked with choice profiles that are easily relatable to the conditions under which the experiment is undertaken. This is especially so in the context of a developing country. The nature of investigative process and the dimensions of utility within the choices are necessary to accurately depict the choice design. Other features required are the socio-economic information of the target group and historical characteristics. Understanding these would help to predict the accuracy of the hypothesis statement.

Identifying relevant attribute and attribute levels

The systematic component of a function is determined by the thoroughness of the analyst's ability to capture all relevant factors relating to each alternative (Ryan et al, 2007) There's a need to obtain a long list of explanatory variables that form the attributes of the experiment. This list can then be narrowed down by various means to include singular options that pertain to the key component of the utilities. The levels are to be decided on the basis of respondents' familiarity to research objectives and policy relevance. Levels of attributes must be within logical reasoning and special care should be awarded for qualitative attributes in order to reduce errors due to ambiguity.

Selection of variables

The processes involved in the selection of attributes and levels in an experiment is least researched in literature. Mangham (2009) highlights the importance of policy concerns, target population experiences, published and "grey" literature review (including government reports and qualitative data) to reflect the objectives of the experiment when choosing attributes and levels. Hall et al. (2004) equally cited literature reviews and extensive qualitative research as ways of selecting these attributes in an experiment. However, the importance of considering the nature of the experiment when making these selections cannot be overemphasized.

Coast and Horrocks, (2007) focused on the development of attributes and attribute levels in the study with the use of semi-structured interviews iteratively tested for clarity and individual variation. It concluded that qualitative methods were critical for attribute selection including the choice of the number of attributes and levels. Coast et al, (2012) likewise proposes that attributes that contain latent constructs in the experiment should be avoided. An example is the use of "utility" as an attribute when investigating the utility of a product or service. This action could be detrimental to fulfilling the objective of the study and may lead to task dominance and bias responses. Other factors to avoid are the intrinsic properties of a task leaning towards a certain personality, and a deterministic rather than stochastic

structure in task development. Attributes that were selected in this research have been itemized in the succeeding chapters.

Selection of experimental design

A combination of attribute and attribute levels form “treatments”. There are step-by-step processes in the construct of an experimental design. After the problem has been identified and characterised to a satisfactory level, the experimental design may be generated. Several packages are available for generating treatments e.g. SPSS (for orthogonal designs), Ngene (for D-efficient designs), SAS, etc. these treatments are allocated columns in a choice set that would be presented as tasks to the respondents.

Several considerations for choice set design are established in Hess & Rose (2009). Examples are:

1. Rating/Ranking: This is an ordering of response variables per the level of preference.
2. Best worst ranking: An indication of best and worst preferred alternative.

We implement the rating method in this Cape Town freeway study because we are investigating ordered choice and risk attitudes.

Construction of choice sets

The presentation of choice task in an experiment is dependent on the nature of research objectives and the manner of approach required to justify the scope of research. Labelled experiments, as the name implies state directly the labels of the alternatives. Generic titles if used in the experiment (A, B, C; I, II, III, etc.) are termed as unlabelled. Labelled experiments do not require identification within the choice set and is beneficial in the restriction of bias within a choice set. Moreover, labelled experiments ignore presumed assumptions that respondents may hold regarding the alternatives.

2.5 Cognitive Burden

Cognitive processes have been researched in psychology to influence the decision-making processes of individuals (Deck & Jahedi, 2015; Nicholson & O'Hare 2014; Arentze et al 2003; Roch, 2000). The impact of complexity in survey on response rate and efficient outcomes remains a relevant issue that is being debated in several environmental, transport and economic fields. Cognitive Load Theory (CLT) suggests that humans can absorb and retain information effectively only if it is provided in such a way that it does not “overload” their mental capacity (Pappas, 2014). CLT in survey is a measure of mental effort utilized by an individual in processing certain information. In social experiments, CLT involves the understanding of questions put forth which is a factor of language, literacy and ability to draw inferences. According to DeShazo & Fermo (2002), processes in survey is rendered more efficient when questions are formulated in a manner that is accustomed to respondents. The target population for this

freeway Pedestrian Crossing Behaviour study has been established as low-income, therefore, factors such as literacy levels and cultural characteristics are carefully considered to effectively elucidate accurate responses during the surveys.

Presentation of choice tasks

Presentation of subsets could either be graphical or verbal depending on the burden of task on the target population. Hess et al, (2009) emphasised the importance of assessing fatigue and boredom in the administration of stated choice experiments. It experimented on five stated choice surveys and employed the knowledge of logit and mixed logit model to estimate the scale heterogeneity across choice tasks and found that it varied across the datasets. Results suggest that familiarization of choice task environment reduces cognitive burden likewise the inclusion of a self-administered option that is flexible. Additionally, a reduced duration of task completion helps in alleviating cognitive loading. Subtle differences in information can prevent respondents from interpreting survey information as intended (Matthews et al, 2007).

From the perspective of a developing country and specifically areas of low literacy levels, task burden may be identified by the number of treatments in a choice subset. The use of pictures aids in the accurate representation of the treatments. It is important to design experiments in such a way that inconsistency and randomness in responses can be observed and appropriately eliminated.

Graphical representation of choice tasks

The choice tasks represented graphically in previous studies are disaggregated pictures that replace attribute levels in the choice task. However only few studies have employed the use of a complete sketch that shows all the attribute levels of the treatment to be combined in one scenario. The use of scenes in experiment increases the sensory engagement of respondents enabling them to view tasks as though they were reality.

He and Gao (2015) compared two versions of surveys in verbal and graphical formats and noted significant differences in the responses towards willingness to pay (WTP). These differences did not necessarily imply better results for either of the two techniques. However, Bateman et al. (2009) employed the use of a split-sample experiment to compare standard presentations of tasks and virtual reality (VR) visualizations which was used to convey same attribute information. It was discovered that preferences obtained from the VR treatments were less variable and recorded significant reduction in willingness to pay between gains and losses for corresponding losses. VR presentations, therefore, reduces respondent prediction errors and improves the overall reliability of results.

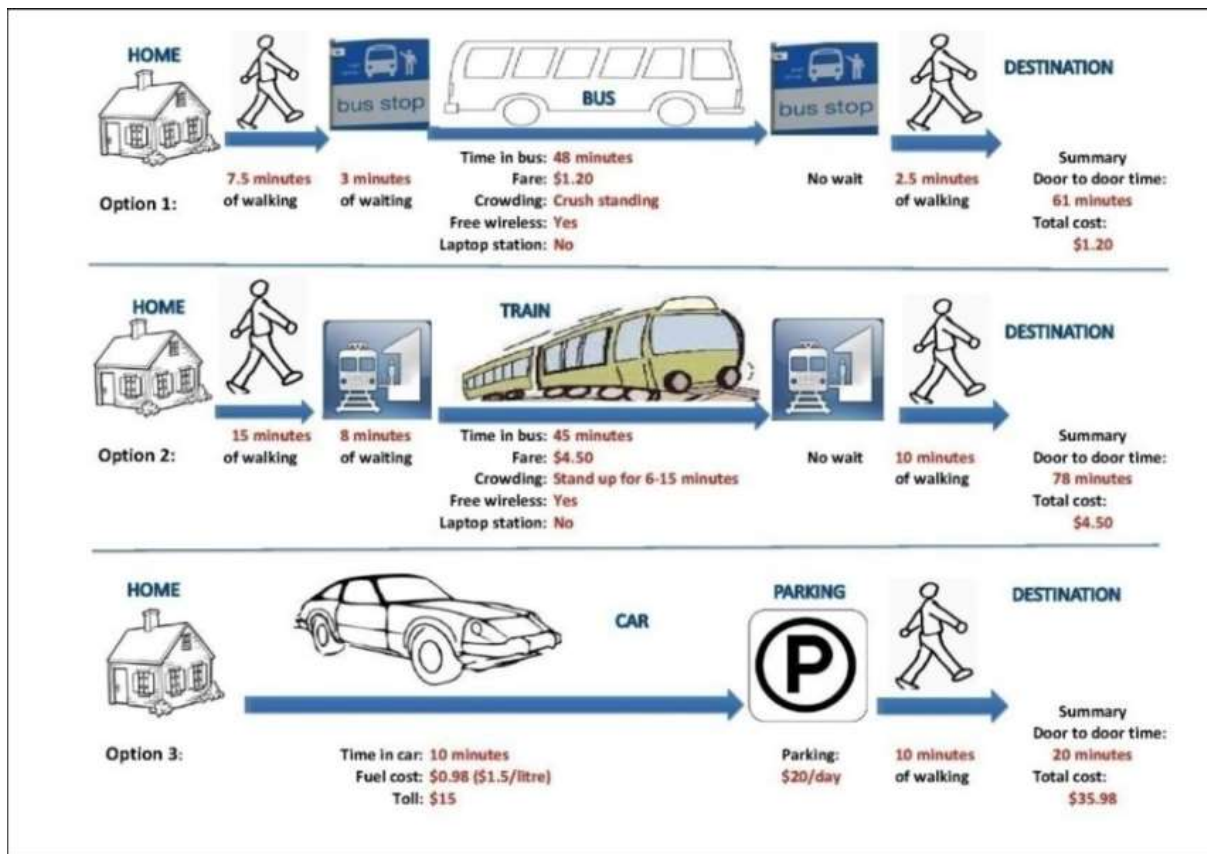


Figure 2.4 Pictorial representation of a choice card (Source: Zheng et al. 2016)

Figure 2.4 show an example of a picture + text choice card. The attribute levels significantly change for each alternative and shows different willingness to pay options for mode choice and accessibility. Alternatives for this task are mutually exclusive.

Distribution of survey tools, sampling processes, language barriers must be put to consideration for an effective survey. Kløjgaard et al. (2012) demonstrates how a qualitative process is important in effectively designing a stated choice experiment. It notes that for increased efficiency, SC experiments must be tested, validated, optimized, re-tested and revalidated to check for unknown discrepancies. Choice sets are to be randomly distributed to respondents to prevent biases from order effect. (Hensher et al, 2015) The analyst thereafter constructs the survey instrument or questionnaire to include elements that make up the entire survey. Other questions that cover the research questions are included in the survey tool and covered during the exercise.

2.11 Data collection methods: survey tools

Four survey methods in data collections have emerged in qualitative research. These are Mail interviews, Telephonic interviews, Online (Computer Aided Personal Interview) and Face to face interviews. Face to face survey: intercept surveys.

1. Mail

Easy and cost efficient. Pressure from the presence of an interviewer is reduced leading to an increased willingness to share information. The response rates are generally low for this method of data collection. Audience is limited to higher class of literacy levels and applicable only to respondents who are able to read. It is easy to misinform or give falsified answers. Moreover, the inability of the researcher to probe on questions raised provides limited responses.

2. Telephone

For many countries with a well-developed directory, telephone surveys are effective. Advantages of this method include rapid data collection, quality control, high possibility of anonymity and flexibility. However, call screening reduces the response rate of interviewees, also there's a likelihood of inattentiveness and weary exchanges leading to inaccurate responses in data.

3. Online interviews

Computer aided surveys cost much less than other methods of survey. It is automated and therefore requires less effort in administration. It is time-saving and convenient for respondents in that it allows for freedom of expression without the intrusion of a third person. Emails may be ignored and population to be reached is limited. Computer assisted interviews may be self-assessed (CASI) or Personalised (CAPI). Recent methods for computer surveys have improved and CASI has diversified to include video and audio self-interviewing.

4. Face- to – face

The face to face method of data collection implies that respondents are able to communicate verbally their thought processes. Higher response rates are recorded with longer duration for interviews. Respondents may be engaged in a more efficient manner leading to accurate collection of data. This method may be expensive, time-consuming and serves a specific need or purpose.

Sampling

The general rules of sampling when estimating sizes of target population for any study as proposed by Orme (1998) is given as

$$N \geq 500 \cdot \frac{L^{max}}{J \cdot S}$$

Where L^{max} represents the highest value of level in the experimental design, J represents the total number of alternatives and S represents the number of choice task that each respondent faces. (Rose & Bliemer 2013)

Sampling comprises defining population within the study area, choosing a frame and setting boundaries by events or incidental measures. This is involved in the probability sampling. Non-probability sampling includes purposive and quota sampling and are functions of non-response sampling.

Additionally, three dominant methods of sampling emerge in probability research. They include:

1. Simple random sampling (SRS)

In SRS, the minimum acceptable sample size is determined by the desired level of accuracy of the estimated probability (Rose & Bliemer, 2013). It represents the entire population of study area without categorizing into sub-groups.

2. Stratified random sampling (StRS)

In StRS, the population is first divided into mutually exclusive groups, each representing a proportion of the total population. These groups can be selected per market segmentation – age, location, household etc excluding choice (Rose & Bliemer, 2013). After which a random sample is drawn within each category for data representation.

3. Choice based sampling

This is a sampling procedure utilised in models where the choice distribution of a population are previously known from revealed data enabling disproportionality among non-dominant alternatives as compared with population occurrences. (Rose & Bliemer, 2013).

Stratified random sampling is a best fit for the study considering the site segmentation applied to the study area. The sampling frame is exclusive to locations surrounding the major freeways in Cape Town.

2.12 Attribute non-attendance (AN-A)

Once a data-set has been retrieved, it is wrong to assume that all the attributes have been attended to or traded-off among each other when in reality some of the attributes have been dominant and respondents have excluded other non-dominant attributes. This approach is termed attribute non-attendance. ANA causes a bias in the estimates and is important for specification accuracy. Scarpa et al (2009) modelled AN-A from a stated preference survey conducted using discrete choice models and concluded that accounting for AN-A improves goodness – of – fit and leads to substantial changes in derived estimates. Alemu et al (2013) also stated the reasons for respondents ignoring attributes in an experiment. One of these reasons is individual effect of the attribute on utility as perceived by the respondent. Others include simplified choices and rationally adaptive behaviours. The study showed AN-A as a critical challenge in survey and that ignoring its possibility would be detrimental to overall analysis.

Two approaches to detecting AN-A emerge in literature: Stated Non-attendance(SNA) and Inferred non-attendance (INA). The stated non-attendance directly questions respondents on their choice and asks if

they have ignored any of the attributes. Hensher et al. (2005) employs this in the willingness to pay analysis for travel time savings. Other studies have implemented SNA including studies analysing heterogeneity in ANA responses (Hess et al, 2013; Campbell et al, 2011). The inferred non-attendance derives the attribute non-attendance from the Latent class models (LCM) and endogenous attribute attendance model. This is as seen in (Hole et al, 2013; Hensher et al, 2012; Scarpa et al, 2012)

2.13. Summary

Since its inception in 1974 by McFadden, choice modelling has been used in the analysis of travel behaviour, market share predictions and in the simulation of diverse variety of products and services. Design of a discrete choice model involves development of a revealed or stated choice experiment. Stated choice methods allow for flexibility in choice preferences among respondents and is useful in eliciting information about hypothetical goods and services. Individuals' choices are influenced by habit, experience, environmental constraints and a lot of other unobservable factors. A range of modelling techniques have been applied in previous studies to predict the behaviour of individuals under varying conditions. Some of the choice models include the standard logit model, ordered response and mixed logit model. These models are often employed in the prediction of pedestrian behaviour on local and arterial roadways. Risk perception analysis on the other hand has been researched independently in transport models and has not yet been linked with pedestrian safety in literature. In the next chapters, we identify human and environmental factors of importance in deciding to cross legally or illegally, design a stated choice experiment due to the unavailability of revealed/observed data and estimate advanced models incorporating taste effect and socio-demographic variables. Establishing a discrete choice process in a developing city involves the consideration of cultural, language and literacy barriers. These considerations are being observed, where applicable, in this research in order to optimize effective data collection and obtain valid results. The demographic characteristics of respondents and risk perception of safety and security are included in the advanced models. Freeway crossing behaviour is vital for policy making and it is therefore necessary to accurately depict the model.

Chapter Three

Conceptual framework for the freeway PCB study

This chapter focuses on data sourced for the research and the processes involved in analysis. We also discuss the case study and highlight the conditions of the crossing environment within the freeway context. To confirm the connection between illegal crossing choice and its contributing factors., a stated choice design is developed and implemented.

3.1 Study area

The study area is the metropolitan municipality of Cape Town along the urban freeway settlement area. The major communities that can be found around the freeways include Nyanga, Langa, Khayelitsha and Mitchells plain. Languages spoken by residents of these townships are IsiXhosa, Sesotho (93% on average) and a few dwellers who communicate in English (3% average). As briefly discussed in Chapter one, illegal crossing behaviour on the freeway is linked to its historical background. The reason for the rise in pedestrian use of freeways may be traced to urban planning during the formal Apartheid and Post-apartheid era. Between 1960 and 1983, an estimated 3.5million people in Cape Town were moved from the city centre and relocated to townships many kilometres away from the city centre.



Figure 3.1 A freeway site in Cape Town

3.1.1 Housing segregation in Cape Town

Spatial engineering was implemented to divide the blacks from the whites. Infrastructures served as physical barriers to prevent an amalgamation of the racial divide. The city centre where the whites now lived was now surrounded by communities of coloured and black labour forces separated by buffer zones and natural habitats which constrained easy access from one part of the divide to the other. This arrangement implied that the local workers still held their jobs at the suburbs but had to make most trips

on foot and public transport via freeway routes, thus increasing the risk of road crashes and endangering their lives in the process. This has led to a steady rise in traffic fatality figures as documented by RTMC 2011 and STATSSA 2012. Over the years, the issue of freeway activity and crossing patterns have continued to pose a challenge to transport authorities and agencies.

However, Ribbens (2014) reports that through the years, fatality rates due to pedestrian injury have decreased. Recently, a comprehensive research was carried out to upgrade facilities through development of road design layout as well as guidelines for the placement of pedestrian facilities. Post-apartheid era had introduced plans to integrate temporal separation in the form of sidewalks, zebra crossing, traffic lights as well as overpasses and subways. At that time, guidelines and policies were developed and incorporated into the pedestrian facility manual as training and workshops held for road authorities and consulting engineers on how to use them. This plan was meant to increase traffic safety leading to a reduction in overall pedestrian accidents. It is unclear how effective this plan has succeeded as there appears to still be a high number of fatalities being recorded annually.

As per the South African Road Classification and Access Management Manual, the freeway is designed to accommodate higher capacity of vehicles in terms of flow speed and uninterrupted mobility for motorised transport. The flow rate is expected to be 70 mph or more. This automatically places the freeway on the highest scale for traffic- pedestrian impact (Tiwari, 2002). The freeway is physically divided, grade separated, has absolutely no intersections, provides on and off ramps with dual roadways which may be accessed via ramps. Moreso, Bicycles and Pedestrians are not permitted anywhere around and infrastructure and for this reason safety of vulnerable road users is compromised.

3.1.2 Current state of freeway crossing in CT

The urban poor reside along the township settlement in South African cities. These areas are the least developed and have limited access to private transport. Public transport and walking seem to be the major mode of transport for the employed and unemployed. This is because these modes afford them inexpensive journeys. They are also characterized by irregularity, discomfort and are highly unsafe. Studies carried out on pedestrian activity on the freeway confirms that illegal crossing activities are mostly recorded among the low – income earners and concludes that there lies a correlation between the urban poor communities and activity on the freeway (Cable, 2016). The survey showed that very poor settlers constituted high percentage of overall responses. Results from this, link the survey data to high number of pedestrians with low educational levels and observes that communities with higher notoriety in illegal crossing records are around Khayelitsha and Langa.

GINI inequality

The GINI coefficient is a ratio between 0 and 1 that compares the income of a population. At the value of zero, every person within the population is at the same income level. At 1, one person has all the income and others have nothing. An increasing GINI coefficient implies an increasingly uneven

distribution among the populace. In 2012, it was documented that Cape Town had the highest inequality figure in South Africa at 0.73 (Hermien, 2016). Closely following is Johannesburg at a reach of 0.72. All of South African cities reportedly scored above 0.6 showing high levels of inequality across the country. This report shows that there are significant differences between the socio-economic characteristics of the population surrounding the freeways and that of the suburbs.

As seen from table 3.1 below, pedestrian activity has almost doubled between 2014 and 2016 – the year for which a recent update is available. In an updated version of Cape Town freeway pedestrian activity reports, the Sir Lowry Pass and the freeway section along Somerset West (SSW) have the highest number of pedestrian walking alongside the carriageways. The N7 has the highest crossing activity on a typical weekday

Table 3.1 Pedestrian activity for freeways under FMS jurisdiction: 2014 and 2016 (Western Cape reports, 2016)

Activity	2014	2016
Total activity for a typical weekday	18 234	29 007
<i>Total walking along activity</i>	9 568 (52%)	18 875 (65%)
<i>Total crossing activity</i>	8 666 (48%)	10 132 (35%)
SSW along activity	1 206	4 991 (4 x 2014)
SSW crossing activity	3 505	1 874 (about half 2014)
Dunoon crossing activity	1 440	2 665 (almost double 2014)

3.1.3 Illegal crossings on the freeway

Walking alongside the freeways and eventual crossing has been a common occurrence on the freeways in Cape Town. Pedestrian freeway count was carried out to determine pedestrian movement on the freeway. These counts were conducted on all major freeways namely N1, N2, R300 and N7. The study associated with this count by the FMS aimed at understanding the choices that pedestrians make when choosing to cross at-grade. To reduce the inconvenience of pedestrians restrained by time in arriving at their destinations, short intercept surveys were conducted. Information collected included demographic, trip purpose detail and was presented to motorists and pedestrians alike. Responses were gathered during the morning and evening peak periods of weekdays. From the study, it was observed that a greater percentage of motorists confess to having witnessed a pedestrian crash or near casualty while plying the freeway. Pedestrian activity on the freeway was generally assumed by most (96%) to be highly dangerous. An acceptable assumption for the illegal crossing behaviour of pedestrians on the freeway is the “no choice” option due to unavailability of a pedestrian bridge to aid safe crossing. Many motorists claim to be aware of the dangers of a pedestrian presence on the freeway and this leads them to drive more carefully – speed reduction, in areas of high pedestrian activity.

For the pedestrians, crossing with the freeway is marked as a highly dangerous activity. However, the footbridge is only slightly less dangerous with respect to personal security and fear of armed/unarmed robbery on the footbridge especially after dark (Sinclair and Zuidgeest, 2015). Time and distance-saving is important to pedestrians who cross at - grade occasionally, a behaviour which motorists tag as being “lazy”. A good percentage of freeway crossers believe that there’s a high danger of traffic accident occurring when they cross illegally. However, the assumption is that the risk is hardly applicable to them. They hold unrealistic beliefs that a traffic fatality would happen to other pedestrians rather than for themselves.

Between May 2010 and 2016, a total of 668 crashes have been recorded on CT freeways. The footbridges at Koeberg reports an incredibly high number of pedestrian crossings. Also, the N7 freeway at Dunoon. There’s a need to understand why people are increasingly accessing the freeway instead of accessing transport from within their communities.

Factors affecting crossing behaviour

Factors affecting road traffic collisions for vulnerable users are mainly three-fold: Human factors, infrastructure/conditions of the environment and vehicular factors. The human factors constitute higher percentage of road collision factors. For this reason, education, public awareness and orientation strategies are heavily implemented in the approach to safer road behaviour. However, conditions of the environment and infrastructure are equally high influencing factors. A finite list of factors responsible for road accidents are as stated below:

1. Human factors: Pedestrians, Drivers, Motorists, Cyclers, passengers; pedestrian texting, alcohol,
2. Built environment factors: Roadway, Weather, visibility conditions, topography, and infrastructure
3. Vehicle factors: vehicle design, equipment.

We employ these factors in the design of the stated choice experiment.

3.2 Stated choice design

Among the several types of CE designs, the stated choice (SP) experiment was employed in this research due to its cost – effective techniques and increasing use in research fields. Revealed information on pedestrian crossing behaviour was inadequate in informing a modelling study. The hypothetical scenarios comprised combination of treatments presented as choice tasks to the respondents. Relevance of design elements were tested through informal discussions with transport agencies and in-depth literature review.

We noted in Chapter 3 that the factorial design records how the change in factor levels influence the decision of respondents and if a combination of treatments produces a different response while factor interaction shows the ability of one factor in a set of variables to produce a different response when correlated with varying levels of other factors. It is the estimation of a joint effect of factors on the

outcome of an experiment. In this case, we investigate the factor effects and examine if they interact. To analyse whether the decision to cross illegally was connected to the presence of human and environmental barriers, a binary choice task was designed for the experimental set-up. The two alternatives in each choice task is to either cross at-grade or use the footbridge.

The process of designing a discrete choice experiment comprised developing, testing, validating and optimising the questionnaire (Kløjgaard et al 2012). Prior estimates were unavailable for this experiment therefore it was imperative that the orthogonal design be used. Orthogonal designs produce combinations that are non-collinear in attribute levels ensuring that each level appear an equal amount of time across the entire choice set. (Johnson, 2013). DCE design process is as shown in **Figure 3.2** below:

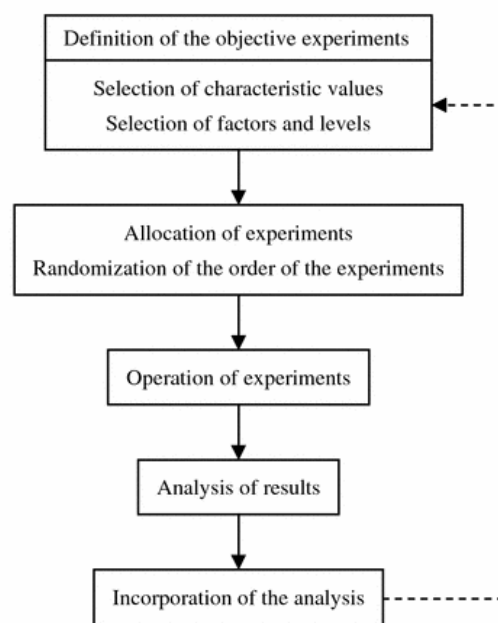


Figure 3.2 Discrete Choice (DCE) process. (Source: Park, 2007)

The first goal in an orthogonal design is to identify the objective aim of the experiment. We establish that the only other alternative to crossing illegally on the freeway is to use the footbridge. Hence the decision to cross is binary in nature and is presented as a dependent variable which is the probability of crossing directly or using the footbridge. The next thing we do is generate a maximum number of different possible factors of influence from as many sources as possible.

3.2.1 Defining attributes by which decision parameters are measured

Identification of attributes in a CE design is the most critical part of the experiment. However, research on methods for factor determination and levels in CE is minimal. The selection of explanatory and generic variables of importance in a DCE depends on deterministic variables which includes the choice-specific characteristics, individual-specific characteristics and the characteristics of the sub-group population. The selection of variables, dependent alternatives and independent linear and non-linear attributes are the basis for which respondents would consider a viable choice selection hence providing quality information that may be analysed systematically. In order to reduce hypothetical bias, Abihiro et al (2014) informs that attribute generation has to be rigorous, transparently reported and reviewed. Attribute and attribute-level identification is consistent with random utility theory which recognises policy relevance as a unique factor in implementing conceptual and theoretical framework in a design plan. These are exhaustive, measurable and defined factors obtained from the integration of local behaviour within the context of the area under consideration and combined in a manner that gives room for trading between alternatives. In itemizing the list of variables involved in this research three stages were implemented.

1. Identification of a comprehensive list of exogenous and endogenous variables through literature review studies, existing conceptual and policy relevant outcome measures, theoretical arguments. (Mangham et al, 2009)
2. Refining list by eliminating factors of non-compliance paring study objectives, research scope, existing knowledge of the characteristics of the sub-population, selecting adjustable components of crossing alternatives that characterize the freeways
3. Finalising process through discussions with transport agencies, enforcement agents, informal discussions with pedestrians, university students who are familiar with the use of the footbridge and the concept of freeways in Cape Town.

In selecting the provisional list of exhaustive variables, available literature was carefully selected and systematically reviewed for keywords such as pedestrian crossing behaviour, low-income pedestrian crossing, attitude towards use of roadway facilities, footbridge and pedestrian crossing (footbridge in itself brought up results relating to structural effects of the pedestrian bridge, dynamics of pedestrian movement on the bridge, lateral vibrations and such), approach to PCB decision-making.

Following Coast et al 2012 that CE attributes should be easy to manipulate for intervention, the design attributes were subject to examination ensuring experiment mutability. This implied that factors relating to weather, climatic conditions, topography were eliminated. Lighting was a difficult concept to portray to respondents and as such was edited out, replacing the same with the factor of convenience broken down into walking distance and additional effort.

Finalizing attribute selection

The final stage of screening was necessary to account for differences in location characteristics. The sample group is unique in terms of language, previous experiences, historical sub-group and cultural heritage when compared with the several studies used in obtaining original attribute data. Mangham et al, (2009) discussed the selection of attributes and attribute level in line with what is normally experienced by the research target population. It is necessary to be able to reflect the true practice and preferences of sample population. Expert opinions ensured that the implications of choosing the variables were well understood and that requirements for validation were met. Research meetings were organized to cover this section of attribute selection. Several of these meetings reviewed extensively the existing design while seeking ways to improve the process such that the final design was readable, elicitable and accurate in retrieving respondent information. When time was restricted, emails were sent through to the consultants for update, further review and contributions. This process took about 12 weeks shortly after the ethics approval was given.

As earlier noted, although there are no standard rules as to the number of attributes that may be included in an experiment, Pappas (2014) notes that too many attributes in a choice experiment makes respondents provide responses that are inaccurate.

3.2.2 Determining levels for corresponding attributes

Attribute levels in this study were decided from a perspective that relates to the population characteristics. Realistic estimates are important to ensure precision of parameter estimates (Mangham et al, 2009) hence it was necessary to consider the different experiences that would be familiar to the respondents to capture the accurate information in data outcomes. Also noted was the effect of each level in the representation of choice task. The levels were perceptually uncorrelated such that respondents were able to clearly detect the changes between the different task runs. Normalising measurement of scale of all attributes across the two alternatives, attributes were divided into quantitative and non-quantitative categories. Factors of traffic, pedestrian crowd and walking time were assigned three levels each following the need for exhaustive and easily detectable characteristics, to provide ease of cognitive process and improve on the presentation of the choice task. Other non-quantitative variables were dummy coded (0-1).

Coast et al (2012) reports that attributes may not retain dominant features of a product or utility. In the case of PCB it would be unnecessary to include the bridge as an attribute or the roadway in the freeway design as an underlying construct. Instead, attributes such as lighting, weather conditions, traffic volume which have no negative implication for the utilities among alternatives were sifted out. To cater to this purpose further, the attributes were categorized in two formats – direct crossing and footbridge attributes. This sub-division enabled a clear cut simplification in decision-making taking into account the relevance of certain factors to the use or non-use of the crossing facility. Moreover, it is required that attributes are mutually exclusive to one another, hence a synthesis of these sub-categories gave rise to a complete

choice task which is presented as an amalgamation of the freeway and footbridge characteristics. In-depth exploration of specific issues and concept was achieved by spending more time with the informants and maintaining communication with diverse sections of the transport industry. This was relevant to understanding the concept of location-specific freeway crossing behaviour without prejudice.

Table 3.2 shows the attributes and attribute levels for the Stated Choice design. The attributes of traffic volume were divided into three levels. Low volumes represented as 5 vehicles per lane on the freeway during a 15-minute period, Medium volumes as 15 vehicles per lane and high volumes as 25 vehicles per lane. This is in line with the minimum and maximum freeway design road capacity in South Africa (SARCAM, 2012).

Law enforcement is identified as the presence of a police personnel on the freeway. In the choice scenario, the law enforcement attribute was depicted as two personnel standing across either sides of the roadway, implying a reasonable level of police presence enforcing compliance to pedestrian-traffic rules. In the SC design, the police presence is dichotomous - either present or absent.

Median is portrayed in the scenario as a concrete jersey wall dividing opposing flow of traffic. The median is hypothesized as a motivation for pedestrian crossing because it provides a platform for breaks when pedestrians cross from one side of the freeway to the other.

Fencing was included in the design and is shown as a high chain link barrier, adjacent to the freeway. Several freeway locations in Cape Town have constructed high fences or guard rails. However, statistics have shown that pedestrians cut through the fences to get access to the freeway. We aim to understand the reason behind this. In the SC design, fence levels are dichotomous - either present or absent.

The footbridge attributes of **crowd-on-bridge and walking** time are qualitative attributes defining the number of pedestrians walking on the bridge and the time travelled to the footbridge along the desired line of trip respectively. Both factors consist of three levels – low levels at 2 person/2 minutes' walk to the bridge, medium levels at 8 persons/8 minutes' walk to the bridge and high levels at 14 persons/14 minutes' walk to the bridge. The numbers were derived from discussions with a smaller group of respondents during pilot survey and deliberations with the research professionals.

Convenience was represented as the additional efforts required to climb up the footbridge. In the near impossibility of using escalators within the township environment, a reduced effort/increased convenience was depicted with the use of ramps instead of a concrete staircase. In this attribute therefore, the levels are presented as ramps or stairs.

Security on the footbridge has been a serious cause of concern for pedestrians who use the footbridge in Cape Town. As such, the presence of a guard or an installed camera was necessary in representing security on the bridge. Levels were represented as absent (0) or present (1).

Socio-demographic variables obtained from respondents consist of age, gender, sense of responsibility, tenure/length of stay in Cape Town and trip information. The sense of responsibility attribute is the possibility that respondents behave differently if they have children. It connotes heightened mindfulness of the risk of at-grade crossing and a cautiousness in deciding how to cross a high flow roadway.

Table 3.2. Attributes and attribute levels

Attribute	Description	Attribute levels*
Roadway attributes		
Traffic volume	Number of vehicles per lane on the freeway	Low volumes represented as 5 vehicles per lane (<i>base</i>) Medium volumes represented as 15 vehicles per lane (β_{t_med}) High volumes represented as 25 vehicles per lane (β_{t_high})
Police personnel	Law enforcement on the freeway to prevent jaywalking.	Two agents present or absent (β_p)
Median	Concrete barriers separating opposing flow of traffic	Median present or absent (β_m)
Fence	Barriers along the shoulders and sidewalk to restrict access into the freeway	Fences present or absent (β_f)
Footbridge attributes		
Crowd	Number of pedestrians on the footbridge at a particular time	Low, represented as 2 pedestrians on the footbridge (<i>base</i>) Medium, represented as 8 pedestrians on the footbridge (β_{c_med}) High, represented as 14 pedestrians crossing the footbridge (β_{c_high})
Travel time	Time taken to arrive at the nearest footbridge	Close distance, 2 minutes walk to the footbridge (<i>base</i>) Mid-level, 8 minutes walk to the footbridge (β_{d_med}) Far distance, 14 minutes walk to the footbridge (β_{d_high})
Efforts	Measure of exertion in walking up the footbridge	Stairs (β_s) Ramp (<i>base</i>)
Bridge Security	CCTV + Guard securing the footbridge	CCTV/Guard (β_e) No CCTV + Guard (<i>base</i>)

*Images with sketches were drawn to scale and correspond to the values highlighted in the table.

**For walking time, a "time travelled" scale was estimated using the average walking speed/distance for an adult, 5.5 [km/h] following Parise et al (2004); Levine & Norenzayan (1999).

3.2.3 Weighing preferences between attributes

Understanding the value that respondents attach to each attribute in a choice experiments helps in regulating the design to avoid dominated attributes in subsets. We assume in this study, that some attributes are more important than others. Amongst these, traffic, distance and convenience. In the design of subsets, it was necessary to apply Pareto optimal design to understand how respondents make trade-offs between the benefits or cost of each attribute levels within the set. Pareto optimal design in behavioural experiments is defined as a design in which no dominating profile exists within the choice sets. Linear main effect variables are generated from factorial design and thereafter used in developing the treatment combinations. This system reduces the effect of a dominating attribute enabling decision makers choose on the basis of preference while considering all the attributes almost equally.

Full/fractional factorial design

In the mixed-level design, the number of runs for a full factorial design where number of attributes is 8,

Levels for each attribute:

3 attributes with 3 levels ($l_1 = l_2 = l_3 = 3$)

5 attributes with 2 levels ($l_4 = l_5 = l_6 = l_7 = l_8 = 2$)

The full factorial design is given as $3^3 * 2^5 = 864$ total scenarios.

Considering this large number of runs, a full factorial design was clearly not feasible. The alternative to using a full factorial was employing a fractional factorial design. With a fractional factorial design, drawbacks associated with a full factorial design are avoided. Where interaction/confounding occurs - effect of the outcome of one factor affecting another, correlated treatments are removed leaving the main effects. Overlap between attribute levels was minimised in the design and the resulting estimation gave 18 runs which was generated using the SPSS software. Table 3.3 shows the orthogonal design for the Binary logit model representing the codes utilised in the model analysis

Table 3.3: Orthogonal choice design*

CARDS	At-grade crossing attribute levels				Footbridge crossing attribute levels			
	**TRAFFIC VOLUME	MEDIAN	FENCE	POLICE	SECURITY (CCTV/GUARD)	EFFORT (STAIRS)	CROWD	WALKING TIME
1	25	0	1	1	1	1	14	5
2	15	1	1	0	1	1	8	14
3	25	0	0	1	1	0	8	8
4	5	0	0	0	0	1	14	8
5	25	1	1	1	0	1	5	8
6	15	1	0	0	1	1	8	14
7	5	1	0	0	1	0	5	5
8	25	1	0	1	0	1	5	5
9	25	0	0	0	0	0	5	5
10	15	1	0	1	0	0	14	14
11	25	1	1	0	1	1	14	5
12	5	0	1	1	1	1	5	14
13	25	0	1	1	1	1	14	5
14	15	0	1	0	0	1	8	5
15	15	0	0	1	1	1	5	5
16	15	1	1	0	1	0	5	8
17	5	1	1	1	0	0	8	5
18	25	1	0	1	0	1	8	8

**18 scenarios are presented in blocks of 6 non-repeated choice sets per respondent. Each respondent decides whether they would cross at-grade or use the footbridge.*

***Quantitative levels are coded – veh/lane for Traffic: 5, 15, 25; number of persons for Crowd on bridge: 2, 8, 14; travel time in minutes for Walking time: 2, 8, 14 respectively; Non-quantitative levels: 0 for absent and 1 if present.*

3.3 Risk perception ladders

Risk perception is defined here as a belief whether rational or irrational held by a respondent about the chance of occurrence of a crash when crossing at-grade or the chance of occurrence of a criminal attack when crossing using a footbridge. The degree of aversion to crossing either with the bridge or directly affects an individual's decision-making process. Risk ladders can establish a linkage between an activity (e.g. crossing) and the perceived risk associated with the activity and in context of assumedly known risks. Risk ladders have typically been developed to consistently measure relative judgments by respondents (Persoskie & Downs, 2015). Several factors account for risk among pedestrians when choosing to cross at any point. People are often willing to accept increased likelihood of severe injury in return for convenience (Ayre et al 1998). A pedestrian who has encountered traffic injury previously would be more inclined to use the footbridge rather than cross with the freeway. On the other hand, an individual with a history of attack on the footbridge would rather face the danger of traffic collision than be reminded of the previous experience of the footbridge attack. These are the levels of risk we hoped to identify and analyse in the study.

Table 3.4 Risk perception categories

Risk ladder scales	Corresponding Likert –scale	Assumedly known risks	
1	Not risky at all	Snake bites	1 in 100,000
2		Death by food poisoning	1 in 50,000
3	Somewhat risky		Residential fires
4			
5	Risky	Contracting tuberculosis	1 in 10,000
6			
7	Very risky	Injury from sharp objects	1 in 500
8			
9	Extremely risky		
10			

Table 3.4 shows the context implemented in estimating risk. The risk perception dialogue is set on a scale of 1 to 10 and itemized as incidents based on the rate of occurrence as reported by national statistics. The general risk perception reveals the baseline of the respondent's attitude towards the danger of the use of a footbridge and crossing at-grade. Choice specific risk dialogues are presented in each choice task to obtain information regarding the perceived levels of risk for each choice task. Indicators of safety and security were the motivating factors for the risk ladders. The idea was to measure the trade-off between the two alternatives in the experiment for increased performance of the choice model. The responses to risk perception were used in the estimating random effect incorporated as latent variables within a heterogeneous normal distribution.

The hazard scales (1 in X) were culled from records of actuarial statistics compiled by World Health Organisation for Africa. The application of heuristics in defining environmental risks is not available in global statistics, therefore, refining of hazard selection was done by sampling. We realize that it was possible for an event to occur de facto but remains unknown to the majority of people. Among these is the HIV/AIDs infection by blood transfusion and death by childbirth. In estimating figures for respective events therefore, it was necessary to test the incidents to ensure that they were in line with familiar happenings around the target communities. As such, residential fires which may not be applicable to upper class in low income countries but well relatable to the township settlements around which the interviews were conducted was included while hazards such as drowning in a pool was omitted. Also, to tackle the issue of complexity, risk ladders were not wordy and only five cases were selected to portray the required risk information.

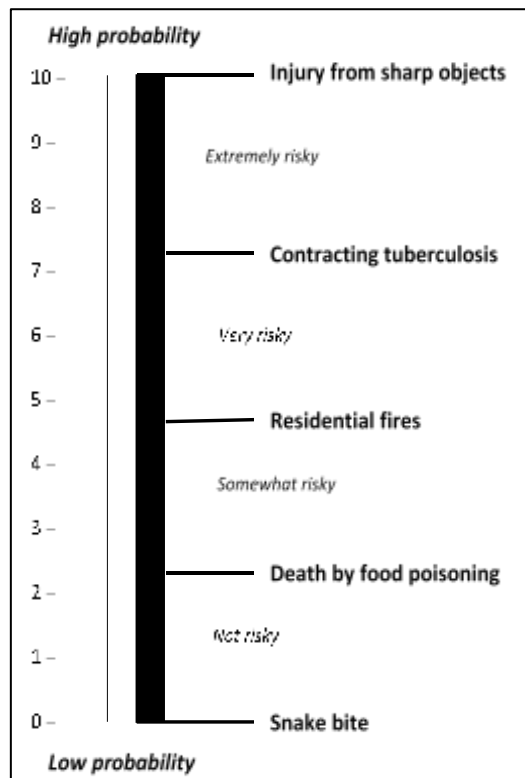


Figure 3.3 Risk ladder for freeway PCB study.

3.4 Inclusion of stated AN-A

In understanding what attributes were ignored by respondents, a section in the choice task questioned on the factors of importance that were considered when making a choice. Choice attributes were represented as a checklist prompting respondents to choose the factors that were of most and least important to them in deciding to cross the freeway. As a general rule, this section was tasked once as the first of choice set presented to the respondent. We used a non-generic, labelled design for the choice task since the alternatives were mutually exclusive to one another.

3.5 Schematic representation of choice tasks

As earlier mentioned, the main effects of all possible treatment combinations from a full factorial design gave a total of 18 runs. The stage of developing the choice sets involved combining all task runs into scenarios. Initially, we implemented pictographs as choice scenarios. The pictographs showed graphic images representing each attribute level for corresponding subsets. After consultations and testing it was suggested that a video be developed displaying the flow of traffic on an electronic device in real time alongside other attributes levels. This idea was reconsidered on the basis of security and efficiency. Respondents may possibly be distracted by the display of high resolution images and provide inaccurate response leading to error variations. Rendered images were suggested next. For similar reasons as the rendered videos including high cost and quality of image in printed format, this method was re-reviewed. Finally it was agreed that a hand drawn sketch of scenarios would provide the best result. The method

was pre-tested and results confirmed optimal engagement. Needless to say, the testing of the methods of presenting the choice scenarios was carried out informally (non-analytic measurements). McCaffery (2011) and Mangham (2009) suggest diagrams, pictographs and sketches to be a most effective means of conducting efficacious survey within the context of low-income and indeterminate literacy levels. In line with this, sketches were used in creating choice scenarios in this research.

Vessey (1994) proposed the criteria for creating choice scenarios based on three main factors:

1. Maximum accuracy at minimum cost – cost effective designs
2. More traditional approach for task complexity, a trade-off between error and effort.
3. Problem solving processes and strategy for target population

Binary outcomes in choice experiment have the advantage of reducing the effect of a dominated alternative hence dominance in alternative is easily eliminated within the subsets. The 18 runs generated were randomly blocked into six subsets of 3 groups. Each respondent was faced with 6 choice scenarios which they selected in no specific order. Figure 3.4 shows card 1 of 18 choice cards. The first part contains the attribute non-attendance questions, followed by the choice scenario with a brief outline of the attribute levels for that subset. The risk perception questions are represented by the ladder and responses are recorded according to detail.

Figure 3.4 Card 1 of 18 choice cards

Questionnaire structuring

The design process led to a build-up of a paper-based questionnaire aimed at eliciting relevant information about choices and crossing motivation of pedestrians who walk along or cross freeways in Cape Town. Qualitative information was obtained preceding the choice scenarios and pretested to ensure similar understanding among respondents. Meetings were once more held with the officials of the transport industry (Mr Randall Cable, A/Prof Mark Zuidgeest, Mr Nick Platte, Mr Anton Struwig and Dr Christoff Krogshoopers) to ascertain the best approach for ordering and structuring the questionnaire. Questions touching tenure and living conditions in Cape Town were discussed. It was suggested that multimodality issues be included seeing as the location of public transport drop off may account for the decision to walk along the freeway hence increasing likelihood to cross at any given point. Trivial information was sorted out to increase response rate. To prevent the tendencies of asking superfluous questions out of simple curiosity, it was necessary to examine each question against the research objectives while considering the sensitive nature of the experiment.

The questionnaire was divided into four short sections. The first section started with a short background into the research without bothering with an in depth the nature of the study. This brief introduction states simply the purpose of the research and introduces the interviewer.

As confirmation for anonymity, it was important that the respondents had prior experience of crossing the freeway (at least once). This meant that they could relate to the experience of crossing illegally. They were also to be within the age bracket required. Ethical issues requiring permission to proceed with the interview was obtained from the respondents since we respect the privacy of participants to not collect, use, or publish privacy-infringing data that could implicate them in anyway (Geuens & De Pelsmacker 2017).

In the second section of the survey, information regarding demographic status in the form of age, gender, length of stay in Cape Town, employment status and sense of responsibility was elicited and formulated to target socio-economic profiles. We opted for short and relevant questions that could be well understood by the respondents in the study. Simple the target Sample group has shown less diverse settings in the context of race, i.e. a majority of blacks and coloured characterized the population, it became unnecessary to ask about race. The economic level for the households around communities along the freeways has been established as low-income. Hence questions relating to income levels was restricted to employment type and trip purpose. Requesting for income level was considered irrelevant.

The next questions introduced risk ladders for general perception of risk just before the choice tasks were presented. Respondents were asked how they would scale the risk of being involved in an accident when crossing with the freeway and the risk of being attacked in a robbery when using the footbridge.

The questionnaire ended with a final question aimed at prompting recommendations for the enactment of transport authorities in city of Cape Town.

There were no contingency or matrix questions which meant that all the information was applicable to any pedestrian crossers walking along or crossing the freeway.

3.6 Empirical surveys.

Pilot survey

A pilot survey could either be a pre-trial of an experiment that is conducted ahead of a major project or a pre-test of a research instrument (Van Teijlingen & Hundley, 2001) Piloting is normally required on a small portion of the population to obtain information that could improve on the efficiency of the main survey process. Collection of preliminary data to develop and test the accuracy of the research tools was relevant to assessing the feasibility of a full scale experimental process. Pilot studies confirms that the research protocol is realistic, workable and that the techniques are effective.

What is typically watched out for in a pilot study includes wordings, flow of questions, range of answers in multiple choice and the methods of disseminating questionnaires. The pilot exercise measured the strength of practicality. Results are not often published, however the information obtained is highly relevant in reducing the risk of an inadequate experiment.

The questionnaire was pretested for response-ability, ease of task, time to complete and engagement of respondent. The pilot testing was carried out in July 2016 to promote efficiency of overall survey; the test for the correctness determined if the instructions stated out in the document was clear enough and that the design was adequate to fulfil the purpose of the study. Results of this pilot survey were assessed, and necessary modifications made to improve survey performance. It was observed that nine choice tasks at a go were burdensome for each respondent, so this was reduced to six. Verbal assistance for images was required to clarify distance travelled so this was modified. Risk perception ladders were also modified to include numeric in a Likert scale. Duration of interview per respondent was kept at a minimum to account for work trips and considering the nature of sites selected, most pedestrians intercepted for an interview were hurrying to work and could not be delayed. During the pilot survey, a 15 minutes' duration was recorded. After the final design, this time reduced to 10 minutes by reducing some cards in the choice set and removing not-so-critical questions in the questionnaire. Initially the number of choice cards presented to each person was 9. This produced a block of 2 (18/2). In optimising the survey method, the block was increased to 3 making it easier for the respondent to choose at a comfortable level and reducing the cognitive burden on respondents.

Ethics review

Ethics clearance was granted by the Faculty Ethics Research committee (ERC) in April 2016. The requirement given by UCT was for all subjects for the research to be equal and above the age of 18 years. However, there is evidence that that quite a large group of crossers fall below the stipulated age. However adequate data was obtained within the required specified age range.

Moreover, by law social responsibility demanded that public offenders be turned in for reprimand. In view of this, it was decided that the illegal crossing questioning would cover hypothetical situations only. All conditions were met during the research process.

Sampling – interview sites

Three major freeways were selected as interview routes in the research. As indicated in the Western Cape Freeway Management System (FMS) Network report (2016), 17 footbridges are currently constructed on the freeway network. Out of these, 9 footbridges record high pedestrian activity along their routes which forms the basis of sampled sites in the research. Figure 3.5 shows a cross section of the footbridges available.

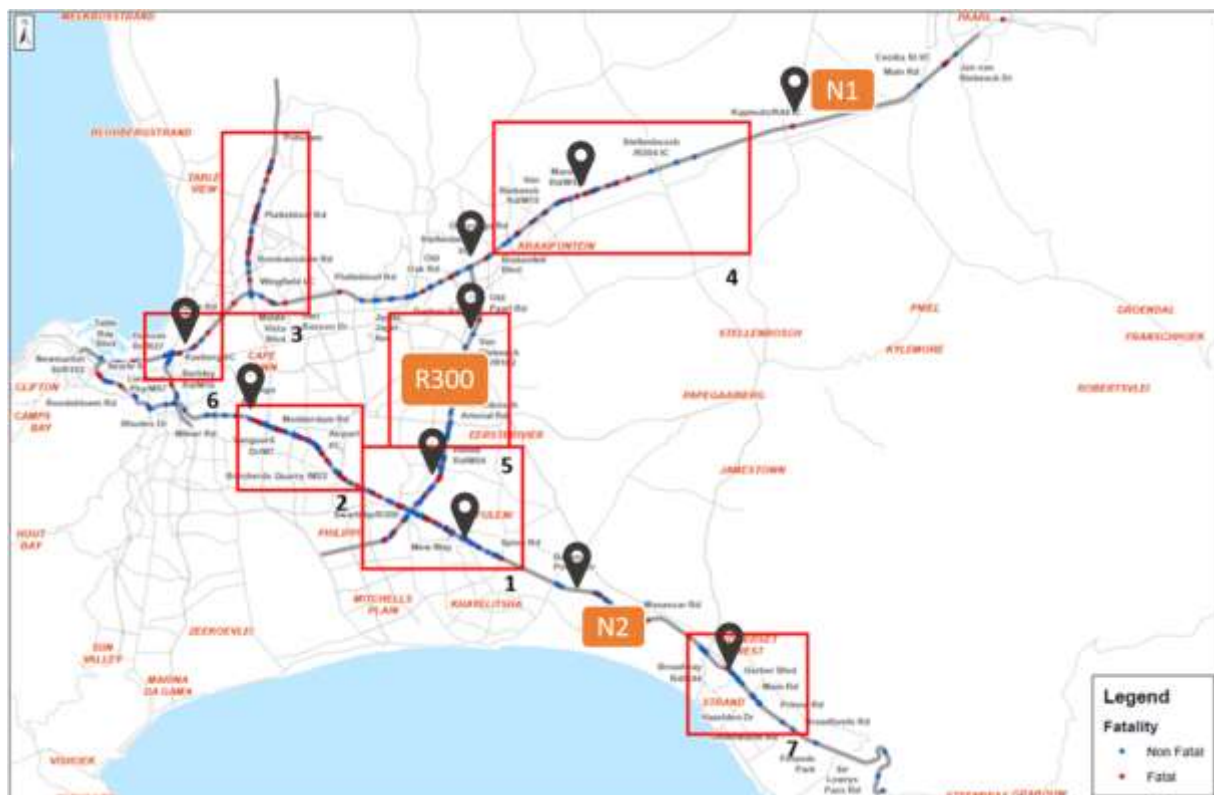


Figure 3.5. Survey locations along N1, N2 and R300, superimposed on map with pedestrian crossing hotspots (Cable, 2016)

Quota sampling was employed in a survey that targeted 300 respondents categorized by locations surrounding the high pedestrian activity freeways. The requirement was for qualified respondents to

have had an experience of crossing the freeway at least once. 10 sites were chosen for the exercise. These were settlements/townships around the N1, N2 and R300 freeways. The N7 freeway was removed from selection due to the absence of footbridges. The scope of the research was restricted to the presence of footbridges within proximity to sites where interviews are conducted. High pedestrian fatality hotspots were targeted for the experiment.

Fieldwork and Data capturing (FDC)

During the survey, to account for safety, interviews were conducted away from the freeway and closer to the communities. Based on previous history with pedestrian offenders, teenagers constitute major defaulters on the freeway during the lower peak periods especially between the hours of 12 and 4 pm. However, to abide by the ethics requirements of the university, these set of persons were not interviewed. Respondents were not permitted to fill the forms themselves as it was necessary to ensure clarity of questions, tasks and eventual response. For this reason, native personnel were recruited to perform the most parts of the interviews. Familiarity with the cultural atmosphere, local language barriers and better viewpoint assisted in ease of presentation hence improving communication and overall responsiveness. The professional fieldworkers were recruited and trained adequately ahead of the main survey which took place in September 2016. A two-hour meeting was organized for this purpose. All interviewers had a reasonable knowledge of the English language. Thus, training was relayed in English. During the training, adequate information was disseminated in a two-way manner such that the recruited personnel supplied previous knowledge regarding surveys and the specifics of the sites under consideration while changes in the current experiment was communicated back to them. It was decided then that survey would be done within the vicinity of the freeways, in pairs and a less formal mien.

This process of administering survey documents in this research was by the intercept method. Intercept surveys have been carried out for decades in several market research studies and is especially popular in mall surveys and pedestrian data collection methods (Miller, 1997; Bush and Air, 1985). The face-to-face approach of the Intercept survey data collection method makes it a simple, direct and affordable means of administering questionnaires (Spooner and Flaherty, 1993). Intercept survey has been researched to be a more productive way of soliciting data from a random population compared to other forms of survey in target population. The approach is more suitable for roadway experiments of medium to high pedestrian population (Ling Z et al., 2015) and has been identified by researchers to provide a more accurate data considering the fact that pedestrians are speculating on their decisions rather than recalling past activity (Piatkowski et al 2015)

In conducting intercept survey for pedestrians in this study, travellers were intercepted along the freeways N1, N2 and R300 using the tested and optimized questionnaire. Before the respondents were interviewed on choice task, they were briefed on what the attributes and levels meant and how they were to respond to the images presented to them. They were informed on what to look out for in the sketches

and what elements were irrelevant to the experiment for example the trees, terrain of roadway, hills etc. Two questions were asked in the choice task. The first of every 6 random choice sets started with a starter question requiring the respondent to state which of the attributes was most important and which was least important in their decision to cross in that scenario. The second question was the choice scenario. Respondents were shown the image for that subset and asked how they would choose to cross. Finally, they were asked to rate the risk of safety and security for the same scenario.

As earlier discussed, medium scale data collection was overseen by professional survey group comprising English and native speakers. Pre -fieldwork activities involved training, scheduling, planning and operations. Training of fieldworkers was done on the 26th of August at the New Engineering Building, UCT. About 30 interviewers showed up for the meeting. A good number of the recruits had been involved in similar survey months before with the research team headed by Sinclair. This meant that a majority had a good knowledge of the research background and were aware of the conditions surrounding pedestrian crossing on the freeways. However, the two-hour session covered missing information, provided in depth understanding of the concepts within the current study while answering questions relating to work structure and survey process. The preparation, running and administrative procedures were handled remotely with the assistance of the transport director of the ITS Global group. Scheduling of times, days and weeks of the month during the first and second stage of the survey is influenced by climatic conditions considering the survey period was during the rainy seasons. Fieldworkers were available for three days in the week when other activities were suspended. The interview sites are unevenly distributed in terms of pedestrian population along their routes. Proportion of interviews allocated to each site is dependent on the influx of pedestrian movement along the freeway in question. Presence of a footbridge within proximity to the location is taken into consideration to affirm the objectives of the research. Communities surrounding the interview sites had relative safety levels hence interviewers needed to be conscious of personal safety from robberies and overall danger.

During the preparatory stages, communication was maintained between stakeholders and transport agencies who had adequate information regarding previous surveys carried out in the region of Cape Town.

Interviews were conducted at three slots of each day. In the early mornings before six it was expected that work trips would be highest and evenings after 6 p.m., home trips would account for the majority of pedestrians found on the freeway. In between these times, fewer pedestrians are expected to be found hence a lower number of interviewees were allocated for afternoon (12 p.m. – 4 p.m.). Some of these respondents fall in the category of visiting friends, youngsters with residences within proximity to the roadway, school students who live across the freeway and the displaced persons.

To increase response rate, time duration for the survey was shortened to a fifth of an hour as the maximum time span for each interview. Previously quarter hour had been recorded for individual

selections and was reported as straining for the respondent. This led to a reduction of choice tasks (from 9 tasks to 6). A little testing afterwards revealed that the reduction increased efficiency of survey time leading to effective engagement, increased interviews within a shorter time frame, decreased cognitive burden on respondent and speedy interviews.

Some challenges incurred during the intercept survey included fear of the interviewers by pedestrians who thought they were being apprehended for their illegal behaviour. This led to pedestrians avoiding the freeways due to the presence of our personnel. A few pedestrians did admit to taking a different route to avoid altercations with the supposed law. Several respondents failed to give a listening ear due to hurry to and from work. Some respondents warned interviewers to stay away from the freeway because there had been reports of pedestrian attacks at those specific areas. Other respondents wanted some sort of incentives before they would contribute to the survey.

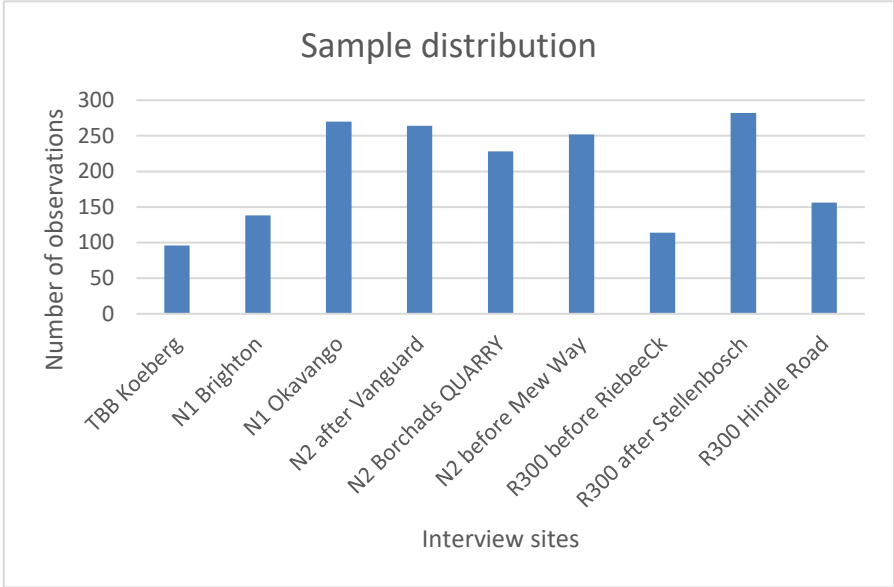
To eliminate response distortion problems, in accordance to (Bush & Hair 1985) interviewers are advised to be discrete in approaching pedestrians. The effect of distortion is seen in the provision of socially desirable response while neglecting truthful answers. The end result is a series of socially acceptable choices and incorrect data. This effect was observed to be likely in a research such as this seeing as the questions pertain to sensitive information where respondents are forced to provide responses that they fear may be used against them. We detect and reduce this effect in two ways.

1. An assurance of anonymity of all information provided during the course of the survey.
2. Ensuring that the interviews are conducted individually (one person per interview) without the inference or presence of a third party.

The second stage of survey went more smoothly than the first. Some of the results of the survey were eliminated from the experiment. The criteria for elimination included 1. Incomplete information 2. Dominant alternative selection – that is, where one alternative (dominant choice) is repeatedly selected in all subsets for each individual choice set.

In the first stage of survey, a total of 180 documents were given out for collection. Resources were inclusive of demographic, risk perception general enquiry, choice tasks and recommendation questions for further action. Of this number, 90% were valid leading to an equal number of questionnaire released for the second stage. In total about 360 interviews were obtained from the survey. Of these interviews 300 questionnaires qualified as complete & accurate. Participation was generally higher in the afternoon when pedestrians were in no rush and could take some time to accurately respond to queries posed by the interviewers. The morning and evening sessions of the survey covered more people but recorded less response rates. The distribution of interviews per site is finalised as shown in Table 3.6 below. We observed a fair sample distribution according to the pedestrian activity recorded per site. In areas of high

activity, like the N1 and N2, observations obtained were in line with the population of illegal crossers from previous studies. Initially, it was decided that at least 20 questionnaires be retrieved per site. However, it was quickly discovered that at some of the sites, pedestrians were less susceptible to illegal freeway crossing. The fieldworkers could then detect such locations and act accordingly in eliciting proportionate responses from the respective site.



* six choice cards were observed by each of 300 respondents

Figure 3.6 Sample distribution by site

Data capture

For quantitative data such as this, repeated data entry is required. This is to eliminate occurrence of error or missing values in the spreadsheet. Cleaning and editing was done by once again, rechecking values against codes used for the analysis, reducing excessive detail and concatenating data to produce a valid dataset worthy of the analysis. Duplicate entries are removed to allow for consistency throughout the dataset. Capturing of data into spreadsheet took a week to complete. Sorting of data into socio-demographic groups, risk perceptions, choice responses and coding followed the entry process.

Chapter Four

Results and Analysis

This chapter reports on the estimates of the DCM parameters representing pedestrian crossing behaviour on freeways in Cape Town. It consists of two sections. The first section discusses sample statistics including the risk distribution and demographic profile of respondents. The second section presents the results of the models that have been estimated.

4.1 Sample statistics

Socio-economic overview (SES) offers insight into sample distribution in terms of age, gender and other demographic variables. Participants for the survey were considered choice crossers because they had the option of crossing the freeway with the use of footbridge. Disparity in responses across respondents may be explained by individual or location characteristics. Ignoring socio-demographic information is assuming that the result of the experiment is not influenced by any external factor (Hammer, 2011).

Three hundred and thirty respondents were intercepted during the survey. Revealed FMS data have shown that on a regular day, an average 1065 pedestrians cross the freeway per day (Cable, 2016). Using this figure, a sample of 330 pedestrians was large enough and representative of the choice crossers' population on Cape Town's freeway. Amongst these 330, only 300 questionnaires were valid enough to be considered for analysis. The criteria for qualification was completeness of all sections in the questionnaire including choice tasks.

Age

Figure 4.1 shows a representative chart of the age range of respondents. Younger pedestrians fall between the ages of 18 years and 35 years old. An older group falls between 36 and 50 years old while the others are aged 51 years old and above. The highest value observed for age during the survey is 65. In line with most PCB studies categorizing crossing defaulters, most freeway crossers are younger people. The youngest respondent was aged 17 years old (1 person) – given that we were unable to interview persons below the ages of 17 years. A mean age of 34 years and standard deviation 9.842 was observed from the sample survey.

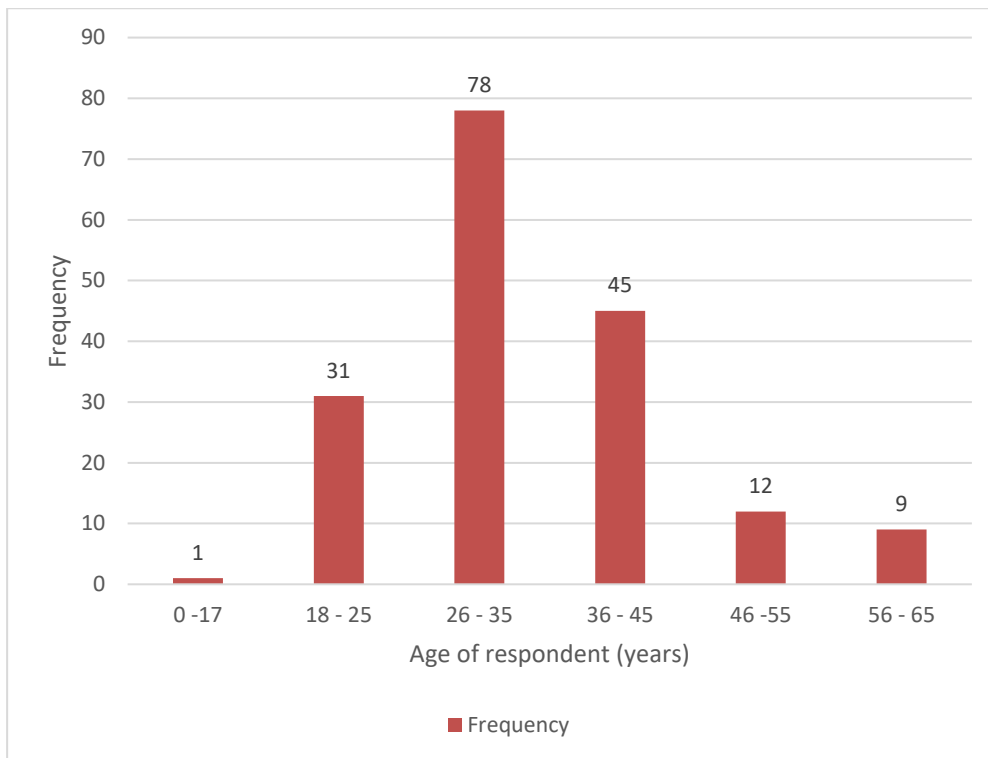


Fig 4.1 Sample distribution by age

Age and Gender

Table 4.1 below shows a cross tabulation between Age and Gender of sampled respondents. Males are seen to be the more prominent users of the freeway.

Table 4.1 Cross tabulation of age and gender

Age (years)	17 -35	36 - 50	51 - 65
MALE	172	76	22
FEMALE	14	11	5

Trip purpose

Home Based Work (HBW) trips account for 91% of all trips. Other trip purposes include school trips (1%) and others (8.3%), which includes visits to friends, job search, shopping, etc. Given that the communities and built up areas are set along on either side of the freeway, pedestrians tend to cross the freeway more frequently in the daytime.

Employment status

In the experimental design, employment status of respondents was subdivided into four categories – Employed persons who perform some work for a wage or salary, in cash or in-kind (OECD 2012), self-

employed, defined as an independent worker who earns an income on the basis of work done by him/herself, unemployed and Retired. In subsequent post-survey data sorting, responses from self – employed and retired persons were seen to be minimal and thus were merged with the employed and unemployed categories respectively. Information from this section shows that a majority of the surveyed pedestrians, precisely 272 persons out of 300 are employed, the remainder, representing 9.3% of the population sample, are unemployed.

Tenure in Cape Town

The length of time a person has resided at a location has been researched to influence public behaviour (Rosenbloom et al, 2008; Behrens 2005). The tenure variable shows that 45% of the sampled respondents have lived in Cape Town for less than 5 years, 45.7% for a little more than a decade and 46% for more than 17 years.

Public transport

In terms of multi-modality, defined in this case as the use of public transport or a shared ride before or after crossing the freeway, 55% of total respondents report that they use public transport before or after crossing the freeway.

Sense of responsibility

67% respondents claim to have children which shows that a good number of freeway users have reasonable levels of responsibility. Testing for responsibility shows the impact of risk levels on crossing choice and measures how much deviation can be observed from general lawful behaviour.

4.2 Perceived risk

Perceived risk is demonstrated here as a respondent's perceived susceptibility to the threat of danger (Ferrer & Klein, 2015) on the freeway or the footbridge. The risk associated with the freeway is the physical risk, which is the possibility of an injury or attack while crossing. A description of the responses obtained for pre-choice risk perception exercise is presented in Table 4.2. The table displays frequency of sampled respondents for general perceived risk.

Risk level	1	2	3	4	5	6	7	8	9	10
Direct crossing	1	0	0	2	0	4	1	8	154	130
Footbridge crossing	0	3	4	2	6	35	26	41	89	94

Table 4.2. Frequency risk perception (pre-choice) in dataset.

As seen above, a relatively high number of respondents perceive freeway direct crossing and footbridge to be very risky at 9-10 on the Likert scale. This is equivalent to injury from sharp objects. Similar results are obtained for footbridge choice crossers indicating a fair perception of risk levels among pedestrians and a normal high for both safety and security risks. The highest frequency for traffic risk is 154 at rank 9 and 130 at rank 10. The lowest level for traffic risk for general crossing which is the event of the occurrence of a snake bite has a frequency of 2 responses proving that little to no respondent perceive direct crossing as "not risky", 2 respondents perceive traffic crossing as "somewhat risky" and 13 respondents think crossing directly is "very risky".

For footbridge crossing, three respondents perceive footbridge crossing as "not risky". The highest frequency for footbridge crossing is 183 at ranks 9 & 10 on the Likert scales. 67 respondents perceive footbridge crossing as "very risky", 12 respondents think footbridge crossing is "somewhat risky" and 35 perceive footbridges as simply "risky".

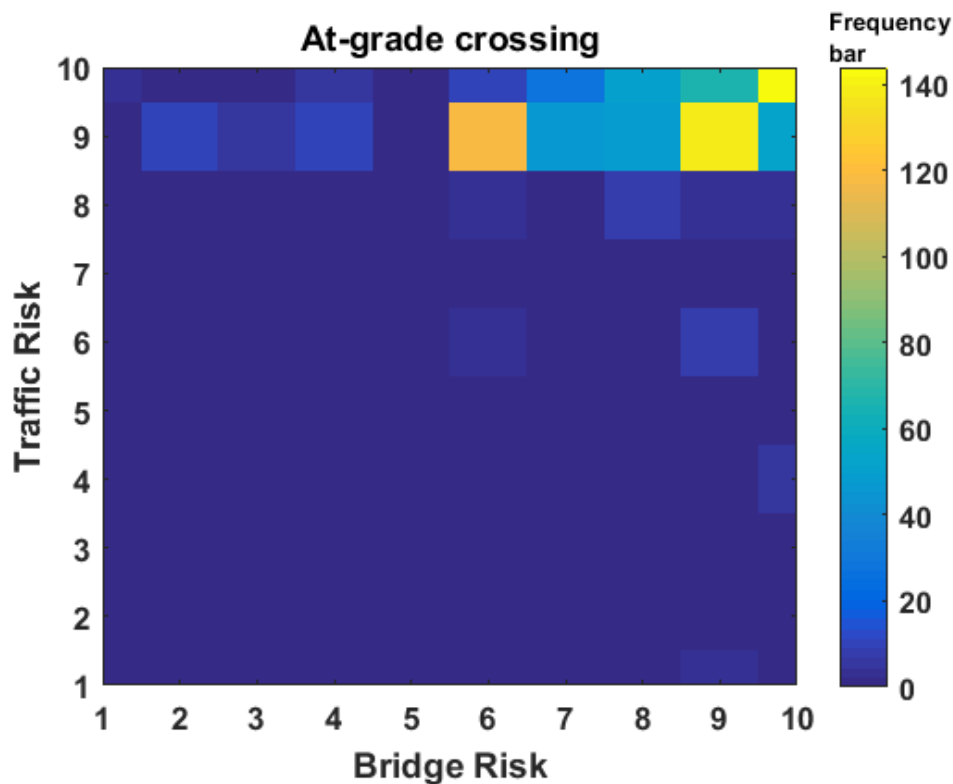


Fig 4.2 At- grade choice and general risk perception (N=1800 x 2)

Figure 4.2 also shows the interaction between general risk perception and the choice of crossing illegally. Most of the respondents who chose to cross at-grade during the choice task i.e. responses from the choice tasks, perceive the risk of crossing directly as well as using the footbridge to be extremely high between 6 and 10. Thus confirming the hypothesis that risk perception influences, to a large extent, pedestrian crossing choices on the freeway.

Table 4.3a. Choice risk (At-grade crossing)

		Footbridge Risk										
Risk scale		1	2	3	4	5	6	7	8	9	10	
General risk		0	3	4	2	6	35	26	41	89	94	
Traffic risk	1	1	20	5	8	17	3	1	0	2	7	14
	2	0	22	20	2	1	1	4	1	4	5	15
	3	0	12	4	3	2	0	1	2	1	4	1
	4	2	13	11	3	6	3	2	4	2	8	26
	5	0	2	4	0	0	0	1	1	1	0	0
	6	4	16	11	15	15	3	3	2	0	22	16
	7	1	10	11	28	2	8	3	2	1	4	14
	8	8	8	7	6	6	1	6	0	2	3	14
	9	154	21	14	7	13	6	8	5	3	23	40
	10	130	21	14	12	9	15	5	4	9	7	37

Table 4.3 (a & b) show the distribution of at-grade and footbridge crossing choice for task-specific risk perception. A significant number of respondents chose extreme values for the perception of risk when presented with hypothetical scenarios. For higher traffic scenarios, 10% of respondents perceive the risk of crossing directly to be very dangerous. Equally, the absence of a guard or security on the footbridge raises the perception of risk for footbridge crossing.

Table 4.3b: Choice risk (Footbridge crossing)

		Footbridge Risk										
Risk scale		1	2	3	4	5	6	7	8	9	10	
Traffic risk	General risk	0	3	4	2	6	35	26	41	89	94	
	1	1	19	1	7	3	0	4	0	2	0	2
	2	0	11	8	1	5	1	1	0	0	1	0
	3	0	10	2	2	1	1	0	0	1	2	0
	4	2	62	4	5	8	0	4	2	3	11	21
	5	0	2	2	1	2	0	0	3	0	0	2
	6	4	28	5	12	13	2	5	1	2	5	16
	7	1	8	4	18	12	13	2	5	0	1	3
	8	8	5	8	5	12	6	2	8	4	3	1
	9	154	80	15	21	11	6	11	6	6	22	12
10	130	150	47	19	30	14	11	7	28	33	52	

A change of perceived risk is seen for the footbridge crossing choice. the footbridge appears to provide a safer option for footbridge choice crossers. Apparently, if pedestrians perceive the risk of using the bridge to be high, they would opt to cross directly, regardless of their perception of at-grade crossing. Furthermore, if the risk of using both alternatives is high, they would rather cross illegally.

Table 4.4 shows that in line with our expectation, both crossing options are considered risky, with footbridge crossing being perceived as *very risky* on average, and at-grade crossing as *extremely risky* on average. The standard deviation for perceived footbridge crossing risk is negatively skewed and is significantly greater than that for freeway crossing risk, which is positively skewed. This suggests that there is more consensus amongst the respondents that at-grade crossing constitutes a greater risk. Yet, it remains interesting to see that the personal risk of using footbridges is acknowledged and seen as very risky. The table also shows that the perceived risk levels and their variability are constant for both crossing options when looking specifically at different age groups (below and above 35 years of age),

urban experience (having been in Cape Town for longer or shorter than 15 years), and whether having children or not.

Table 4.4. General stated risk perception levels of at-grade crossing and footbridge crossing

General risk perception	Mean at-grade risk	Mean bridge risk	SD traffic risk	SD bridge risk	N
all	9.30	8.39	0.94	1.71	300
age below / equal 35	9.25	8.51	1.03	1.65	186
age above 35	9.38	8.19	0.77	1.81	114
in Cape Town less than 15 years	9.32	8.21	0.73	1.75	166
in Cape Town more than 15 years	9.28	8.42	1.15	1.68	134
children	9.38	8.49	0.61	1.55	200
no children	9.14	8.20	1.37	2.00	100

When respondents were asked to indicate their perceived risk levels for each of the six choice scenarios that were presented to them, the overall risk perception levels drop considerably compared to the earlier stated general risk perception levels. As earlier mentioned, at-grade crossing is seen as risky on average and footbridge crossing is perceived as somewhat risky on average, suggesting that the choice tasks were different from the actual situation on ground. Also, the gap between perceived at-grade risk and footbridge risk has widened considerably compared to the general risk perception, while the variation in risk perception levels varies more between socio-demographic groupings based on age, urban tenure and family responsibility. We see this in Table 4.5

Table 4.5. Choice task specific risk perception levels of at-grade crossing and footbridge crossing

In-choice risk	Mean at-grade risk	Mean bridge risk	SD traffic risk	SD bridge risk	N
all	7.03	4.57	2.98	3.46	1800
age below / equal 35	7.14	4.61	2.92	3.46	1116
age above 35	6.86	4.51	3.07	3.40	684
in Cape Town less than 15 years	6.94	4.53	2.97	3.46	1001
in Cape Town more than 15 years	7.15	4.62	2.98	3.48	799
children	6.91	4.46	2.95	3.46	1205
no children	7.28	4.78	3.04	3.58	595

Relationship between age and risk perception

To show impact of age differences on risk perception, we present graphical representations of age against risk perception as shown in Figures 4.3 - 4.6. We observe for general risk perception (4.3 & 4.4) that older pedestrians find the footbridge to be less risky than young pedestrians. The relationship between age and choice risk perception is shown in figures (4.5) – (4.6). A clear difference is observed between age-road risk and age-bridge risk. It is obvious that older people have higher perception of risk for freeway traffic than for footbridge attacks.

As much as the risk of road crossing is high (at 9 – 9.2) for younger ages, the perception of risk increases proportionally for ages 40 and above. Bridge risk is high for both category of age groups. However, the risk of using the bridge decreases for ages 40 and above.

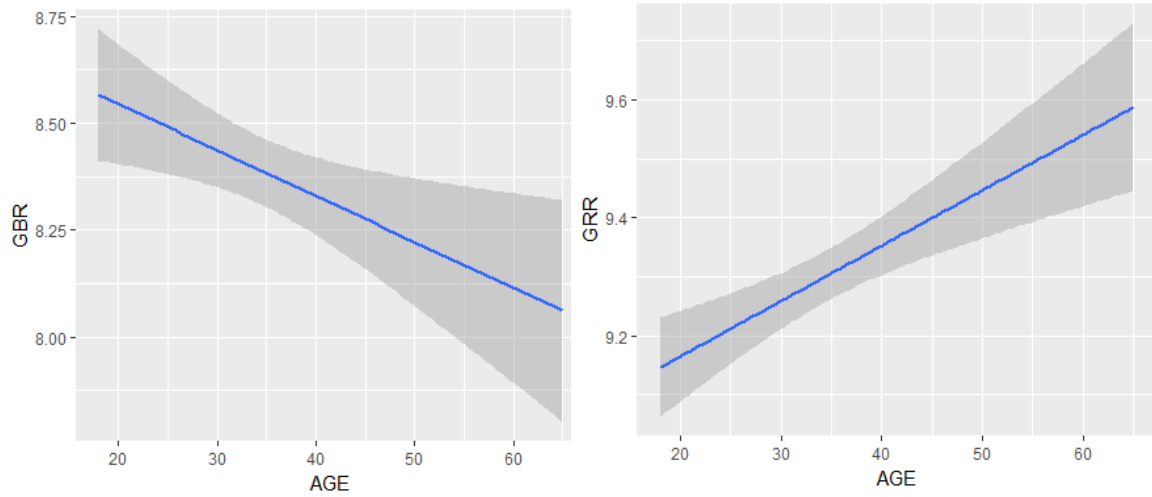


Figure 4.5 -4.6 Association of Age vs Mean General road risk (GRR) and General Bridge risk (GBR)

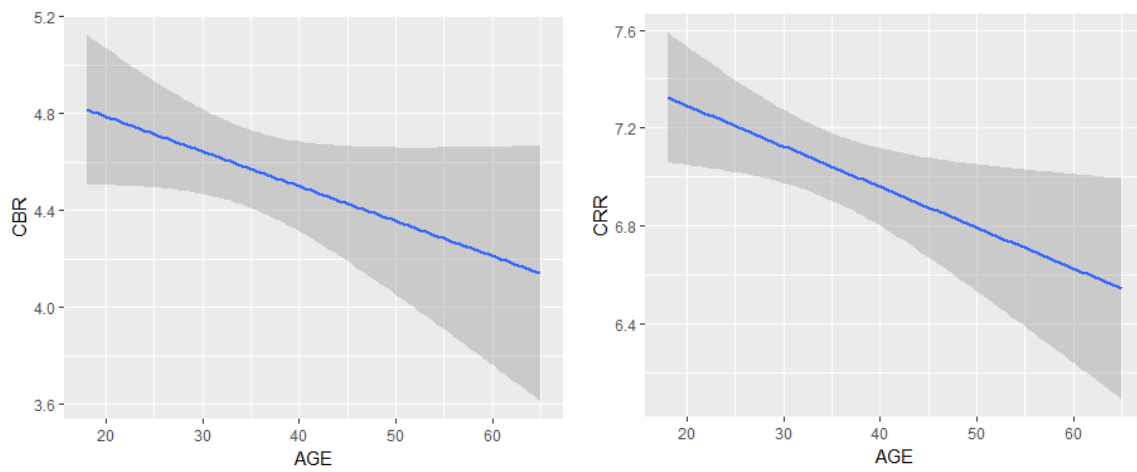


Figure 4.7 -4.8 Association of Age vs Mean Choice road risk (CRR) and Choice Bridge risk (CBR)

4.3 Choice Modelling

In this section, we examine pedestrian crossing behaviour as a function of choice attributes and individual characteristics. Four variables are connected to the choice probabilities of at-grade and footbridge crossing as discussed in **Chapter 3 section 3.3**. Using methods described in **section 2.3** we test for correlation between the latent variables of safety and security which represent the two risk factors of freeway crossing. Traffic safety risk applies to at-grade crossing and is defined as the likelihood and extent to which a person who crosses at-grade may be in danger of an accident. The risk factor of security is related to footbridge crossing in which a pedestrian crossing with the footbridge is likely to face an attack of robbery. The impact of risk situation on pedestrian crossing choice is measured. We continue to explore the association of freeway pedestrian crossing behaviours.

4.3.1 Contrast coding

Confirming the right experimental analysis involved categorising independent variables into its linear and non-linear characteristics. The fundamental building blocks for modelling the approach towards response variables are 1. The random utilities and 2. Translating the functions into a description of binary choices.

4.3.1.1 *Random utilities*

Illegal crossing on a freeway implies that a pedestrian does not cross the roadway using the required roadway facilities especially when they are available. The crossing choice model understands that the pedestrian is the sole decision maker of crossing. With the data obtained from field survey, part worth utilities for all attribute levels were analysed to confirm that respondents could interpret the choice task on an ordinal scale. This means that for the quantitative attributes, a non-linear string was defined for levels 2, 8, 14 for walking time and crowd on bridge and 5, 15, 25 for traffic volume. The outcome of these part utilities have been computed using R software.

4.3.1.2 *Translating functions to binary choices*

The linear function is a series of categorical variables usually expressed as a sequence of K-1 dummy variables implying that each statistical test for independent variables confirms whether the mean of every level in the function is statistically & significantly different from the mean of the base category.

We allow for treatment/contrast coding in the expression of utility where the contrast coding permits a re-centering of categorical variables such that the model intercept is the mean of all data points across the distribution rather than of one level of a category. Modelling continuous data as a non-linear function assumes independence of attribute coefficients. The results from modelling continuous non-linear functions are not always wrong, however, the overall effect of the set of coded variables are changed. With treatment coding, the problem of interpreting baselines is eliminated especially during interaction modelling.

Obtaining contrast variables for use in utilities involved the creation of dichotomous variables where each level of the multivariate factor is juxtaposed to a specified reference level. In this research, the quantitative attributes of traffic, crowding on bridge and walking distance with three levels specifies dummy coding using the low levels as default base references. We thereafter create 2 dichotomous variables where higher levels would contrast other levels with level 1.

The coding as highlighted in **Table 4.6** estimates high traffic volumes against low traffic volumes and medium traffic volumes against low traffic volumes. For the footbridge alternative, far distance to footbridge is against low walking distance and midway distance (8 minutes' walk to footbridge) against low walking distance. Likewise, with respect to pedestrian crowd on the bridge, Higher crowding on bridge contrasted with the lowest number of pedestrians on the bridge. The other qualitative variables are not contrast coded, as they are already dichotomous.

Table 4.6 List of treatment codes for independent variables

	Attribute	Level			
1	Traffic	(veh/lane)	T1	T2	
0	High volumes	25	0	0	
1	Median volumes	15	0	1	
2	Low volumes	5	1	0	BASE CONSTANT
2	Pedestrian Crowd	(persons)	CR1	CR2	
0	High volumes	14	0	0	
1	Medium volumes	8	0	1	
2	Low volumes	2	1	0	BASE CONSTANT
3	Walking time	(minutes)	WT1	WT2	
0	Far	14	0	0	
1	Mid-way	8	0	1	
2	Close	2	1	0	BASE CONSTANT

Alternative-related variables take into account the influence of categorical variables. The inclusion of these variables causes a change in the intercept of response variables. Independence of irrelevant alternatives

(IIA) implies that for any individual, the ratio of the probabilities of choosing two alternatives is independent of the presence or attributes of any other alternatives. We also assume IID for extreme value distribution in longitudinal data. The event count (Table 4.5) shows that among the 300 respondents that participated in the survey, a majority chose the footbridge crossing alternative for most of the choice tasks.

Table 4.7 Event count for sampled respondents

Choice	Observations	Percentage (%)
At - Grade	785	43.6
Footbridge	1015	56.4

* 15 surveys recorded dominant alternatives where the footbridge was chosen as the preferred alternative for all six choice tasks.

4.3.2 Utility functions

At-grade crossing is estimated, relative to the baseline reference which is the footbridge crossing, hence the footbridge crossing alternative doesn't have an ASC coefficient. The modelled parts of the utility for the at-grade crossing alternative ($j=1$) is depicted in equation 4.1, while for the footbridge crossing choice ($j=2$) is depicted in equation 4.2 (with β_{knj} fixed over respondents n):

$$V_{n(\text{at grade})} = ASC_{\text{at grade}} + \beta_{t_{\text{med}}} \text{Traffic}_{\text{med}} + \beta_{t_{\text{high}}} \text{Traffic}_{\text{high}} + \beta_f \text{Fence} \quad (4.1)$$

$$+ \beta_m \text{Median} + \beta_p \text{Police} \quad \forall n.$$

$$V_{n(\text{footbridge})} = \beta_{d_{\text{med}}} \text{Distance}_{\text{med}} + \beta_{d_{\text{high}}} \text{Distance}_{\text{high}} + \beta_{c_{\text{med}}} \text{Crowd}_{\text{med}} \quad (4.2)$$

$$+ \beta_{c_{\text{high}}} \text{Crowd}_{\text{high}} + \beta_s \text{Security} + \beta_e \text{Stairs} \quad \forall n.$$

Alternative Specific Constant (ASC) computed for at grade crossing alternative.

$\beta_{t_{\text{med}}}$ refers to the coefficient of volume of traffic on the freeway set to medium/15 vehicles per lane.

$\beta_{t_{\text{high}}}$ is the vector coefficient for traffic volume set to 25 vehicles per lane.

β_f is the vector coefficient for fence barrier set to 1 when present and zero when absent.

β_m is the vector coefficient for median jersey wall at the middle of the carriageway.

β_p is a vector coefficient that connotes presence for 1 and absence, zero for law enforcement agents along the sides of the freeway.

For the footbridge utility string,

β_{d_high} is the vector coefficient for medium distance required to arrive at the nearest footbridge along a pedestrian line of trip.

β_{d_high} refers to vector coefficient for high distance of 14 minutes travelled to the footbridge along the desired line of trip.

β_{c_med} is the vector coefficient for medium number of pedestrians set to 8 persons on the footbridge

β_{c_high} is the vector coefficient for maximum number of pedestrians using the footbridge at a given point in time and is set to 14 persons.

β_s , the vector coefficient for presence of an armed guard + a CCTV coverage on the footbridge while

β_e represents the vector coefficient for the efforts exerted in climbing up a footbridge structure.

The vector coefficients are classified according to the category of alternative.

4.3.3 Ordered logit models estimating risk perceptions

Personality and behavioural attributes are complex features to estimate. However, changes in choice behaviour may be predicted by interacting such attitudinal terms with respective socio-economic and explanatory factors. The result of this is the cumulative estimate of the observable variables conditional upon the risk factors identified. Three propositions are made in this research under the ordered choice set-up. The first is the relationship between general risk perceptions and socioeconomic characteristics which shows the influence of age, tenure, sense of responsibility and employment status on pedestrian risk perception of at-grade and footbridge crossing. The second follows the same order except the risk levels here are relative to the choice scenarios presented within the choice tasks. As such they are specific to the choice experimental processes. Basically, there are four things that an ordered logit model analyses subsequently:

1. General risk perception of road crossing
2. General risk perception of bridge crossing
3. Risk perception of road crossing in each choice task
4. Risk perception of bridge crossing in each choice task

Thresholds are estimated since the response is ordered, and not continuous. In the general risk analysis, the coefficients of socio-economic variables explain the differences in risk perception of respondents, that certain respondents have different perceptions of risk for crossing at-grade and using the footbridge. In the choice-specific risk analysis, we also use socioeconomic variables to show that certain human factors influence choices and consider the effect of the built environment attributes on respondents' choices. The last analysis describes choice behaviour between bridge and road crossing and simply explains the choices among respondents using the binomial and mixed logit model (using the alternative specific constants only).

Goodness-of-fit

Qualitative goodness-of-fit is tested makes use of the final log-likelihood, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and adjusted rho-squares. **Table 4.8** shows the goodness of fit measures of the two models. As earlier described, AIC and BIC values are best at lower numbers.

Table 4.8. Goodness-of-fit for models with and without mixing

Goodness-of-fit tests	Base model	Mixture model
LL(final)	-8522.88	-8240.63
Parameters	59	71
AIC	17163.76	16623.27
BIC	17488.00	17013.45

Both models for generic variables performed well with their respective model specifications. However, the parameters associated with the choice component of the ordered response model and mixed logit models show lower standard errors and better t-ratios than the binomial logit model. This confirms that elements of perceived risk and heterogeneous variables play a critical role in the estimation of accurate models. The mixed logit model outperforms the other models and has the best performance for model. Furthermore, the likelihood ratio values show proof of a superior goodness of fit of the mixed logit model. In order to achieve convergence for the single heterogeneous model, existing levels data are excluded from the equation such that the final estimates are related to the retained levels only (King et al., 2009). For example, in the single heterogeneous model, certain variables and attribute levels were omitted to achieve convergence. We present results from the BNL logit model accounting for non-ordered responses across all observations and a mixed logit model that reveals the heterogenous preferences of individuals on a scale using single selections.

As a first step, we look at the overall statistics for our two models as seen in Table 5, i.e. the base model, which does not incorporate random heterogeneity across respondents or correlation between the different survey components, and the model with the full level of heterogeneity. We see that the mixture model offers an improvement in log-likelihood by 282.25 units for 12 additional parameters; this gives a likelihood ratio test value of 564.50, while the 99% critical χ^2_{12} value is 26.22, showing that the mixture model comprehensively outperforms the base model.

Table 4.9 shows results for the general risk perceptions held by respondents of different socio-demographic groups (parameter estimates and threshold values φ_i). Using a threshold value of 1.4 for the robust t-statistic, it can be concluded that the estimates are highly significant. We look at the individual components

of both models in turn, where each time the findings are contrasted from the two separate models. We start with the general risk attitudes, i.e. the risk ladders asked prior to the first choice task, with results shown in Table 4.9. In this survey component, respondents indicate their general risk perception around crossing at-grade or using the footbridge before they face actual choice tasks. It is possible therefore, to only relate these to human factors, such as length of tenure in Cape Town, age, employment, having children and/or accessing or egressing from public transport. Respondents chose high responses in general for these risk ladders as seen earlier in Table 4.2, and it was necessary to combine any responses below 7 into a single category for the road crossing, and any responses below 5 for the bridge crossing. For at-grade crossing, it is seen that respondents who are not employed provide a lower risk rating than those who are employed, where this difference is significant above the 90% level of confidence in both models. This is potentially also linked to education. For bridge crossing, we see that those aged under 30 perceive the risk to be lower than those aged between 30 and 40, while those aged over 40 again perceive the risk to be lower, even more so than the under 30 group.

Table 4.6 General risk perception

			Base model		Mixture model	
			Estimate	rob t-rat	estimate	rob t-rat
General risk attitude (road)	respondent characteristics	not employed	-0.5938	-1.69	-0.8873	-1.82
	threshold parameters	φ_7^{\wedge}	-3.6765	-9.83	-5.0574	-3.81
		φ_8	-2.9558	-11.07	-4.2266	-3.5
		φ_9	0.209	1.71	0.2233	1.09
General risk attitude (bridge)	respondent characteristics	aged under 30	-0.5075	-2.23	-0.543	-2.03
		aged over 40	-0.9174	-3.05	-1.0966	-3.07
	threshold parameters	φ_5^*	-3.4102	-10.76	-3.9685	-6.23
		φ_6	-2.0503	-10.02	-2.4481	-5.76
		φ_7	-1.5066	-7.73	-1.7974	-5.21
		φ_8	-0.8535	-4.8	-1.0198	-4.08
		φ_9	0.4145	2.4	0.5113	2.09

Log-Likelihood (final): -8.522.882; *AIC:* 17163.76; *BIC:* 17488

base thresholds are fixed at zero

Baseline reaction towards crossing the freeway however, is the use of the footbridge. This means that under normal circumstances, pedestrians would be more inclined to cross legally using the footbridge without including the effect of any of the independent variables.

Table 4.10. Choice risk perception - footbridge crossing

Choice task specific risk rating (bridge)	respondent characteristics	no children	0.1372	1.37	0.1192	1.15
		aged under 30	-0.1248	-1.37	-0.1386	-1.44
	bridge characteristic effects	distance high	0.3184	3.33	0.35	3.55
		crowding low	0.4651	4.59	0.521	4.87
		with security	-2.6086	-18.44	-2.6944	-19.36
		stairs	-0.1517	-2	-0.1713	-2.22
	threshold parameters	φ_1	-2.4851	-17.67	-2.5655	-18.32
		φ_2	-1.8339	-14.26	-1.8944	-14.67
		φ_3	-1.2551	-10.53	-1.297	-10.58
		φ_4	-0.6849	-5.9	-0.7085	-5.89
		φ_5	-0.3973	-3.41	-0.4094	-3.37
		φ_6	-0.1345	-1.12	-0.1343	-1.06
		φ_7	0.0592	0.48	0.069	0.54
		φ_8	0.3236	2.55	0.3475	2.6
φ_9		1.0048	7.75	1.0641	7.7	

Log-Likelihood (final): -8.522.882; *AIC:* 17163.76; *BIC:* 17488

We next turn to the ordered model for the choice task specific risk ladder responses, where we now have sufficient responses in all categories to estimate a full set of thresholds. Unlike the pre-choice task responses, we can now also relate the answers to the characteristics of the choice task.

In Table 4.10, weaker socio-demographic effects, with increased risk perception for respondents without children and reduced risk levels for those aged under 30 (but with neither significant at usual levels) are observed. In terms of bridge characteristics, the risk perception is clearly higher for bridges that are further away or those with few other pedestrians on the bridge.

The first factor model (Table 4.10) was performed to examine the behavioural indicators related to footbridge risk. Using the latent variable of security, six interaction terms appear to be significant for the model of best fit. From the analysis, it is clear that the variable “crowd on the bridge” has the lowest risk odds and increases with increasing crowd volumes. With a factor of 0.07, the risk of crossing with the footbridge increases for low number of pedestrians on the bridge. Pedestrians show higher risk when there are increased numbers of co-crossers. crossing with the footbridge. Both of these finding can be linked to a perception of a greater risk of being attacked, either on the way to the bridge or on the bridge. This is in line with Park (2008) who notes that the presence of a crowd along a closed space provides more sense of security thereby reducing the risk of an attack.

The risk of crossing with the bridge when the pedestrian has no children than when they have children is increased by a factor of 0.14. For pedestrian under the age of 30, the risk of crossing with the bridge decreases with increasing age. When the distance to the bridge is increased at high values, the risk of using the footbridge is significantly increased at a value of 0.32. Risk differences for ages above 40 and employment status are insignificant at zero. Security on the footbridge is highly influential to the perception of risk on the bridge. Higher presence of armed personnel and CCTV coverage means less risk of security. The presence of stairs instead of ramps reduces in severity the risk involved in using the footbridge.

Table 4.11. Choice risk perception - at-grade crossing

			base model		mixture model	
			estimate	rob t-rat	estimate	rob t-rat
Choice task specific risk rating (road)	respondent characteristics	not employed	-0.2299	-1.47	-0.4997	-1.84
		no children	0.2835	1.94	0.4628	2.51
		aged under 30	0.2002	1.38	0.4263	2.32
	road characteristic effects	medium traffic	0.6374	5.8	0.9097	7.71
		high traffic	1.7709	11.5	2.4147	13.03
		fence	-0.194	-3.03	-0.2385	-3.16
		road median	0.1022	1.88	-0.0288	-0.45
		police present	-0.4941	-6.23	-0.6988	-6.97
	threshold parameters	φ_1	-2.1175	-12.91	-2.7567	-11.86
		φ_2	-1.3831	-9.29	-1.9093	-8.87
		φ_3	-1.1274	-7.62	-1.6044	-7.37
		φ_4	-0.3543	-2.68	-0.6467	-3.16
		φ_5	-0.2645	-1.99	-0.5316	-2.59
		φ_6	0.287	2.13	0.1871	0.92
		φ_7	0.6747	4.84	0.7243	3.6
φ_8		0.949	6.66	1.1098	5.46	
φ_9		1.8499	12.03	2.388	11.87	

Log-Likelihood (final): -8.522.882; *AIC:* 17163.76; *BIC:* 17488

Results for the model for choice task specific at-grade crossing risk perception are shown in **Table 4.11**. As in the pre-choice task risk ladder, we see that respondents who are not in employment are likely to indicate a lower level of risk for at-grade crossing than those who are employed, where this is more

significant in the mixture model. The opposite applies for respondents without children and those aged under 30, where again, the significance levels are higher in the mixture model.

Road risk is influenced by employment status and shows that employed pedestrians have a higher road risk than unemployed persons. These estimates are statistically significant at the 1.4 t-ratio value. Same goes for respondents with no children. Sense of responsibility increases with the risk of crossing at-grade.

Under 30s pedestrians have a lower risk of footbridge crossing compared to pedestrians between the ages of 30 and 40. Choice tasks presented within the experiment seem to have portrayed a less dangerous image for footbridge crossing among younger pedestrians. The unemployed, representing a small fraction of the entire sample, are risk averse towards freeway crossing showing sensitivity over choice and with a factor of 0.5, employed pedestrians are positively risk seeking under normal freeway conditions.

Changes in risk behaviour is affected by the factors of roadway and footbridge conditions. As proven in many studies, when traffic is higher, the risk of crossing at-grade is increased (Cantillo et al, 2015). The presence of a barrier - fence or median reduces the risk of direct crossing by 24 and 2% respectively. Police presence reduces the risk of crossing at-grade. The dominant variable in risk perception and generic variable is high traffic volume and security on the footbridge. Farther footbridges and lower crowds increases the risk of crossing legally. Security and comfort level proportionally reduces risk of crossing with the footbridge. Number of pedestrians on bridge is interchanging of signs for levels medium and high in the mixed logit model.

The effect of risk perceptions of safety and security shows that pedestrians perform differently under varying levels of individual variability. It also confirms that pedestrians make difficult decisions when trading-offs between the alternative to cross at-grade or to use the footbridge. The coefficients of the variables security (Armed guard on bridge and CCTV camera), also traffic volume on the freeway are high indicating a dominant influence over the crossing choice process. The impact of law enforcement is seen to fluctuate between the two models and convenience is adequately sampled among responses in the experiment.

We see similarities in the choice specific risk associated with socio-economic characteristics for at-grade and footbridge crossing. The choice risk of bridge crossing is higher for those without children than for pedestrians with children. Same with road risk. Pedestrians with a high sense of responsibility believe that at-grade and footbridge crossing are less risky (this is explained by fear of traffic accidents and the fear of being attacked on the footbridge. Choice is difficult for this category of pedestrians).

4.3.4 Choice analysis

Apart from the ordered response model, two models were developed for the estimation of the binary data. These models employ the standard logit functions developed with and without the inclusion of heterogeneous data respectively. Implementing models of non-heterogeneous nature creates a great amount of bias, causes misspecifications and produces erroneous data (Ben-Akiva, 1999) hence models incorporating heterogeneous data are developed here as well.

4.3.4.1 Choice model

The traditional multinomial or binomial logit model accounts for standard differences in the mean of choice responses across observations. The response category – Footbridge crossing is selected as the baseline reference cell for the model. Log-odds for at-grade crossing provide intercept for that alternative as well as variations utilizing the different categorical variables. The standard BNL has an unordered response variable structure and analyses nominal response data. The first step in estimating BNL is to what type of model is to be estimated. Two models: constant only and alternative related variables emerge. The constant value is the fixed value representing the average effect of all factors that influence choice but not included in the utility specification (Koppelman & Bhat, 2006). Results of the standard binomial model as computed in R are given in **Table 4.12**.

Table 4.12. Results of binomial model with an unordered logit structure

		base model		mixture model	
		estimate	rob t-rat	estimate	rob t-rat
Baseline road preferences	mean constant	-0.1206	-0.62	-0.1044	-0.46
	shift for employed respondents	0.456	2.05	0.6693	2.58
	Shift for respondents resident in CT for over 16 years	-0.3175	-2.06	-0.2953	-1.66
	Shift for respondents without children	0.3147	2.04	0.3059	1.72
	Shift for respondents aged over 40	0.5707	2.83	0.799	3.34
Road attributes	medium traffic	-0.3471	-2.34	-0.462	-2.7
	high traffic	-0.9563	-6.03	-1.1687	-6.18
	fence	-0.4707	-4.52	-0.5337	-4.27
	road median	-0.1186	-1.1	-0.0885	-0.71
	police present	-0.0113	-0.09	0.015	0.1
Bridge attributes	medium distance	-1.5986	-9.85	-1.7524	-8.83
	high distance	-2.0524	-10.1	-2.4758	-10
	medium crowd	-0.1681	-1.22	-0.0732	-0.44
	high crowd	0.25	1.75	0.3556	2.17
	security present	0.9045	7.18	1.1049	7.19
	stairs	-0.1559	-1.5	-0.0989	-0.81

$L(0) = -1247.665; L(C) = -1097.239; L(\hat{\theta}) = 300.852; P^2 = 0.113$

The main findings from the analysis show that given conditions of road traffic (medium and high volumes), barriers and law enforcement all affect the probability that a respondent would cross the freeway directly. Similarly, walking distance, pedestrian crowd on the bridge, security and convenience affect the probability that a pedestrian crosses at-grade or not. Parameterisation corresponds to factors such that the effect due to the first level of the factor is zero (Collet, 2003). Following the linear transformation of the utility functions for At-grade and footbridge crossing, Traffic, distance and crowd levels originally set as direct crossing attributes are categorized as separate variables in the final utility. Hence, the coefficient for medium volumes in the case of traffic shows a difference of 34% less likely success rate compared to zero odds for low volumes and 60.9% difference for high volumes relative to medium volumes. Likewise, “Walking

time” and “Pedestrian crowd on bridge” show variations relative to corresponding “low” levels of each factor. Goodness of fit for attributes is tested using robust *t*-ratios and *p*-values. Ratios greater than 1.4 suggest that the coefficient is statistically significant at the 95% confidence interval. Attributes of median barrier, police enforcement and medium volume of crowd on bridge show a low correlation with the dependent variable (lower *t*-ratios). These factors are not significantly different from zero when the utility levels are zero-centred.

Coefficients of high crowd volumes and security presence on the bridge show a higher likelihood for footbridge crossing than direct crossing. An increased confidence is observed for security on the footbridge showing that the control alternative- footbridge crossing is preferred over at-grade crossing and holds the highest odds ratio for legal crossing.

When traffic volumes increase, the likelihood that a pedestrian crosses the freeway reduces proportionally. The presence of a fence along the freeway reduces the likelihood that a pedestrian would cross directly. When jersey walls (concrete median) are present, pedestrians are more likely to cross with the footbridge. Likewise, the absence of a police agent increases the likelihood that a pedestrian cross directly.

Walking distance to the footbridge if increased decreases the likelihood that a pedestrian cross with the footbridge. This is in line with Cantilo et al (2015) that observed that the probability of being delayed along a line of trip has a significant effect on crossing choice. Larger distance diminishes the probability of safer crossing alternative.

A tricky situation is presented with the crowd level on the footbridge. Apparently, it is less likely that a pedestrian cross with the footbridge if there are considerable number of co-crossers using the bridge. However, at a higher volume, depicted by a fully crowded footbridge based on the choice scenario presented in the task, pedestrians would be more likely to make safer crossings using the footbridge. The impact of perceived risk is clearly depicted as a trade-off between the feeling of security among more persons than fewer people, a compelling case of group dynamics.

4.3.4.2 Heterogeneity around the mean

Taste variation in experiments has an effect on the outcome of choice models (Hensher et al, 2015; Chesher and Santos Silva, 2002; Fowkes and Wardman, 1988). **Table 4.13** presents the shifts in the alternative specific constants (ASC) for specific group of freeway choice crossers. The results of these shifts demonstrate another form of heterogeneity in the dataset. The vector coefficients are compared to the baseline values of general at-grade crossing.

Table 4.13. Alternative specific constants

Variable	Parameter	Odds ratio	Rob. t-ratio	
ASC_at grade_general	$ASC_{at\ grade}$	-0.1206	0.8894	-0.62
ASC_at grade_not employed	$ASC_{at\ grade\ no\ empl}$	0.4560	1.5778	2.05
ASC_at grade_not PT	$ASC_{at\ grade\ not\ PT}$	0.0000	1.00	N/A
ASC_at grade tenure_under_5	$ASC_{at\ grade\ tenure\ 5}$	0.0000	1.00	N/A
ASC_at grade tenure_over_16	$ASC_{at\ grade\ tenure\ 16}$	-0.3175	0.7280	-2.06
ASC_at grade_no_children	$ASC_{at\ grade\ no\ child}$	0.3147	1.3698	2.04
ASC_at grade_under_30	$ASC_{at\ grade\ under\ 30}$	0.0000	1.0	N/A
ASC_at grade_over_40	$ASC_{at\ grade\ over\ 40}$	0.5707	1.7695	2.83

Here it is seen that employed pedestrians are more likely to cross directly due to increased permissible waiting times. The difference between the probability of an employed pedestrian crossing with the footbridge and an unemployed pedestrian crossing at-grade is 0.46 ($p < 0.001$; CI 95%). Pedestrians who have lived in Cape Town for more than 16 years are more familiar with the crossing environment, have either direct or third-party experience with the dangers of footbridge use are more liable to crossing illegally. Pedestrians without children take more risk in crossing the freeway, proving that the level of responsibility is a significant factor in freeway crossing choice. Pedestrians over the age of 40 would more likely cross using the footbridge confirming that elderly pedestrians, the most vulnerable group of road user's techniques (Lobjois et al 2013), are likely to cross using safer options not considering risk perception or other influencing factors. In summary, we observe that un-employed crossers prefer at grade crossing. Crossers without children strongly prefer to cross at grade. Older pedestrians have a higher baseline preference for at grade crossing while having been in Cape Town for longer, motivates safe footbridge crossing.

4.3.5 Cholesky's transformation – correlation analysis

One problem in the analysis of research data is the occurrence of multivariate data which are not completely independent i.e. the correlations among them are not zero. To prevent collinearity, a structure is generated to observe the correlations between these parameters.

The purpose of estimating correlation structure is to improve on the accuracy of model interpretation by reducing inefficiency brought about by model distortion as expressed through bias within the logit coefficient and as a variation in standard errors (Hensher, Rose & Greene, 2015). In this section, we link the choice-specific and general risk perceptions together and determine if and how much a change in the built environment or traffic affect choice.

First, we obtain covariance values of the indicators. In estimating collinearity of risk perception parameters, we estimate the contribution of the risk effect on the general outcome of crossing choice. A triangular matrix for the random variables incorporating heterogeneity is produced from the covariance values of the risk parameters. It is assumed that the response for each choice task is influenced by unobserved variables of safety and security, or attitude towards the choice variables. Several authors through series of linear and non-linear model analysis have documented this theory (Marrazo et al. 2010; Wilkinson, 1965). A confounding variable explains the correlations between the explanatory and risk perception variables. As discussed in **section 2.3.4**, the purpose of the Cholesky decomposition is to generate correlated random variables. The correlation matrix is obtained by parameterizing the covariance through standard deviations for the two variables for which correlation is tested. Randomness across people in the ASC for road crossing and the four different risk variables (general and task specific, for road and bridge) is effected including correlation between the random components. The components of the Cholesky matrix (multivariate normal with $\varepsilon \sim (b, \omega)$) is shown in **Table 4.14**. In the Cholesky transformation, draws are obtained from the multivariate normal (risk variables and the $ASC_{at-grade}$)

Table 4.14. The components of the Choleski matrix

	Mean (b)	SD (ω)
General road risk	0 (fixed)	1.89
General bridge risk	0 (fixed)	1.06
Task specific road risk	0 (fixed)	1.55
Task specific bridge risk	0 (fixed)	0.47
$ASC_{at\ grade}$ in mixed model	-0.1044	1.10

In the estimation of the Cholesky matrix, we had to constrain three parameters to zero given very low levels of statistical significance. The remaining parameters in Table 4.15 have varying levels of significance, and differ in signs. The main implications become clear when looking at the implied variances in Table 4.14 and correlations in Table 4.15. We see higher variance across respondents in the risk attitude towards road crossing, both in the general and the choice task specific attitudes, where for both road and bridge crossing, the variance is greater for the former than the latter. We also see substantial variance in the ASC for at-grade crossing in the choice model, which shows that while the mean preference for at-grade crossing is not significantly different for road crossing, major differences exist across respondents.

Finally, we see interesting findings for the correlations. The pre-choice task risk attitudes are highly positively correlated between road and bridge (0.85). The road risk attitude is positively correlated in the

general and choice task specific attitudes (0.7), while the opposite applies for the bridge risk (-0.3) before and after the choices. At the task level, there is negative correlation between the bridge and road risk perceptions. Those respondents who indicate higher risks for either bridge or road before the crossing have lower utility for the at-grade crossing in the choice task, a finding that is maybe difficult to explain. What is more in line with intuition is that higher risk perception for the at-grade crossing in the choice tasks leads to reduced utility for the at-grade crossing, while higher risk perception for the bridge crossing increases the utility for the at-grade crossing.

Table 4.15 shows the correlations for general and choice-specific risk perceptions. It is observed that positive correlations exist between the general perceptions of road and footbridge risk. Negative correlation is seen in two risks within the choice task (-0.34) showing that within the element of choice, at-grade risk perception increases with a corresponding decrease in footbridge risk perception. Higher road risk perception correlates with reduced ASC for at grade crossing and there exists a strong correlation between general risk perception of the bridge and general risk perception of road. This figure (0.84) confirms that pedestrians have high risk opinions towards the use of footbridge and traffic safety. The correlation value (>0.5) implies the existence of a strong trade-off between crossing at-grade and using the footbridge, for freeway crossers. Looking at the alternative specific constants, clearly general road risk perceptions hold lower values, showing that under normal conditions, the risk of crossing directly is decreased regardless of choice situation. The risk perception of using the footbridge (choice footbridge) is increased when the null hypothesis of crossing at-grade is kept at a constant (ASC). Moderately strong correlation is observed between choice-based road risk perception and general road risk perception, i.e. pre-survey or general risk shows stronger risk perception than in the choice tasks. This implies that higher perception of road risk corresponds to perception of choice-specific risk and pedestrians are more inclined to shift to safer modes of crossing when interventions are implemented.

Table 4.15. Correlations for general and choice specific risk

	<i>General_road</i>	<i>General_bridge</i>	<i>Choice_road</i>	<i>Choice_bridge</i>
<i>General_road</i>				
<i>General_bridge</i>	0.847578811			
<i>Choice_road</i>	0.703651722	0.230336983		
<i>Choice_bridge</i>	-0.350835989	-0.297361151	-0.344858376	
<i>ASC</i>	-0.386138815	-0.327283077	-0.408764896	0.264451886

4.4 Results in policy analysis

Marginal utilities

To provide interpretable outcomes in a random utility model, it is important to estimate substitution rates which represent the ratios of attribute coefficients identified in the model. The marginal rate of substitution is defined as the rate at which respondents are willing to trade off one attribute for another (Bennett & Blamey (Eds.), 2001). Application of marginal rates of substitution is more commonly found in monetary estimations of willingness to pay. However, seeing as there exist no cost or price in attributes within this experiment, we present the non-monetary substitution rates of at-grade crossing and footbridge use as a linear function displayed in Table 4.16.

Table 4.16 Substitution rates of freeway crossing attributes

	Traffic(High)	Traffic (medium)	Fence	Median	Police
Distance (medium)	3.79	1.50	3.28	19.80	116.83
Distance (high)	5.36	2.12	4.64	27.98	165.05
Crowd (medium)	0.16	0.06	0.14	0.82	4.88
Crowd (high)	0.77	0.30	0.67	4.02	23.71
Security	2.39	0.95	2.07	12.48	73.66
Stairs	0.21	0.08	0.19	1.12	6.59

By definition, a pedestrian's willingness to value higher traffic interventions over a reduction in the medium (half-way) distance of 640 metres* to the footbridge is ~4. This is the unit required to keep the utility of pedestrian crossing constant across alternatives. In the same vein, the trade-off required for medium traffic of 15 vehicles and a reducing distance of footbridge along the line of trip is 1.5. This show a lower preference for higher traffic than for lower traffic volumes. Pedestrians value the attribute of Police on the freeway over higher walking distance to the bridge, implying that the presence of a law enforcement agent would most likely reduce their illegal crossing behaviour compared to the far distance of the bridge along their line of trip. The farther the distance to the footbridge without the presence of a restrictive personnel or a fence or median, the less the ability to maintain legal crossing behaviour of the freeway. All three of barriers and law enforcement attributes record high values in relation to distance to the footbridge.

The use of stairs has the lowest trade off estimate with traffic showing a lower willingness to trade off traffic flow effects for convenience. Substitutional rates can also be explained in terms of changes in group operational characteristics (Cano, 2014). For example, from the table it is observed that the presence of a maximum crowd on the footbridge has the same effect on the crossing preference of pedestrians as the

traffic volumes, and presence of a police personnel on the freeway. This is clearly represented in table 4.17. The effect of a reducing high flows of traffic is compensated by higher crowd number on the footbridge is higher than that of a reduction in medium flows of traffic traded-off by same number of crowd on the footbridge.

Table 4.17 Operational substitution rates for quantitative attributes

Attributes	Compensating attribute	Units
High Traffic volume	14 pedestrians	19 veh/lane
Medium traffic volume	14 pedestrians	5 vehicles/lane
Police	14 pedestrians	24 personnel
Police	8 pedestrians	5 personnel
High Traffic volume	1120 metres	134 veh / lane
High Traffic volume	640 metres	94 veh/lane

**Standard measure for walking distance is 80m for 1 minute of walking time.*

Each substitution value helps in understanding which element of freeway crossing should be emphasized to obtain optimal pedestrian satisfaction for safer crossing. For example, it is a relief to know that changes in traffic according to the results would be less appreciated than the presence of law enforcement, infrastructure and security. For a freeway, the traffic volumes, speed and flow can hardly be modified according to the South African Road Classification and Access Management Manual (SARCAM, 2012). The outcome of the substitution rates in this research assist in the decision to restrict freeway traffic interventions thereby allowing the relevant authorities channel their strategies towards improving elements of freeway structures that can actually be changed and modified.

As a final step in our analysis, we now look at a number of implied relative sensitivities, i.e. trade-offs between different components. These are reported in **Table 4.18**. We start with exploring the importance of the increased utility that specific segments of respondents have for at-grade crossing, as reported earlier in Table 9. Increased utility is compared with the reduction in utility resulting from increasing traffic. The presence of a non-linear coding for the traffic attribute complicates matters, and the assumption that the change in utility is linear between the different levels is developed. As an example, the estimate of -0.3471 for medium traffic in the base model implies that each additional vehicle going from 5 to 15 vehicles accounts for a reduction in utility by 0.03471. The same logic is applied to the change in utility from the middle to the higher level, and for the crowding attribute. It is observed that a substantial increase in traffic over the base level of 5 vehicles per lane is needed to make at-grade crossing as unattractive as bridge crossing for respondents who are in employment, where the numbers are similar for both models (11.79 vs 12.93 additional vehicles). For the second trade-off, respondents, resident in CT for under 16 years (i.e. the

opposite sign from Table 9), record a much bigger difference between the two models, with the mixture model showing that for such respondents, there would need to be 6.39 additional vehicles per lane to make at-grade crossing as unattractive as bridge crossing, while it is 9.15 for the base model. A much lower trade-off also arises for the mixture model for respondents without children (6.62 additional vehicles compared to 9.07) while for respondents aged over 40, the highest trade-offs are observed, with the two crossing types only becoming equivalent with an increase by 13.67 vehicles and 14.77 vehicles, in the base and mixture models, respectively.

Finally, we consider trade-offs between the different at-grade and bridge characteristics noting that the presence of a fence is as strong a deterrent to at-grade crossing as an increase in traffic by 12.03 vehicles per lane in the base model, and 11.01 in the mixture model. For bridge crossing, the trade-offs relative to walking time are evaluated. Here, we see that respondents have a very low willingness to walk further. As an example, an increase to the highest level of crowding (from 2 to 14 people) only compensates for around 1 minute in additional walk time, while the willingness to walk further to a bridge with security measures is higher, but still low, at 3.39 minutes in the base model, and 3.78 minutes in the mixture model. This shows a strong need to position bridge crossings closer to each other.

Table 4.18: Implied relative sensitivities

Trade-offs between at-grade and footbridge crossing alternatives:	base model	mixture model
additional vehicles needed per lane (over 5) to make road crossing as unattractive as bridge crossing for those in employment	11.79 [veh]	12.93 [veh]
additional vehicles needed per lane (over 5) to make road crossing as unattractive as bridge crossing for those resident in CT <u>under</u> 16 years	9.15 [veh]	6.39 [veh]
additional vehicles needed per lane (over 5) to make road crossing as unattractive as bridge crossing for those without children	9.07 [veh]	6.62 [veh]
additional vehicles needed per lane (over 5) to make road crossing as unattractive as bridge crossing for those aged over 40	13.67 [veh]	14.77 [veh]
impact of having a fence as a deterrent to at-grade crossing evaluated in terms of vehicle increase from 5	12.03 [veh]	11.01 [veh]
willingness in minutes to walk further to a bridge in return for increase from 2 to 14 pedestrians	0.94 [min]	1.22 [min]
willingness in minutes to walk further to a bridge in return for security measures	3.39 [min]	3.78 [min]

4.5 Respondents' suggestions for freeway crossing

In the final question preceding the choice task, respondents respond to the question “what would you like to bring to the attention of the transport authorities regarding the issues of safety and security on the freeway?” Figure 4.8 shows an overview of the suggestions put forward.

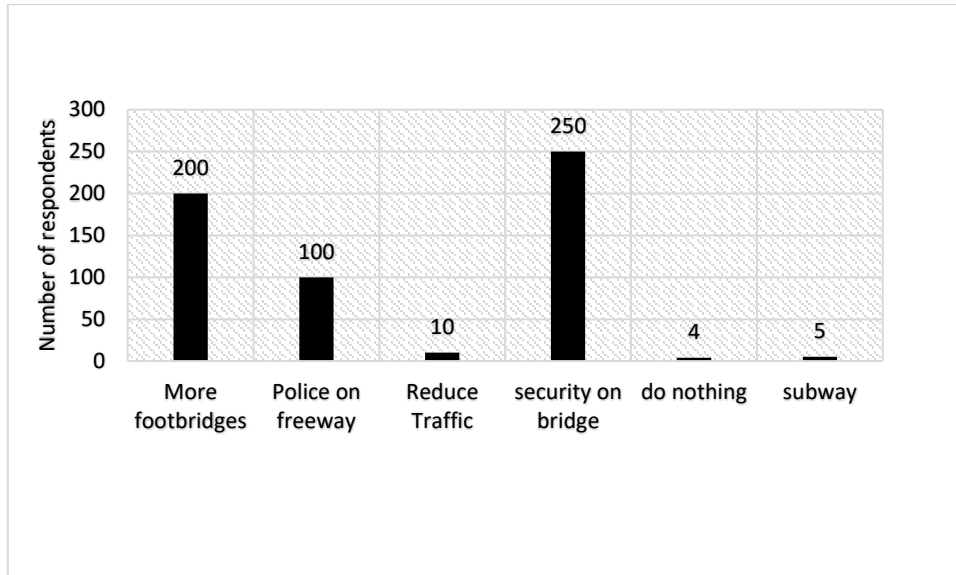


Figure 4.8 Respondents' appeal to transport authorities.

It is possible that pedestrian access to the freeway is inevitable because the question sought to elicit propositions that would create a complete shift from illegal to footbridge crossing. Many respondents indicated that they do not have a choice rather than to cross at-grade under the present circumstances. Changes in land development planning and practice appears to be the best approach to eradicating the problem of illegal crossing on the freeways.

4.6 Concluding remarks

The aim of this section has been to assess pedestrian crossing behaviour along freeways in Cape Town. The methods employed in analysing the dataset includes ordered and binary logit, also incorporating heterogeneity around the mean of individual variables. Risk perception analysis show that socio-demographic characteristics account for changes in the behaviour of pedestrians on the freeway. The goodness of fit measures were examined by comparing of the different elements of the models in terms of log-likelihood and rho-squared values. Choice analysis also show expected signs to the coefficients of built-environment variables and the shifts of alternative specific constants.

Chapter Five

Implication of preference information on freeway crossing behaviour.

We have shown from this study that binary models are capable of predicting freeway pedestrian crossing behaviour based on socio-demographic and built-environment characteristics. We estimated three models in response of independent and risk variables:

1. Ordered response model to estimate the effect of on risk perception on choice.
2. Binary model determined standard choice probabilities.
3. Heterogenous model improved on the outcome of the basic choice model.

Running these analyses helped us to make relative predictions about crossing behaviour and the effect of attribute changes on choice and risk compositions. This section will discuss the experiment and how the results influence real behaviour.

5.1 Stated Choice outcome

Pedestrians that cross the freeways are generally classified into two categories namely choice and captive crossers. The choice crossers are those who have a choice to either cross directly on the freeway (at-grade) or use the footbridge. Captive crossers on the other hand, have only a single option of crossing the freeway (at-grade). The captive crossers lack opportunity to decide how to cross the freeway. Due to marginality in scope of research, we focus on choice crossers who have experienced both ways of freeway crossing.

A research conducted by Sinclair and Zuidgeest (2015) provided insight into the attributes that influence the decision-making process of pedestrians when choosing to cross. The objective was to examine and analyse the behaviour of pedestrians towards crossing with the freeway (illegally) when a safer option is available. Factors of safety and convenience stands out as heuristic attributes that contribute to the predictive choices of pedestrians. We carry out an in – depth research to expand on the results of this study. Within the case study area, captive users were found along the N7 freeway and therefore excluded from the target population.

The finalized areas of concentration were the N1, N2 and R300 freeways of Cape Town municipality. High pedestrian activity along these routes make these selections viable for the study. In the beginning of the study, attributes of traffic volumes, police enforcement, fence and median barriers were selected for at-grade crossing while walking time, crowd on bridge, effort and security levels were defined for footbridge crossing. It is possible that some pedestrians would have considered other factors in their decision to cross the freeway. However, increasing the number of attributes in the choice task is burdensome/would

negatively impact the outcome of the experiment. Risk perception for the ordered logit and relevant socio-demographic information were included in the experimental design. Incorporating these factors into the model was observed to have increased the overall model fit. The risk perception factors were represented by ladders that ranged from low probabilities to high. The addition of a Likert scaling in the risk experiment also enabled the analyst to capture the ordinal nature of safety and security.

5.1.1 Freeway crossing survey

Choice crossers were tasked under the assumption that they had crossed the freeway at least once and were above the age of 18. The trip purpose was divided into home-based work trips, school trips others. Survey response rates were higher during the early morning and late evening peak periods. Casually dressed interviewers also helped to absolve the fear of legal sanctioning thereby alleviating the tense nature of the survey environment. This showed that complex and sensitive situations in survey may be addressed by casual approach.

5.1.2 The dataset

Sample dataset showed a higher presence of males on the freeway than females. This risk seeking behaviour of males have been researched in literature (Holland & Hill 2007; Granié, 2009) to be influenced by perceived value of crossing rather than lower safety conscious levels. It's also a depiction of gender roles for men as conformity has been proven to be a significant factor in the internalization of risk-taking behaviours among male pedestrians (Tom & Granié, 2011).

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. 90% of the sampled respondents have lived in Cape Town for more than 5 years indicating habitual behaviour and group dynamics as critical factors for determining risk perception (Räsänen et al, 2007). The action of other crossers consistently influence to a great extent the choice of individuals to cross at-grade or use the footbridge.

The use of a public transport before or after accessing the freeway showed that many pedestrians are likely unable to complete trips involving public transit without needing to walk along or cross the freeway. It is therefore necessary to improve on accessibility of urban networks around the freeway.

Risk perception for low levels at 1 – 5 reveal lower outcomes for traffic and footbridge risk. General levels of freeway crossing risks show an increasing tendency towards higher risk for freeway crossers same as for footbridge users. Pedestrians perceive the risk of crossing the freeway directly to be highest at 9 and 10. This is in line with hypothesis statement. The risk behaviour towards road crossing does not change gradually as in the case of footbridge crossing. Pedestrians view direct crossing as rather extremely dangerous with only few 16 respondents choosing risk levels between 1 and 8.

Fifteen respondents have low perceptions towards bridge risk showing a risk-averse attitude towards raised crossing. The rest 95% perceive footbridge crossing to be higher within the range of 6 and 10. As the perception levels increase for footbridge risk, the number of respondents likewise increase, thus implying maximum sensitivity towards criminal attacks on the bridge. 61% of the sample respondents have the highest perception of bridge risk ranging between 9 and 10. The implication of this is that direct freeway crossing is considered to be more dangerous than the use of footbridge.

5.1.3 Model estimates

As described in chapter three, different models were developed and calibrated for the purpose of identifying the most representative analysis of data. The criteria for model selection of best performance was based on the accuracy of variance and around the mean coefficients and the goodness of fit values using LL, AIC and BIC and in the case of the choice models, Halton draws were selected in estimating the shift coefficients for specific road users. We observed consistency in the model estimates with which previous studies in pedestrian crossing choice behaviour record. The magnitude of variation in the odd ratios and standard errors among the different models point to the reliability of model results.

Ordered-responses and risk correlation parameters

Zaalberg et al. (2009) already showed that adverse natural events are associated with higher individual risk perceptions. From the results of analysis, the risk perception of at-grade crossing is observed to be more pronounced than that of footbridge crossing as demonstrated by the significant values recorded for road risk crossing model. The differing results of risk perception throws light on how pedestrians perceive the risk of illegal crossing. It is therefore critical to spur pedestrians towards the danger of illegal crossing behaviour, a task which is achievable by ensuring adequate road risk awareness.

In general, risk perception for employed persons proofed to be higher than for unemployed. The outcome of risk effect on employment status is higher than sense of responsibility showing a lower aversion to at-grade crossing for pedestrians with children than for the employed. Cooper (2003) confirms this finding by noting that perception of risk is affected by personalities, appraisal of situations and work safety norms. In addition, pedestrians who have children and are older than 30 have a higher perceived risk for crossing the freeway directly. The presence of police personnel and a fence barrier reduces road risk perceptions showing that pedestrians respond well to physical and human enforcements and view crossing directly to be safer under such circumstances. The impact of police presence on risk may be linked with the speed of drivers on the freeway. Risk of crossing the freeway is more likely reduced if drivers are conscious of law enforcement personnel regulating the speed of vehicular flow.

Robust t-ratios for the risk perception coefficients were significant for traffic, fence and distance barriers under the ordered logit structure showing that traffic flow and enforcement highly determines the perception

of risk for at-grade crossing. This is also confirmed in Cooper (2003) who reports that prior experience affect people's perception of risk.

We also observe non-trivial correlations between all covariance factors. The choice probability for freeway crossing has the lowest correlation for task specific bridge risk at a value close to zero while the highest value is recorded for general perceptions of road and bridge risk. The impact of these values lie in the estimation of the random parametric model showing that significant effects are accurate for a respondents' individual choice probabilities over the lines presented by population distributions.

The choice model

According to the results of the choice model, respondents clearly demonstrated a higher preference for footbridge crossing rather than freeway crossing. This is in line with several studies confirming that pedestrians are more likely to choose safe modes of crossing (Papadimitriou et al, 2016; Cantillo, et al, 2015; Sinclair & Zuidgeest, 2015).

The alternatives of direct and footbridge crossing were considered competitive and exhaustive for pedestrian crossing choice on Cape Town's freeway. With every inclusion of attribute and attribute levels, the intercept coefficient was significantly affected. If all the attributes had equal effect on the decision to cross, the probability of choosing to cross with the freeway directly would be reduced.

The unobserved variable, ε is a random variable with a known population distribution represented by the individual characteristics of the sample. We cannot measure the utilities directly due to the abstract nature of the error component, ε , hence we create what is known as a probabilistic theory to explain the happenings of the data or events recorded. In doing this we learn the unobserved differences through indirect estimation of odds and parameter coefficients.

In the estimation of odds ratio, the coefficients of the logit expression were transformed using the exponential function (e^β) while the probability of choosing either alternative is computed as:

$$P = \frac{odds}{1 + odds}$$

The indicators of safety and security were applied to the risk perception parameters for modelling heterogeneity. We considered the variations in the estimates of parameter coefficients where taste among individual respondents in the experiment is included and interpret the results in connection with the model performance. Convergence was achieved for the sample as confirmed by the outcome of reasonable log-likelihood ratios. Convergence in computational analysis implies that the parameter estimates which are based on beta coefficients are closest to the maximum value (MLE). Also examined are the values of each given coefficient, compared relatively to a specific constant, α .

Variables that are of utmost importance to freeway crossing behaviour are traffic, walking distance and level of security. This is because the response to traffic safety affects the overall reaction towards crossings. How pedestrians perceive the level of risk on the roadway influences their decision to cross. Julian Hine (1993) reports on changes to crossing behaviour under varying traffic conditions for free-flow mixed use roadways and notes that the criteria for traffic volumes in cases such as these (and for the freeway) are especially significant. Waiting time and traffic volume also has a joint effect on crossing choice (Sisiopuki and Akin, 2003; Hamed 2001; Sharples and Fletcher, 2001). Pedestrians would cross legally if footbridges were closer to the desired line of trip as this reduced delay in waiting times, especially in the case of high traffic volumes.

The presence of security impacts the decision to use the footbridge. In the low income, high crime populated city of Colombia, Cantillo et al. (2015) reports that security on the footbridge with emphasis on safety from robbery attack is of utmost importance to pedestrians in the decision to cross the roadway. We observed here also that increased security on the footbridge is likely to reduce the risk of crossing illegally.

The effect of median barrier and fence on the freeway is split considering the restricted information available for pedestrian attitude towards obstructions on the freeway. Tang et al, (2016) and Bowman & Vecellio (1994) emphasize that median presence acts as a hindrance to crossing and reduced pedestrian casualty, while other studies have represented medians as better means of assisting pedestrians to cross over to the other side of the carriageway (Gupta et al, 2015; Bartlett et al, 2012; Zegeer et al, 2005).

Large pedestrian crowds make footbridge crossing safer, which is similar to results obtained in the risk interaction outcomes of this study. The presence of large crowds implies that at that moment the footbridge is less prone to a dangerous robbery attack. Also, it implies the presence other non-threatening crossers who would rise to the occasion of defence should an incident take place on the bridge. For the attackers, an environment where maximum number of persons reduces the isolated effect of a single robbery. This is emphasized by Ramsden (2015) stating that increased cognitive load of attackers led to a shift from employing simple violence methods to gun violence. Hence, when rational thinking is reduced, the brain settles for less action. An outbreak of violence involving higher mechanized weapon is less likely on the footbridge.

Taste variations across respondents are observed where the effect of individual characteristics is randomly distributed. Some of the individual variables do not interact significantly with the operational attributes of both site and latent variables, showing that there's a more uniform perception of risk for the built-environment variables.

Estimates of crossing factors give indications of the likely effects that a change in the units of the observable variables would make on the pedestrian choice of crossing. This information assists authorities in the appraisal of existing facilities and provides guidance for upcoming freeway projects.

Test for AN-A

Test for non-attendance in the experiment showed a reflection of environmental and population complexity. Given the conditions of the freeway communities including population and diverse socio-demographic characteristic, responses recorded did not reflect adequate information suitable for further analysis. In the first stage of survey, multiple selections were made for “most and least factors that are important to you” showing that respondents did not consider single factors as most or least important in choosing to cross the freeway. However, this information is important for priority goals and useful policy changes in terms of intervention implementation.

5.2 Recommendations to transport Agencies and government parastatals

Identifying a problem, seeking options and implementing the chosen strategy are essential steps in transportation planning. In this section of the research, we decide on how the theoretical framework can be used to analyse and predict policy trends in freeway pedestrian crossing. We consider the following trends in the application of model outcome to real life policy situations.

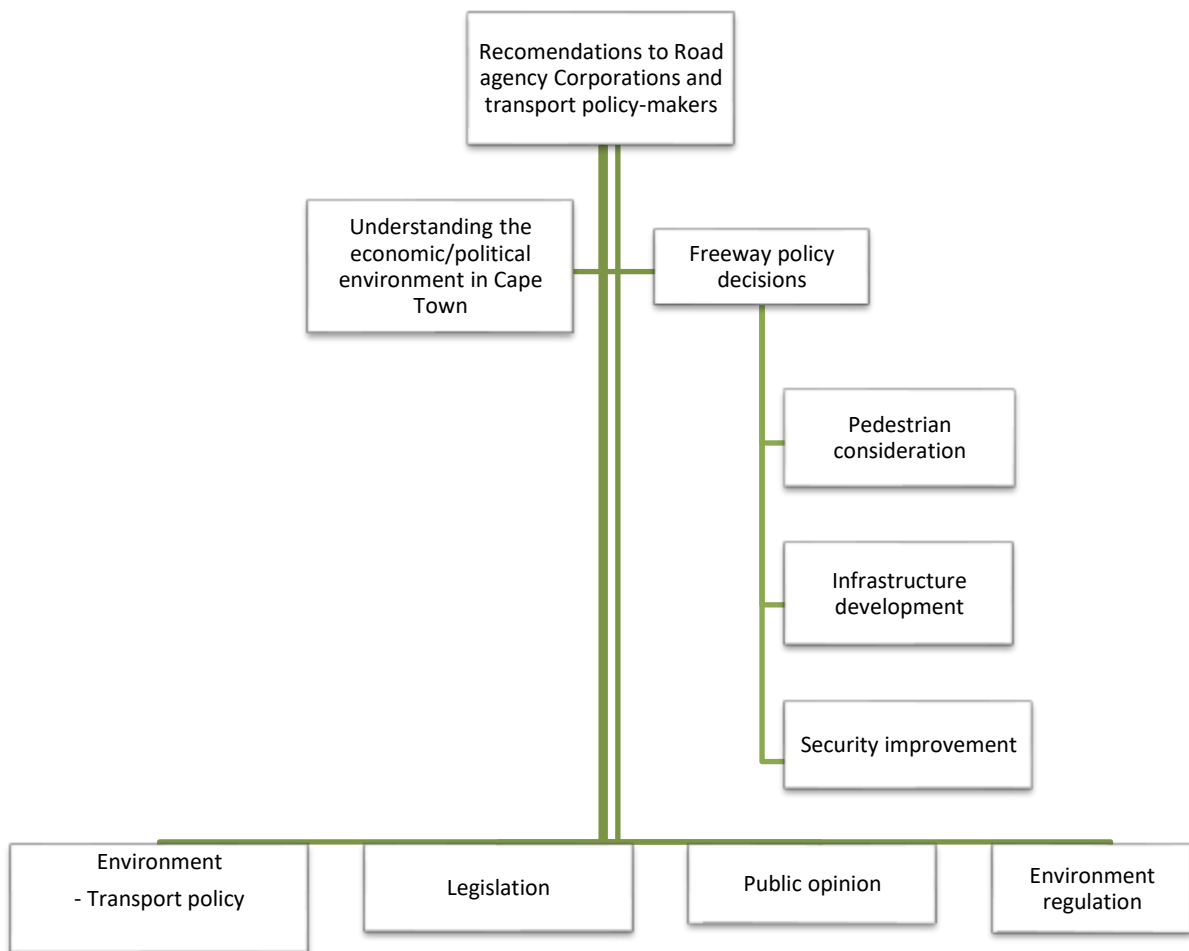


Figure 5.1. Recommendations for policy interventions

According to Sinclair & Zuidgeest (2015), ideas generated towards behavioural interventions include:

Pedestrians

- Creating more opportunities for pedestrian awareness.
- Initiating community based projects that focuses on enlightening community dwellers on the risk of crossing the freeways.

Motorists

- Heightened consciousness of pedestrian activity along freeways
- Watchfulness of pedestrian-vehicle interactions.

Engineering interventions for low income countries as identified by (Gupta et al, 2015) is on the basis of population and location attributes. High-level advanced strategies which are commonly applied in HICs for safety among vulnerable road users are not immediately available for use in African cities. Hence, tech intelligent transport systems and collision avoidance procedures to reduce traffic related incidents on the freeway are minimal.

The process of policy formulation and implementation is a complex one that requires an assessment of the current situation, raising awareness, ensuring that the policies are strictly adhered to, acquisition of state and government approval, and much more. Transition from a priori state of a passive crossing behaviour to an active one will require drastic action for such changes to be observed. Financial disincentives in the form of tolls to reduce excessive traffic, construction of public transport corridors and shopping complexes on adjacent land areas within the communities will eliminate unnecessary activity on the freeway.

In this research, pedestrians between the ages of 18 and 30 years, show a high penchant for freeway at-grade crossing. Practical initiatives through electronic and digital media while lobbying for definite freeway policy change as administered by the World Health Organisations (WHO) in the past may be applied to the freeway crossing scenario for effective mitigation of illegal crossing.

The length of time that a regulative order has been enforced in matters relating to law forms is critical for long term implementation. Enforcement goes hand – in – hand with legislative commands and ensures the severity of the law. Staton, (2016) reviewed the impact of legislation on the overall outcome of injuries and deaths noting that a reduction of crash statistic was demonstrated with the immediate enforcement of legislative orders. A reduction in law enforcement led to a floundering of the rules of road safety which in turn increased traffic crash outcomes of that year. Enforcing the use of reflective dressing for example would affect the thought pattern of pedestrians and eliminate extraneous movement on the freeway especially late at night.

A reduction in pedestrian activity along roadways has been observed in connection with the presence of police agents. More pedestrians are law abiding when there are risks of altercations with the relevant

authorities as seen from the outcome of this research. Hence, locations of high fatalities and hotspots can be insured for consistent protection and regulatory.

5.3 Summary

Complex solutions are restrained under the Cape Town freeway environment. However, improvements are attainable with proper use of available tools and practices. Enforcement, security, increased freeway protective barriers are in line with the results of this research and in collaboration with proven methods of preventive operations researched in other studies. Application of localised interventions towards an improved freeway environment that is all inclusive and safe for vulnerable users can be achieved.

Chapter Six

Conclusion

Current freeway environment in Cape Town utilizes the pedestrian bridge as a safe alternative to crossing the freeway. Many pedestrians do not make use of this facility and resort to walking across, thereby breaching the rule of law and endangering their lives in the process. This study has investigated this behaviour, and elicited preferences of choice crossers toward crossing interventions for the freeway. Identifying the problem, seeking the most effective solution and implementing the chosen strategy are essential steps in transportation planning. This research has examined pedestrian crossing preferences on the freeway as a preventive means of reducing pedestrian-vehicle collisions.

Research summary

A stated choice survey was conducted to obtain data for the estimation of binary logit models. Over the years, the South African National Road Agency Ltd. (SANRAL) has recorded an increasing number of pedestrian activity around the freeways. Investigation began with the introduction of the Freeway Management System (FMS) which captured pedestrian movement and reported statistics on the number, time and frequency of freeway pedestrian activity. A rising interest in the subject matter was established with the high number of pedestrian-vehicle fatalities recorded from the year 2010 and upwards. Investigations became vital in assessing and providing solutions to the problem of freeway crossing.

This research analysed the sensitivity patterns of pedestrians towards crossing a high-speed roadway. Several research have identified pedestrian crossing behaviours at signalised intersections. However, only a few have studied the crossing behaviour of pedestrians on freeways and arterial roads especially one that models pedestrian behaviour in a low-income city. Individual characteristics and risk perception play a huge role in the decision to cross the freeway, attributes of which have been omitted in several Cape Town roadway studies. In order to accurately assess the position of infrastructure development and attitude of pedestrians towards elements of freeway and footbridge, choice modelling was necessary to categorize the contributing factors into human and individual variables and to understand their individual effect on pedestrian choice. An orthogonal stated choice experiment was designed from the combination of 8 attributes and a mixed level (2 x3). Generation of treatment was done with the use of SPSS statistical software. Choice tasks were sketched with the aim of reaching the less educated and to perform a more effective and relatable survey. This was implemented after pilot tests, discussions with transport officials and a familiarization with the target study area. Choice tasks were generated using a fractional factorial design based on the number of attributes and attribute levels in the design. A paper-based, face-to-face intercept interview was carried out within the vicinities of three major freeways – N1, N2 and R300 to obtain preferences for crossing interventions on the freeway. This study has examined the freeway crossing

attributes of location specific and individual characteristics under hypothetical scenarios. General and choice-specific perception of risk for at-grade and footbridge crossing have also been identified.

Different types of Logit models were developed. The ordered logit model took into account the ordinal nature of risk perception in response data, while the standard binary and mixed logit model explained the choice behaviour under normal attribute influence with the incorporation of scale preferences.

Literature review conclusions

The objective of the systematic literature review was to draw out motivations behind the decisions of pedestrians in a roadway setting under conditions of raised crossings and within the context of LMIC. The literature review discussed studies on logit models and extracted specifications which have been employed in stated choice for identifying pedestrian crossing attributes under diverse conditions. We have been able to establish that a sparse amount of literature exist for freeway crossing. However numerous studies have touched on the issues of general pedestrian crossing and cognitive patterns among choice and captive crossers. We find that stated choice surveys have been effective in major fields of research as compared with revealed preference information. Moreover, stated choice methods present a more debatable concept for future development. Logit models that integrate random variables into their structures provide better fit for performance and has been observed to be a most common means of estimating logistic models due to its ability to measure complex conditions.

Literature that employed the use of discrete choice methods were reviewed to examine the stated choice processes involved in previous studies. Considering the sensitive nature of the experiment, the importance of ensuring correctness of information entered as data, and the difficulty in reaching target population by other electronic means, the intercept survey proved to be the best approach for effective survey. More research on this subject matter will increase the literature base for freeway crossing and encourage diversity for methods to be employed in analysis.

In sampling the study area, a look into the pedestrian activity figures indicated that the working classes make for more movement along the freeways. This number encompass users of public transport and private car owners. The quasi sampling technique was implemented following the target population estimated leading to a selection of 300 qualified respondents.

Survey questionnaires and main exercise

Before implementing the survey, it was necessary to decide what demographic attributes were relevant to the objectives of the research. In excluding certain demographic information, consultations were made and the study area was duly investigated. In the order of questionnaire, the informed consent was first a pre-qualifying section that aimed at supplying information about the research and evaluating respondent familiarity with the freeway-crossing environment. The survey was sectioned into four short parts the first

being the socio-demographic questions; second, the choice task preceded by a general risk perception module; and third, a question aimed at receiving suggestions for future changes on the freeway.

Validation testing through a pilot survey was conducted to ascertain the efficiency of the survey instruments. This testing was carried out on a small number of pedestrians along the freeway by the interviewer. The pilot survey recorded minor changes that needed to be made on survey tools to improve the effectiveness of final survey. This was implemented consequently before the main survey.

Trainees were recruited for the main survey. The interviewers were professional personnel who had conducted similar exercise previously. They were experienced in face-to-face surveying and versed in the native language of the populace. A two-hour training was organised by the research student.

Interviews were carried out subsequently and time duration for each respondent was set to 10 minutes. Random pedestrians who were walking and crossing within 500 metres of the footbridge in the early hours, midday and evenings (peak periods) of a weekday were interviewed. Proximity to the bridges was a requirement during the survey. The safety of interviewers who conducted the survey meant that interviews could only take place at a distance from the freeway. No choice task was presented to any respondent two times, thus maintaining orthogonality in the experiment. The number of respondents interviewed in each location was based on the characteristics of that location. This meant that areas of high pedestrian activity like the R300 after Stellenbosch, N1 at Okavango and N2 after Vanguard Drive received more responses in data than other freeway locations. A total of 1800 valid observations were obtained from the results of the experiment. Panel data was input to spreadsheet and sorted for analysis.

A descriptive statistic was carried out on the data and the distribution was categorized into the different demographic characteristics and risk perception of each choice responses. Among these categories are the employment status, sense of responsibility, gender, age, public transport drop-off (the possibility that a respondent used a public transport before and/or after crossing the freeway).

Model estimations

The context of high risk crossing environments appears to polarise across crossing choices for pedestrians in Cape Town. Results from risk analysis show by a factor of 0.5, employed pedestrians are positively risk seeking under normal freeway conditions.

Changes in risk behaviour are affected by the factors of roadway and footbridge conditions. As proven in many studies, when traffic is higher, the risk of crossing at-grade and eventual pedestrian injury is increased (mark Nie & Yang, 2015; Liu & Tung, 2014; Chalabi et al, 2008). The presence of a barrier - fence or median reduces the risk of direct crossing by 24 and 2% respectively, posing the notion that fencing presents a stronger defence against illegal crossing. Police presence reduces the risk of crossing at-grade as shown in the natural behaviour of individuals towards law enforcement presence (baUlfarsson et al, 2010). The

dominant variables in both risk perceptions and crossing choice are high traffic volume and security on the footbridge. Farther away footbridges and lower crowds increases the risk of crossing legally implying that pedestrians are risk averse to shorter walking distance and large footbridge crowds. Security and comfort level proportionally reduces risk of crossing with the footbridge

Analysis of choice without the inclusion of individual attributes showed that conditions of road traffic (medium and high volumes), barriers and law enforcement significantly affect the probability that a respondent would cross the freeway directly. Similarly, walking distance, pedestrian crowd on the bridge, security and convenience affect the probability that a pedestrian cross with the footbridge. Coefficients of high crowd volumes and security presence on the bridge show a higher likelihood for footbridge crossing than direct crossing. A simulation based study whereby the models are applied to different scenarios to forecast changes in crossing patterns with different freeway sections may be developed in future to capture crossing attitudes when factor coefficients are changed by one unit.

In the correlation of risk parameter indicators, the test for collinearity among predictor variables of general and choice specific risk perceptions and outcome yields both significant and in-significant values. Pedestrians put themselves in danger when safe modes of crossing is linked with increased walking times (Yang et al, 2015). Cantillo et al (2015) also observed that the probability of being delayed along a line of trip has a significant effect on crossing choice. Larger distance diminishes the probability of utilizing a safer crossing alternative.

Willingness to trade off one attribute over another was computed using substitutional rates of marginal utilities. Lower preferences were recorded for higher traffic volumes, police absence on the freeway and far distances to the footbridge compared to other known attributes. Substitutional values helped in prioritizing critical factors of importance. Furthermore, the most effective mitigation measures are those that are linked to priority attributes. Recommendations for policy changes include awareness creation, security for footbridge/at grade crossing, and structural positioning for traffic volumes and walking distance.

We itemize possible considerations from the outcome of this research:

1. According to Sinclair and Zuidgeest (2015), pedestrians constantly make trade-offs between choosing to cross safely and deciding otherwise. The criteria for safety in this study is relative to the level of protection from traffic accidents and robbery attacks on the footbridge. This explains the almost equal odds between the choice of the two crossing alternatives. Larger choice sets may be experimented in future to include alternatives which are not implemented in this research.

2. Choice crossers were found at locations on the freeway which is mainly the N1, N2 and R300. Results have been obtained from this group of pedestrians only. However, it is imperative to understand how pedestrians behave under conditions of captive crossing. We note further that integral research may be

carried out to ascertain the generalization of the results presented here, as to include crossers who are found on freeways where there are no footbridges available, e.g. the N7 freeway. Information relating to pedestrian preferences from this set of users will be useful for a comprehensive freeway policy creation in future.

3. All values and estimates are constrained in terms of season of year and time of the day. Peak hour surveys have been represented in this research. The behaviour of pedestrians when crossing at non-peak periods could be identified & confirmed with the findings from this study.

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APPENDIX

APPENDIX 1 ETHICS APPROVAL FORM

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:



Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: <http://www.ebe.uct.ac.za/usr/ebe/research/ethics.pdf>

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant	Ms Mercy Iyinoluwa Dada	
Department	Civil Engineering	
Preferred email address of applicant:	Ddxmer001@myuct.ac.za	
If a Student	Your Degree: e.g., MSc, PhD, etc.,	MSc
	Name of Supervisor (if supervised):	A/Prof Mark Zuidgeest
If this is a research contract, indicate the source of funding/sponsorship	SANRAL – South African National Roads Agency	
Project Title	Illegal Crossing Behaviour of Pedestrians on Cape Town Freeways: A choice experiment	

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Ms Mercy I. Dada	Signed by candidate	23 Mar 2016

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Prof Mark H. Zuidgeest		23 Mar 2016
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).	Click here to enter text.		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	George Sithole Click here to enter text.		6 April 2016

APPENDIX 2 QUESTIONNAIRE

IsiXhosa



Kwinani lemibuzo: _____

Indawo: _____

Umhla: _____

Ixesha losuku: _____

Mholweni,

Igama lam ngu.....thina sikude iYunivesithi Yasekapa. Singathanda ukukubuza imibuzo embalwa malunga bangayinqumli indlela. Siya kuthabatha imizuzu elishumi kuphela ixesha lakho.

Ngowuphi unyaka wazalwa?

[1999 nangaphezulu, ukuphelisa ndlebe]

Wakha ndayiwela le freeway?/ukuba uwele endleleni phambi?

Ewe

Hayi

[Ukuba akukho, ukubulela umntu ma bahambe]

{Kuqhubeka}

Kukufunayo usixelele iyimfihlo. Siza kusebenzisa kuphela inkcazelo yophando. Akukho gama efunekayo kwaye uyeke nangaliphi na ixesha.

Singenza ubhazabhaza ikhuseleke xa unceda nathi, nalo olu dliwano.ukuba unemibuzo tsalela inombolo yefowuni 0618445692

Ukuze ndiyaqhubeka? Ewe, ngaba unokuqhubeka

Hayi, ukuphelisa ndlebe

1. Isini

Indoda

Imazi

2. Ixesha elide kangakanani na wayehlala kappa? _____

3. Musani ukuba abantwana ababudala busukela 0 no 12

Ewe

Hayi

Ukucikideka Ukheto

Ndiza kukubonisa imifanekiso 9. Undixelele ukuba bawele ngqo okanye sebenzisa ibhulorho ngamnye kubo. Akukho mpendulo

Card 1		Card 2		card 3		Card 4		Card 5		Card 6	
A	F	A	F	A	F	A	F	A	F	A	F

A - Ndiza kusebenzisa indlela

F – Ndiza kusebenzisa ibrorho

Umngcipheko waqonda

Ngoku ndiya kuvavanya ukuqonda kwakho wokhuseleko kule ndlela yaye ibrorho, Ngokomlinganiselo-0 ukuya kwi- 10,

Kulindeke ukuba libe kwingozi ukuba kwenzeka kule ndlela?

Impendulo _____

Kulindeke ukuba buphangwe phezu ibrorho?

Impendulo _____

Olunye ulwazi

Xa usebenzisa ibrorho ngaba udlula kuyiwela emva abasebenzisa izithuthi zikawonke?

Ewe

Hayi

Ubuya cinga usebenzisa ibrorho kule ndawo kusoloko?

Ewe

Hayi

Kukho nantoni na ongathanda ukuba axelele ngale freeway

Enkosi inxaxheba yakho

English



Questionnaire No: _____

Location: _____

Date: _____

Time of Day: _____

Hello,

My name is (Interviewer's name). We are conducting a research into pedestrian crossing behavior on freeways in Cape Town.

Do you mind if we ask you a few questions about the freeway for about 10 minutes? You must have crossed the freeway at least once and be 18 years old or older.

☺ What year were you born? _____

If less than 18 years old (1999 and above), end the interview

☺☺ Have you crossed the freeway at any time? Yes No

If NO, thank the respondent and end the interview.

[Continue]

Any information that you provide would be treated with confidentiality and would only be used in the study. No names are required and you are permitted to withdraw at any time during the interview.

We expect this research to benefit you by gaining a better understanding of how pedestrians cross the freeway and providing suggestions for improved safety across freeways in Cape Town.

If you have further questions, you may call the researcher on 0618445692

May I continue? Yes, proceed. No, **terminate interview**

Gender

Male

Female

1.1 How long have you been living in Cape Town? __

1.2 Do you have children aged between 0 – 12 years old? Yes No

Trip information

1.3 Do you usually cross at this location after a Public Transit drop-off? Yes No

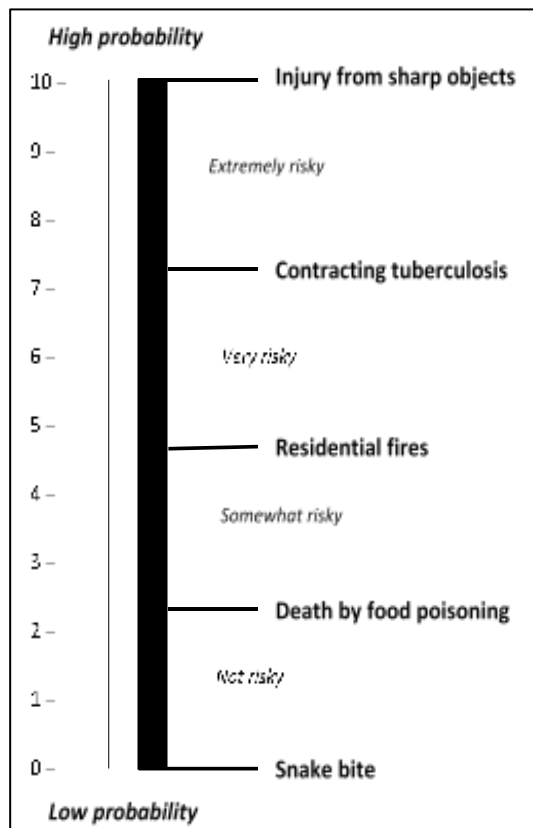
1.4 Where do you normally go after you have crossed the freeway?

Home Work

Other _____

Risk perception

Consider the ladder shown below.



A. Indicate the probability of **getting involved in a traffic accident** when crossing this freeway directly.

Answer: _____

B. Indicate the probability of **getting robbed** while crossing with the footbridge at this location.

Answer: _____

Choice experiment

You will be presented with 6 choice cards.

- A. Select the option that you would most likely choose when crossing in the given scenario. Note that there are **NO** wrong answers.
- B. Among the factors highlighted, determine which is most important to you in deciding whether to cross using the footbridge or not.

1.6 What changes would you like to bring to the city's council that would make you prefer to cross the bridge at all times?

Appendix 3 SPSS commands for generating fractional factorial design

Design

;alts = alt1, alt2

;rows = 16

;eff=(mnl)

;model:

U(alt1) = b1*A[5,15,25] + + b5*E[0,1] + b6*L[0,1] +

b7*M[0,1]

u(alt2) = b2 * B[2,8,14] + b3*C[2,8,14] + b4*D[0,1] + B8*N[0,1]

Degree of freedom is given as ==> $S = K(J-1) = 8*(2-1) = 8$ runs.

Appendix 4

First ten observations from SC experiment. [Total no of observations = 1800]

S/No	Respondent ID	Choice	av1	av2	TRAFFIC	CROWD	WALKING TIME	FENCE	POLICE	SEC	EFFORT	MEDIAN	
1	1	2	1	1	1	1	1	0	0	1	0	1	
2	1	2	1	1	3	1	1	0	1	0	1	1	
3	1	Respondent 1 observed 6 non-repeated subsets	3	2	3	0	1	0	0	0	1		
4	1		2	1	1	1	0	0	0	0			
5	1		2	1	1	1	2	1	1	1	0	0	
6	1		2	1	1	1	1	2	1	0	1	1	1
7	2		2	1	1	1	1	1	1	0	1	1	1
8	2		1	1	1	3	1	1	1	1	0	1	1
		Choices observed by respondent 2	2	1	1	3	2	2	0	1	1	0	0
			2	1	1	2	1	2	0	0	1	0	1
			1	1	1	1	2	1	1	1	0	0	1
12	2		1	1	1	1	1	3	1	1	1	1	0
13	3	2	1	1	3	3	1	0	1	1	0	0	
14	3	2	1	1	2	2	1	0	0	0	1	0	
15	3	2	1	1	2	1	1	0	1	1	0	0	
16	3	2	1	1	2	1	2	0	0	1	0	1	
17	3	1	1	1	1	2	1	0	1	0	1	1	
18	3	1	1	1	3	2	2	1	1	0	1	1	

Appendix 5. Panel data displaying respondents' demographic information

SITE		TIME OF DAY	AGE	GENDER	T (0 - 5 YRS)	T (6 - 10 YRS)	T (11 - 15 YRS)	T > 15 YRS	Children (>12yrs) Y/N	STATUS	PT	TRIP PURPOSE
N2 after Var	207	AFTERNOON	41	0	NO	NO	NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	208	AFTERNOON	41	0	NO	NO	NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	209			0			NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	210			0			NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	211	AFTERNOON	41	0	NO	NO	NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	212	AFTERNOON	41	0	NO	NO	NO	YES	YES	EMPLOYED	NO	WORK
N2 after Vanguard	207	EVENING	35	1	NO	NO	YES	NO	NO	EMPLOYED	YES	WORK
N2 after Vanguard	208	EVENING	35	1	NO	NO	YES	NO	NO	EMPLOYED	YES	WORK
N2 after Vanguard	209	EVENING	35	1	NO	NO	YES	NO	NO	EMPLOYED	YES	WORK
N2 after Vanguard	210	EVENING	35	1	NO	NO	YES	NO	NO	EMPLOYED	YES	WORK
N2 after Vanguard	211	EVENING	35	1	NO	NO	YES	NO	NO	EMPLOYED	YES	WORK

Cards observed by respondent 1

Respondent 1 was Male

Appendix 6. Sigma values

	Estimates	T-ratios
sig_risk_road_general_1	1.894	1.88
sig_risk_bridge_general_21	0.8973	2.76
sig_risk_bridge_general_22	-0.5618	-0.95
sig_risk_road_31	1.0882	3.93
sig_risk_road_32	1.0668	5.35
sig_risk_road_33	-0.2635	-1.51
sig_risk_bridge_41	-0.1644	-2
sig_risk_bridge_42	0	NA
sig_risk_bridge_43	0.2695	2.71
sig_risk_bridge_44	0.3463	2.74
sig_asc_road_51	-0.4255	-2.68
sig_asc_road_52	0	NA
sig_asc_road_53	0.8864	7.18
sig_asc_road_54	-0.4975	-3.57
sig_asc_road_55	0	NA