

AN INVESTIGATION INTO THE REDUCTION OF ROAD SAFETY RISK IN CAPE
TOWN THROUGH THE USE OF MICROSCOPIC SIMULATION MODELLING

By

RAHUL JOBANPUTRA

A Thesis submitted for the Degree of

DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING

University of Cape Town

August 2013



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AN INVESTIGATION INTO THE REDUCTION OF ROAD SAFETY RISK IN CAPE
TOWN THROUGH THE USE OF MICROSCOPIC SIMULATION MODELLING:

A Vehicle-Pedestrian and Infrastructure Interaction Assessment

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Declaration

I declare that the contents of this thesis are entirely my own work, except for the specific and acknowledged references to the published work of others made in the text.

To the best of my knowledge and belief, it contains neither material previously published by another person nor material to which a substantial extent has been accepted for the award of any other degree of the university.

Candidate:

Rahul Jobanputra:

Signed at:..... this day of 2013.

Supervisor:

Associate Professor Marianne Vanderschuren:

Signed at:..... this day of 2013.

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ABSTRACT

The record of road traffic fatalities in South Africa at around 15,000 per year has continued unabated over the last decade and has led to South African cities consistently featuring at the top of the list of worst known locations for road fatalities around the world. Worryingly, these statistics show that more than half of these fatalities are pedestrians. With the increasing rates of urbanisation and motorisation being experienced this record is likely to continue or decline unless greater emphasis is placed on road safety.

The underlying reasons for the fatality rates are complex. They are influenced by a combination of road network planning and design, the settlement patterns and by behavioural and law enforcement issues. In particular, the road network planning and design concepts have led to a hierarchical road infrastructure system of provision that comprises of many arterial and distributor roads where vehicular speeds are high and, there is limited, or no provision for non-motorised travel outside of the central city areas. The historic settlement patterns dictate that the urban poor, who walk or use public transport for their travel needs, travel long distances, mostly along these arterial routes. As a result, pedestrians often have to cross delimiting arterials and distributor routes with the concomitant danger of road crashes.

Recognising the need to address the issues of the urban poor, the legislative and policy environment for town planning, transport and road infrastructure provision, is firmly aimed at the provision of improved public transport and access. However, despite these objectives, and the commitment by the South African Government to reduce road fatalities road safety continues to be a persistent problem.

The approach adopted by local authorities and practitioners to address the road safety issue relies on a reactive assessment of historic crash data to determine hazardous locations. However, this data is unreliable due to recording issues and, it does not contain sufficient detail for comprehensive investigation; the result is a distinct possibility of inappropriate conclusions.

Evidence from countries with low road fatality rate shows that a focused and dedicated systems approach to road safety has yielded significant benefits. Further, the literature shows that these countries apart also use complimentary, alternative evaluation methods and predictive modelling to proactively assess or predict safety at particular facilities or the benefits of countermeasures. However, the majority of these methods focus on vehicles only and given the level of pedestrian fatalities and the unreliability of the crash database, may not be appropriate for South Africa.

Using case studies in Cape Town which consider traffic calming devices and infrastructure in different spatial locations, this investigation shows that micro-simulation modelling can be used to provide a better understanding of the interaction between the road-user and the infrastructure, and through the some innovative use of modelling output, it can also be successfully used to evaluate the benefits of engineering countermeasures and provide a comparative safety evaluation of urban infrastructure with different operational characteristics.

University of Cape Town

‘Education is the most powerful weapon which you can use to change the world’

Nelson Mandela

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Rahul Jobanputra

August 2013

Executive Summary

The number of fatalities and serious injuries resulting from road traffic incidents has become an issue of major significance around the world. In comparison to any international standard the road safety record in South Africa, especially the impact on the most vulnerable group of road users – the pedestrians is appalling. This record of fatalities, at around 15,000 per year, has continued unabated over the last decade and has led to South African cities consistently featuring at the top of the list of worst known locations for road fatalities around the world. With the trend of increased rates of motorisation being experienced in developing countries, this situation is likely to continue to be poor or may even decline.

To understand why road safety is such a problem and why it persists, data for the City of Cape Town was used as a representative urban area in South Africa. Initial investigations into this issue focussed on a review of historic and current transport policies to understand their influence on current infrastructure provision in the City, the direction that national and local policies and strategies of the last few years have determined the nature of transport supply and utilisation and, to provide an infrastructural context to the road safety problem. These revealed the following.

For the majority of the population, travel in South Africa, especially within urban areas, is dictated by apartheid-legacy settlement planning, which segregated city centres/economic opportunities from the labour force by means of green buffer spaces and corridors. Post-apartheid spatial planning has changed little – and, if anything, commuting volumes along historic paths have increased as the cities have grown over time and into more global players.

Road network planning and design concepts imported from an early car-centric era mean that the road infrastructure provision is based on a hierarchical system of arterials and distributor roads based on speed, with little regard for non-motorised travel outside of the central city areas. The settlement patterns dictate that the urban poor (the majority of the population) travel long distances, mostly on arterial routes and are dependent on public transport and walking for their travel needs (up to 63% of all trips). As a result pedestrians often have to cross delimiting arterials and distributor routes with the concomitant danger of road crashes.

Significantly (from a safety perspective), the hierarchical road system results in levels of service which allow high vehicular speeds on freeways and arterials in the planned and developed areas but which is often in conflict with the limited non-motorised transport provision in informal settlement areas (usually on the peripheries of existing neighbourhoods or adjacent to highways and arterials). The infrastructure provided can thus be described as a mixture of developing and developed world standards - with commensurate travel conditions and facilities.

Research on average walking commutes in Cape Town shows that the mean and 95th percentile walking trip lengths can be considerably longer than those conventionally assumed in practice (around 800m as assumed in traditional road hierarchy philosophies), and that a significant proportion exceed conventional parallel arterial or distributor frequencies of 1.5km. Despite this, and despite walking being the dominant mode of transport for the vast majority of people, there is a dearth of sidewalks and formal crossing facilities, which inevitably leads to conflict with motorised transport. Furthermore, the inconsistent nature of infrastructure provision means that pedestrian routes, in particular - if they exist at all - are not interconnected systems which would allow safe, efficient passage coinciding with desire lines.

Executive Summary

Primarily, in recognition of the need to improve the mobility and accessibility, and thereby to economically uplift the majority of the population, the South African national transport policy has, for some years, been aimed at providing better and more public transport and NMT facilities (see for example: NDoT, 1996 and 2009). Strategies to develop priorities and implement new facilities are being actively pursued at the local level. The Government is also aware of the disproportionate road traffic death toll borne by pedestrians in cities (around 60% of the overall total) (RTMC, 2010). The consequences of better and more public transport services and NMT facilities should be an improvement in the safety of the more vulnerable users as well as achieving the Government's mobility and equity ideals.

In parallel, South Africa's legislative and policy environment for planning, transport and road infrastructure has considerably improved, on a par with many developed world practices. South Africa is a signatory to the goals agreed in the Global Plan for the Decade of Action for Road Safety 2011-2022 (the 'Moscow Declaration'), and many of the pillars of this plan have been followed by responsible Provincial Authorities.

Despite these efforts, road safety continues to be a persistent problem, particularly in urban areas. It could be that these policies and implementation programmes have yet to take effect, and that it is only a matter of time before their effects on road safety will be felt. However, changes will be limited over time due to budgetary constraints and, in the meantime, there has to be an acceptable level of service for private vehicles and public transport, which needs to be balanced with adequate crossing points and safe shared surfaces. But it remains a concern that despite carefully organised infrastructure and behavioural rules, shared surfaces inevitably lead to some kind of conflict.

It is internationally recognised that a systems approach for improving road safety, has helped to reduce fatality rates in most developed countries despite recent increases in motorisation. The systems approach recognises that road safety is a multi-sectoral issue – all sectors, including health, need to be fully engaged in responsibility, activity and advocacy for road crash injury prevention.

Despite knowing about systems responses, historical data are still commonly used in South Africa to assess and predict levels of road safety, and to estimate the success of new and existing safety strategies and various types of safety influencing measures at specific traffic facilities. But the random nature of crashes and the likelihood of data recording errors mean that there is a significant possibility that resulting assessments will be inappropriate.

If, as is mooted, human error is the root cause of the road safety problem, then an understanding of the way in which pedestrians and vehicles interact on shared infrastructure should help establish the road safety risk for each situation. Such an understanding would facilitate the appropriate assessment of engineering interventions or modifications to help reduce risks without the need for historic crash data.

Might statistical and predictive modelling enable an understanding of these interactions? Advances in statistical and predictive modelling have seen their use increase in road safety modelling and risk minimisation strategies. Many of the models used for transportation planning purposes are general in nature, and have proved less useful for safety analyses at specific locations and facilities where important safety related factors need to be taken into consideration. The majority of these models also use historic crash data as their foundation. Largely as a result of such issues, though, the use of surrogate and/or proximal safety indicators has been advocated, both as measures for diagnostic safety analysis purposes and to provide a suitable statistical basis for safety prediction modelling.

Using this finding, this thesis considers proximal safety indicators as an alternative to historical crash data, and outlines the various concepts, theories and methods related to effective short-term traffic safety assessment in this regard.

Safety indicators can be used to measure the spatial and/or temporal proximity of safety critical events and are assumed to have an established relationship with crashes. They have the advantage of being more frequent than crashes (near misses, for example) and therefore require a shorter period of study to establish statistically stable values. They are also responsive to the specific characteristics and conditions of particular traffic locations or facilities, making them useful in before-and-after study designs, and other safety assessment strategies. A critical requirement of proximal safety indicators is the establishment of their validity, i.e. how well they represent actual 'safety' as a theoretical concept. Other questions concern the reliability of the various measurement techniques, their advantages and disadvantages and their usefulness from a practical perspective.

Microscopic traffic simulation allows dynamic traffic modelling that can provide a flexible test environment in which road user performance effects of new and alternative designs, and other safety influencing factors related to the roadway, such as speed and flow can be estimated. Although the main focus of traffic simulation models was, and to a large extent, still is, to help predict transport infrastructure requirements and traffic efficiencies, recent advances mean that models can now simulate the interaction between vehicles and pedestrians, and therefore the safety implications of infrastructure provision where space is shared. This can be at a street, precinct or even suburb level, and for various situations, as simulations can be modified to suit most local conditions through local input data and adjustable parameters

The assessment of safety through simulation can be carried out proactively without the need for crash data as models can output predicted details of proximal safety characteristics such as speed, flow, headways along with safety-relevant interactive processes such as gap-acceptance in yielding situations. Significantly, simulation also allows sensitivity testing without implementation; it is relatively cost-effective and provides visual output for expert and non-technical audiences.

The formulation of viable safety evaluation methodology based on the outcomes of micro-simulation modelling of specific urban contexts therefore offers significant benefits. In addition, the simulation should allow a better understanding of the interaction between the infrastructure, vehicles and pedestrians and because of this it should facilitate a better evaluation of the road safety risk of the situation under consideration. These statements formed the hypothesis of the research that follows.

It was expected that this work, whether successful or not, would reveal many of the potential possibilities and limitations associated with this type of modelling. If successful, the results from this investigation could be used to provide guidance to practitioners on the relative safety of existing and future infrastructure design, engineering counter-measures, as well as a method of ranking the relative safety of infrastructure, in comparison to each other, in a local context. A further aim was also to develop an approach to safety modelling that is sufficiently robust to test the viability of its use in other cities, with suitable adaptations to modelling inputs.

To test the hypothesis, the research was split into two case study chapters – one that dealt with the evaluation of surrogate safety as a result of changes to vehicular outputs for traffic calming measures, and one that dealt with the simulation output for vehicle-pedestrian interaction for two very different infrastructure situations and characteristics.

Executive Summary

Three criteria were set at the outset of the modelling exercise to establish whether the simulated output of proximal safety measures (and thus safety risk) at each of these locations was representative of actual safety: i) the simulated output of safety measures should enable distinctions to be made between design alternatives; ii) surrogate safety evaluations should correlate with actual measured performance; and, iii) simulated surrogate safety reductions for interventions or modifications should correlate with published data. To be fully representative, it was deemed necessary that the simulations fulfilled all three criteria.

The rationale for the first case study was, firstly, to ensure that the simulation tool was able to predict from an unmodified case that each traffic-calming measure would have a safety impact. The other objectives were to make sure that it distinguished between each measure and that the output would be comparable to published findings as well as field observations of speed for the same measure. The simulations (and field studies) were undertaken during off-peak periods to ensure that pedestrians would not influence the results because of their random appearance and crossing behaviour. Even if they are included in the analysis and their flows/behaviours kept constant between tests, their presence would mask the true volume and speed reductions of the measures.

The relationship between speed and road crashes has been studied extensively and is very clear - in general, the faster the driving speed, the greater the probability and severity of a crash.

Studies of relationships between crashes and traffic flow are not as straightforward. They generally conclude that reduced congestion and smoothed traffic flow are likely to improve safety, although there is some evidence that increased congestion leads to reduced speed and therefore reduces the risk of crashes. Intuitively, it can also be stated that increased travel increases exposure and thus the level of risk.

The results of this exercise showed that the simulations are capable of predicting changes in traffic speed and volume for the measures considered, and that they compare favourably with internationally published results. The study also shows that the predicted changes could be used to estimate the likely changes in the likely number of fatalities and serious injuries as a result of these interventions.

The second case study areas were selected because they have had, or currently have, road safety issues, and because there is significant interaction between all road users. The purpose of this study was to establish whether the simulations can: (i) capture whether the areas will suffer from road safety issues; (ii) provide an indication of the type and number of safety critical events through the use of the software's collision viewer and criteria based deceleration rates from vehicle and pedestrian trajectories; and, (iii) predict any changes to the number and type of vehicle-pedestrian incidents as a result of appropriate modifications to the road (such as the traffic calming measures considered in the first case study) and, if so, whether these changes would be comparable to published findings for similar modifications.

Initial investigations focussed on a section of the Lansdowne Road corridor (Study Area A), a major arterial route linking the settlements on the periphery of Cape Town to the City centre as well as other areas of employment in the south-eastern part of the city. Study Area B is a major intersection at one of the entrances to the city's CBD – the Coen Styler/Buitengracht Street intersection.

Several model issues were encountered during this exercise, most of them related to the non-compliant nature of road users in Cape Town. However, with the exception of simulating vehicle/pedestrian behaviour during shared surface crossings, the majority of these issues relate to

extreme situations that are seldom encountered on a daily basis and were thus deemed to not affect the outcomes sufficiently to prevent a reliable safety analysis.

Despite these challenges, and through the application of some innovative modelling and evaluation techniques, it was apparent that the resulting simulations of the operational characteristics of road users provided a confirmation of the viability of the use of micro-simulation to evaluate the potential safety of infrastructure in various settings.

Furthermore, it can be concluded from the outcomes of this study that micro-simulation (i) is an extremely useful and scientific method for practitioners to evaluate the potential safety benefits of urban infrastructure; (ii) its use would obviate any possible observer differences or inconsistencies of other frequently used safety evaluation techniques; and, (iii) it can be used as a proactive investigative method of assessing the safety performance of either hypothetical designs or existing infrastructure.

In addition, options can be evaluated and ranked through the use of indexing techniques. A 'Potential Collision Index' was developed in this thesis to evaluate the likely severity of vehicle-pedestrian collisions. It uses vehicle and pedestrian trajectories and vehicle speeds to evaluate likely injury severities from published data and from this, a numerical value. The total score of a particular situation during an equivalent simulation period provides its likely 'Index'. A comparison of scores obtained for each situation evaluated provides its relative safety risk. Although this index may benefit from a refinement process to allow for the inclusion of a severity scale and a calibration process through the use of before-and-after studies it does provide a method to compare likely safety performances on a like-for-like basis. And, as this method is comparative, again, it does away with the reliance on a reactive analysis of historic crash data and does not require statistically reliable, extensive and accurate crash data records.

Because detailed simulation modelling such as this takes into consideration many site-specific values, it allows sensitivity analysis of the safety influence of many different traffic parameters as well as the effect on other important objectives such as accessibility, capacity and environmental issues, which are an important part of transportation planning work.

The consideration and further development in automated post-processing systems for simulation outputs would help alleviate the requirements for manual evaluations of their outcomes, and enable an evaluation of longer simulation periods which would ultimately provide better and more averaged assessments of safety performance.

The work undertaken in this research pointed to the need for a greater understanding of the complex relationships between safety indicators and other variables (such as speed and speed variance, traffic flows, traffic compositions, turning percentages) and important behavioural processes (such as gap-acceptance and road-user behaviour) so that the dynamics of the road system can be more accurately and comprehensively simulated and better predictions of safety performance can be made. Developing statistical models that adequately predict the number of crashes based on safety indicators will also add to the value of safety analysis work in the future. Such models require a suitable national database that is accessible to safety analysts and modellers to be developed.

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Glossary of Terms and Acronyms

<i>Accident/Crash</i>	Event between road-users that results in injury, fatality or property damage
<i>CBD</i>	Central Business District
<i>Crash causation</i>	Underlying reasons that pre-empt a traffic accident, most usually involving an unforeseen chain-of-events. Accident causation is often attributed to one of the three main components of the traffic system: road-user, vehicle or roadway, or a combination of thereof
<i>Crash severity</i>	Result of a crash in terms of injury severity, fatality and in some cases also property damage
<i>Crash rate</i>	Number of crashes in accordance with a measure of exposure
<i>Crash risk</i>	Risk of involvement in a crash (for different road-user classes). Objective risk reflects accident frequency in relation to a measure of exposure or population
<i>Calibration</i>	Process used in Traffic Simulation to (statistically) ensure that the functioning and behaviour of a particular model and/or sub-model corresponds with observed empirical measurements or predetermined values
<i>Car-following</i>	Term used to describe the status of a vehicle that has a time/distance gap or headway less than a predetermined maximum value
<i>Collision</i>	Impact event between two or more road-users/vehicles, or a road-user (vehicle) and stationary object
<i>Collision course</i>	Existence of a common projected conflict point in time and space for two (or more) road-users/vehicles, usually based on momentary measures of trajectory, speed and distance
<i>Conflict</i>	A potentially unsafe interactive event that requires evasive action (braking, swerving or accelerating) to avoid collision
<i>Conflict distance</i>	A momentary measurement of (spatial) distance to a common conflict point for a road-user/vehicle in a conflict situation
<i>Conflict observation</i>	Method that is used by trained observers to determine Time-to-Accident values in accordance with the Traffic Conflict Technique. Based on the subjective estimation of speed and distance for road-users/vehicles that are in a conflict situation
<i>Conflict point</i>	Common spatial location of projected trajectories given momentary measures of speed and distance for two or more road-users/vehicles
<i>Conflict zone</i>	Common area used by road-users/vehicles approaching from different trajectories
<i>Conflict severity</i>	Seriousness of a potential collision or near-accident measured by temporal or spatial proximity

<i>Conflict speed</i>	Momentary measurement of velocity for a road-user (vehicle) in a conflict situation
<i>Critical-gap</i>	Average measure of gap-acceptance in a yielding situation where the probability of acceptance is estimated to be equal to the probability of rejection, mainly used for capacity calculation
<i>Deceleration Rate</i>	Rate at which vehicle in consideration must decelerate to avoid collision
<i>Driver behaviour</i>	Largely misused and over-simplified term used in traffic engineering that is used to describe the actions and/or variability of drivers in different driving situations. Should relate to the study of individual behavioural processes that underlie driver actions (performance)
<i>Driver performance</i>	Generally refers to the skill and ability level of drivers in relation to the driving task
<i>Evasive manoeuvre</i>	Action that is taken by a road-user to resolve a conflict situation and involves braking, accelerating, and/or swerving
<i>Exposure</i>	Measure of spatial or temporal duration in the traffic system in relation to the number of dynamic system objects road-users, vehicles (axles), etc.
<i>Fatality</i>	Death resulting from a traffic accident (usually within a 30 day period after the accident occurrence)
<i>Gap-acceptance</i>	Process that describes and measures interaction between prioritised and non-prioritised road-users. Generally involves spatial or temporal measurement of gaps or lags in prioritised streams that are accepted or rejected in relation to a particular yielding manoeuvre
<i>GDP</i>	Gross Domestic Product
<i>GSRP</i>	Global Road Safety Partnership
<i>Initially Attempted Post-Encroachment Time</i>	Time lapse between commencement of encroachment by turning vehicle plus the expected time for the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle
<i>iRAP</i>	International Road Assessment Programme
<i>Maximum search angle</i>	The maximum angle a pedestrian or agent is allowed to search to avoid a collision or an obstacle
<i>Macroscopic (macro-) simulation</i>	Simulation at a less detailed (aggregated, macroscopic) level
<i>Mesoscopic Simulation</i>	Simulation at an intermediate level of abstraction in comparison to microscopic and macroscopic simulation modelling
<i>Microscopic (micro-) simulation</i>	Simulation at a very detailed (microscopic) level
<i>Near-crash</i>	Safety critical event that has close temporal and/or spatial proximity to a crash

<i>NMT</i>	Non-Motorised Transport
<i>Obstacle angle step</i>	The angular increment specified to simulate the movement of a pedestrian or agent when avoiding an obstacle
<i>PMT</i>	Private Motorised Transport
<i>Post-Encroachment Time (PET)</i>	A safety indicator that represents a measure of the temporal difference between two road-users over a common spatial point or area. This should be below a predetermined maximum threshold value (typically 1 to 1.5 seconds). PET measures do not require the existence of a collision course, but does require transversal trajectories
<i>Pre-crash</i>	Term used in this thesis to describe the relationship between the processes preceding crashes
<i>PT</i>	Public Transport
<i>Required braking rate (RBR)</i>	Measure of conflict severity based on a momentary measure speed and distance to a conflict point that represents the average (linear) braking required to avoid a collision from the point the measure is taken
<i>Safety continuum</i>	Theoretical concept inferred in relation to the use of proximal safety indicators whereby all interactions are placed on the same scale with safe passages at one extreme and accidents involving fatalities at the other
<i>Scan area factor</i>	A factor that specifies how large the scan area is for vehicles when they are looking for pedestrians or agents. The scan area is a trapezium extruding from the front of a vehicle. The width of this trapezium at the end nearest the vehicle is controlled by the scan area factor; the length of the trapezium is controlled by the speed of the vehicle
<i>Serious conflict</i>	Conflict event in accordance with the Traffic Conflict Technique that is of sufficient severity to be classed as ‘serious’ according to a threshold function that takes into consideration the Time-to-Accident value and conflicting road-user speed
<i>Safety critical event</i>	Term used to describe a situation where there is an identified accident potential or where a proximal measure of safety is meets predetermined criteria (including threshold values)
<i>Simulation (traffic)</i>	Abstract imitation of the operation of a real-world process or system over time and event occurrence. Traffic simulation is concerned with the modelling of processes in the traffic system and can be conducted at different levels of abstraction depending of the purpose of the study
<i>Time Extended TTC (TET)</i>	Safety indicator measure based on Time-to-Collision. Represents a measure the period of time during which conflicting road-users are under a maximum TTC-threshold. Can be summated for a specific facility and/or measurement period
<i>Time Integrated TTC</i>	Safety indicator measure based on Time-to-Collision. Represents a measure

<i>(TIT)</i>	of the integral of a TTC-event while under a maximum TTC-threshold (i.e. difference from threshold multiplied by time-resolution). Can be summated for a specific facility and/or measurement period
<i>Time-to-Accident (TA)</i>	Safety indicator measure determined in accordance with the Traffic Conflict Technique. Based on a subjective estimation of speed and distance by trained observers for conflicting road-users in relation to a common conflict point. The Time-to-Accident measure is recorded only once at the time when evasive action is first taken by a conflicting road-user. TA-values are used in conjunction with speed to determine whether or not a conflict is a serious or non-serious event in accordance with a threshold function
<i>Time-to-Collision (TTC)</i>	Safety indicator measure based on an objective measure of speed and distance for conflicting road users in relation to a common conflict point. The Time-to-Collision measure is recorded continually throughout a conflict event and is not dependent on evasive action by the conflicting road-users. The minimum TTC-measure recorded during a conflict event is usually taken as the defining value. TTC values above a predetermined threshold are ignored
<i>Traffic conflict</i>	An observable situation in which two or more road-users approach each other in time and space to such an extent that there is a risk of collision if their movements remain unchanged
<i>Traffic system</i>	Systems theory view used to describe the processes of the traffic system as dynamic and complex interactions between and among key elements at various hierarchical levels. The three main elements are usually identified as: the roadway infrastructure, the road-user, and the vehicle
<i>Under-reporting</i>	Term used to describe the fact that many accidents are not reported to the police and therefore are not represented in accident statistics. Under-reporting increases with higher levels of accident outcome severity. Accidents involving vulnerable road-users are typically under-reported
<i>Validation</i>	In simulation, validation refers to the process of ensuring that output generated by the model after calibration, correspond (within statistical tolerances) to values measured in the field, thereby ensuring model representativeness
<i>Validity</i>	Validity concerns the accuracy with which a measure represents a theoretical construct (often assessed through consensus)
<i>Vulnerable Road-Users (VRUs)</i>	Term generally used to describe pedestrians and cyclists, but may also include mopeds and sometimes also motorcycles in view of their susceptibility to injury in the event of an accident
<i>WHO</i>	World Health Organisation

1 Introduction

Since the invention of the private motor vehicle over a century ago, it is estimated that about 30 million people have been killed in road crashes worldwide. The first road crash recorded in South Africa happened in the evening of 1 October 1903 in Maitland, Cape Town. The driver of the vehicle entered a level crossing through an open gate only to find the opposite gate closed. Before he or his passenger could open the gate or reverse, they were struck by the Johannesburg express train travelling at full speed. The passenger was thrown clear and the driver suffered only minor injuries. The motorcar was badly damaged (see photograph below). The inquiry into the crash stated that there was a 'remarkably casual attitude by drivers of motorcars' towards level crossings (RTMC, 2005). A century later, a total of about 393,977 persons (1.31% of the world total) were killed in crashes on South African roads (RTMC, 2005). Over the last decade the recorded number of fatalities per annum shows that South Africa has one of the worst traffic fatality rates in the world (see IRTAD, 2009; OECD, 2011; or RTMC, 2010)



Figure 1: 'Early Motoring in South Africa'
Source: R.H Johnston, C.Struik Publishers, 1975.

1.1 Research context and problem statement

Transport is often referred to as the lifeblood of a city - a vital element of any functional city, making it possible to bring people, goods and services together when and where needed. Transport connects people, and people with opportunities. As such, access to good transportation is a key factor in improving quality of life. It does, however, have some undesirable effects on the environment and society, such as: congestion, air pollution as well as personal injury or fatal crashes (CoCT, 2006).

Travel in South Africa is dominated by walking and public transport (approximately 63% of all trips) (DOT, 2005). Travel patterns, especially within the nine metropolitan areas are pre-dominantly influenced by apartheid spatial planning, which segregated city centres/economic opportunities from the labour force by means of green buffer spaces and corridors. Post-apartheid spatial planning has changed little – and, if anything, commuting volumes along historic paths have increased as the cities have grown over time and into more global players.

Partly as a consequence of this historic planning ideology, and partly because of the adoption of the pre-70's US style of road planning, roads in South Africa continue to be based on a hierarchical system with little in the way of pedestrian facilities outside of the main city areas, in particular in the areas with the highest population densities. Significantly, this hierarchical system results in levels of

service that allow high vehicular speeds on freeways and arterials in the planned and developed areas but there is little or no non-motorised transport provision in informal settlement areas (on the peripheries of existing neighbourhoods or adjacent to highways and arterials). Infrastructure is a mixture of developed and developing world standards with commensurate travel conditions and facilities. The unplanned, informal settlements where the majority and poorest people live, usually migrants from rural areas with little or no education and who, initially at least, are reliant on walking as their main form of transport; they often have little or no exposure to the metro environment where motorised transport rules the roads. Consequently, there is a large variation in pedestrians' abilities to use urban streets safely, understand driving behavioural norms and anticipate road hazards.

In Cape Town, where the modal split mirrors the national, the mean and 95th percentile walking trip lengths can be considerably longer than those conventionally assumed in practice (around 800m as assumed in traditional road hierarchy philosophies), a significant proportion of which exceed conventional parallel arterial or distributor frequencies of 1.5km (Behrens, 2005). Despite this, and despite walking being the dominant mode of transport for the vast majority of people, there is a dearth of non-motorised transport (NMT) facilities (e.g. sidewalks), which inevitably leads to conflict with motorised transport. Furthermore, the inconsistent nature of infrastructure provision means that pedestrian routes, if they exist at all, are not interconnected systems that allow safe, efficient passage coinciding with desire lines.

Primarily in recognition of the need to improve the mobility and accessibility and thereby to economically uplift the majority of the population, the South African national transport policy has, for some years, been aimed at providing better and more public transport and NMT facilities. Strategies to develop priorities and implement new facilities are being actively pursued at the local level. National Government is also aware of the disproportionate road traffic death toll borne by pedestrians in cities (around 60% of the overall total) (Forensic Pathology Services, unpublished). The consequences of better and more public transport services and NMT facilities should be an improvement in the safety of vulnerable users, as well as achieving the Government's mobility and equity ideals.

In parallel, South Africa's legislative and policy environment for planning, transport and road infrastructure has considerably improved to be on a par with many developed world practices. Further, the Nation is, inter alia, a participant in and follows the goals agreed in the Global Plan for the Decade of Action for Road Safety 2011-2022 (the 'Moscow Declaration'). Many of the pillars of this plan have been followed by responsible Provincial Authorities.

Despite these planning and design efforts, road safety continues to be a persistent problem, particularly in urban areas. It could be that these policies and implementation programmes have yet to take effect, and that it is a matter of time before their effects on road safety will be felt. However, planning and design changes are necessarily limited over time due to budgetary constraints and, in the meantime, there has to be an acceptable level of service for private vehicles and public transport, which needs to be balanced with adequate crossing points and safe shared surfaces. But it remains a concern that despite carefully organised infrastructure and behavioural rules, shared surfaces inevitably lead to some kind of conflict.

In the meantime, investigations into any road safety issues continue to be conducted using historic traffic crash data with some statistical analysis using this data. These have led to the formulation of engineering counter-measures mainly for identified hazardous locations. But the random nature of crash occurrence and the lack of a reliable database of historical crashes with sufficient details to

comprehensively investigate the nature and reasons for crashes mean that these methods could lead to inappropriate conclusions.

It is widely recognised that a systems approach for assessing road safety (see for example: WHO, 2004) via pre-crash, crash involvement and post-crash risk assessments¹, has helped to reduce fatality rates in most developed countries despite increases in motorisation. The systems approach recognises that road safety is a multi-sectoral issue – all sectors, including health, need to be fully engaged in responsibility, activity and advocacy for road crash injury prevention, not just the transport safety investigator. Further, the WHO (2004) state that: *‘Road crash injury is largely preventable and predictable; it is a human-made problem amenable to rational analysis and countermeasure’*.

Despite knowing about systems responses, and the fact that it is well known that there are deficiencies with National and local-level crash and injury databases (and that the levels of road traffic fatalities and injuries may well be greater²), historical data are still commonly used in South Africa to assess and predict levels of road safety, and to estimate the success of safety strategies and various types of safety influencing measures at specific traffic facilities. But the random nature of crashes and the likelihood of data recording errors mean that there is a significant possibility that resulting assessments will be inappropriate.

The reasons why there is a large occurrence of vehicle-pedestrian conflicts, that it is a multi-sectoral issue and is amenable to mathematical modelling, are therefore not being adequately addressed. In particular, although human error is usually the root cause of the high numbers of collisions, crashes can be prevented by a safe design of the traffic system. This assumes a joint responsibility between the road user and the system designer where the system designer would be responsible to arrange the system in such a way that it could be used safely (see for example SWOV, 2010). An understanding of the way in which pedestrians and vehicles interact on shared infrastructure would therefore help establish the road safety risk for each situation and, would facilitate the provision of more appropriate infrastructure, either proactively, without the need for historic crash data or retrospectively in response to problem areas.

Developments in statistical and predictive modelling have seen their use increase in road safety modelling and risk minimisation strategies. However, as many of these also rely on the availability of accurate and statistically reliable crash data, their use should be tempered with the knowledge of the limitations of the underlying data and, with the knowledge that a more holistic systems approach can yield safer traffic environments as demonstrated in countries such as the Netherlands and Sweden.

Traditionally, traffic microscopic computer simulation models have been used to predict transport infrastructure requirements and traffic efficiencies. Recent advances now mean that models, amongst other impact evaluations, provide the opportunity to simulate vehicle and pedestrian movement, and their interaction (and thus pre-crash and crash involvement) risk at a street, precinct or even suburb level for various situations. Although most models have been formulated using data and settings drawn from developed world situations, it is possible to modify them to simulate most local conditions through empirical input data and adjustable settings. The output allows the analyst to

¹ Pre-crash is defined as the concept, design or evaluation phase, crash involvement as the existing infrastructure or retrofit risk and post-crash as the emergency response or service.

² In the Western Cape, Provincial Government’s programme called ‘Safely Home’ and the City of Cape Town’s overhaul of their TRAFMAN traffic incident database system will improve on previous record collection and dissemination. The Western Cape is also considering the use of on-site electronic data capture systems which has been tested in many countries and proven to be more reliable (<http://safelyhome.westerncape.gov.za/>).

evaluate potential crash risk of infrastructure with or without the use of historic crash data via proxies or surrogates for road safety. Simulation also allows a systems-based approach as the analysis can be carried out for feasibility or design stage evaluation and for post event or audit based analysis of counter-engineering safety measures. These aspects are important from a societal perspective as the cost of crashes to any nation is not only the economic cost but the loss of productivity over time and the fact that most crashes involve persons on whom others are dependent (see WHO, 2004).

Given the trend of increasing levels of motorisation and urbanisation; the planning and design issues, and the nature of the road safety issue in South Africa, it is likely that the current road safety issue will be exacerbated. Furthermore, crash data remains neither reliable nor accurate (see for example: Mabunda et al., 2009; RTMC, 2009 and, Jobanputra and Vanderschuren, 2010) which implies that traditional methods of ‘black-spot’ (post assessment) analysis as well as recent advances in statistical methods may be inappropriate (in some instances) or may not be comprehensive enough. Therefore, a better systems type approach and tool that allows the evaluation of road safety risk both proactively (ex-ante) and retro-actively would be more appropriate. A research framework identifying the interaction between the infrastructure, vehicles and pedestrians in terms of the safety risk and the various characteristics and techniques available for assessment are indicted in Figure 1a.

This study presents a detailed review of the literature on the road safety issue in South Africa , in general and, through a review of other road safety evaluation techniques and case studies using Cape Town as a representative of urban areas in South Africa, it assess the potential of micro-simulation in terms of its suitability as an additional tool to assess and predict road safety issues particularly in relation to the interaction between pedestrians, vehicles and infrastructure provision.

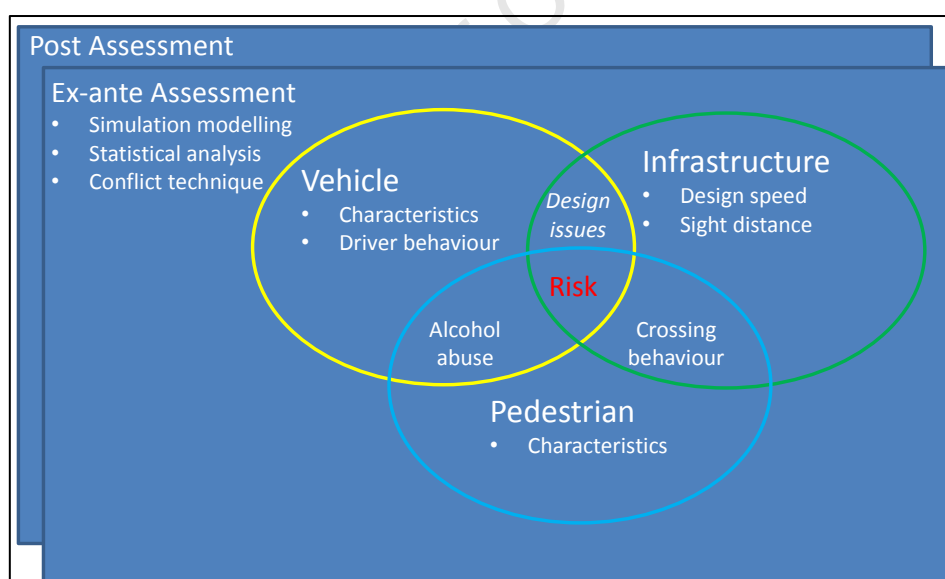


Figure 1a: Research Framework

1.2 Research objectives

The main objective of this thesis is to evaluate an alternative method of road safety assessment and, if it proves to be appropriate, to provide a sound basis for its adoption to complement techniques already in use.

Areas in Cape Town were used as study sites to be representative of the road safety situation in urban South Africa – as it is the urban areas in which the majority of safety critical incidents occur.

The sites were selected following a detailed and thorough review of the available historic crash data from the local authority (the City of Cape Town, referred to as the City hereafter), as well as other reliable sources as these provided a comprehensive picture of where collisions were occurring, when they were occurring and who was involved.

Key research questions formulated to achieve the objective and to provide a more holistic background to the road safety issue in Cape Town were:

1. *What is Cape Town's road safety record and how does it compare to international standards?*
2. *What are the particular motorised and non-motorised characteristics that have influenced this record?*
3. *What are the legal, policy and regulatory framework responses to the road safety issue? Are they appropriate for the situation?*
4. *In conjunction with policy and regulatory responses to the road safety problems, what else can be done to assess, evaluate and reduce the road safety risks?*
5. *If predictive modelling can help reduce road safety risks, which road safety method would be appropriate for evaluation of vehicle-pedestrian and infrastructure interaction risk in South Africa?*
6. *If micro-simulation is used for safety evaluation, can it be applied to assess the relative safety of the road system through the interaction between its components, and how can the results derived be adequately validated for a broader local context?*

The answers to some of the initial questions enabled the formulation of the research hypothesis which was: the road crash risk in a specific urban context (at a local intersection or street level) can be better predicted, and therefore reduced, through a better understanding of interactions between infrastructure provision and vehicle and pedestrian behaviour characteristics from the innovative application of microscopic simulation software in the road safety field.

It is expected that this work, whether successful or not, will reveal many of the potential possibilities and limitations associated with this type of modelling. If successful, the methods used in this investigation could be used by practitioners to assess the relative safety of existing and future infrastructure design, engineering counter-measures, as well as to rank infrastructure safety relative to each other in a local context. Also, if successful and sufficiently robust, this approach to safety modelling could be used to test the viability of its use in other cities.

1.3 Scope and limitations

The research has been developed from a review of South African road crash statistics, its policy, regulatory framework and planning practices. Because of this, its scope is limited to South Africa and, although the analysis method developed in this research could be regarded as being generic, it has not been explicitly tested elsewhere. With adequate calibration it should be possible to test the applicability of the technique developed anywhere in the world.

As the majority of crashes occur in urban areas, to understand the nature of the road safety problem, data for crashes in Cape Town in the Western Cape, South Africa was used to represent issues that could occur in other urban areas in South Africa. The case study roads are located in Cape Town and were selected on the basis of their historical crash records and variation in context to allow a test of the performance of the method used on roads with different characteristics and functions.

As the analysis is fairly data intensive, there was a reliance on secondary, published data from the City of Cape Town and the Forensic Pathology Services to guide the study initially. The method

developed also required a significant amount of empirical input data to enable adequate calibration of the simulated outputs - another reason for limiting the case study roads to roads in Cape Town.

This thesis is primarily concerned with the use of dynamic micro-simulation modelling for safety estimation and comparison purposes. The study entails an in-depth investigation into the potential and limitations of this approach, and an identification of particular problems related to modelling detail, the representation of road-user behaviour and vehicle performance. Model calibration and validation are critical issues that will be considered. It is intended to demonstrate the potential and limitations of 'safety simulation' from an evaluation of case studies and comparing outcomes. Through this, it is anticipated that the study will further the current level of knowledge in the field of traffic safety. The assessments and predictions are to be based on proximal or surrogate safety indicators and associated measurement techniques.

Important issues concern safety indicator validity and measurement reliability, as well as practical issues related to their use in safety assessment studies in the field. These are confirmed through comparative evaluations of the case studies.

1.4 Research approach and methodology

The processes of the research formulation, the research problem and the development of a hypothesis and supporting research questions were supplemented by a preliminary literature review on all aspects of road safety, planning and design principles, the legislative framework and discussions with practitioners and academics.

An investigation of the available data sources indicated the nature of the road safety problem in the city and assisted in the selection criteria for suitable case study roads. It was clear that the safety of pedestrians is of major concern and that the interaction between them and vehicles would constitute a worthwhile study.

An expanded literature review led to a deeper understanding of safety evaluation techniques in current usage. From this, it was concluded that simulation modelling would be the most appropriate technique for safety evaluation in Cape Town. This in turn led to the establishment of the requirements of the proposed modelling tool, a possible method, its use in the past, as well as a broader understanding of its use in similar studies.

Empirical data was collected for the three case study roads in Cape Town based on the requirements of the modelling tool and to satisfy calibration requirements for the various input parameters. A duplicate set of data was collected at a different time interval to validate the model outputs. Data collected ranged from the usual vehicle and pedestrian flows, turning movements and road geometric details to operational aspects of the road and speeds specific to link roads, vehicle composition and vehicle driver and pedestrian behavioural characteristics (those possible). A more comprehensive list of data requirements is listed in section 6.6.1.

The resulting simulation outputs were compared to the data collected from field investigations for calibration and validation purposes. Notably, the software requires the specification of a large number of parameters related to pedestrian behaviour which impact calibration to varying degrees. These values could not easily be collected from field investigations and therefore, a process of sensitivity analysis and re-calibration had to be undertaken.

The focus of the majority of traffic simulation tools is to help predict required levels of provision and assess traffic efficiency. Some are used in the assessment of space requirements for pedestrians.

However, it was apparent that the use these tools to assess road safety of infrastructure at any level, would require the formulation of a method based on proven/known road safety indicators - and one that could be validated, either through before-and-after studies or through the known effects of safety countermeasures (i.e. positive, neutral or ineffective, not necessarily actual numbers).

Proximal and/or surrogate measurements of safety have been used in the past to measure short-term safety performance of road infrastructure. The output of simulation models provides, *inter alia*, vehicle speed, headways, volumes and pedestrian walking speeds - all of which are measures that can be used to estimate safety.

The research was then split into two case study chapters – one that deals with the evaluation of safety as a result of changes to outputs of vehicular characteristics for traffic calming measures; and one that deals with the simulation output for vehicle-pedestrian interaction for two very different infrastructure situations and characteristics. The first case study was used as an intermediate step which ensured that the model could output results of vehicle characteristics for different traffic calming measures that would enable a distinction to be made between the results and which would be comparable to findings for the same measures in the literature.

The second case study presents a more complex issue where there is friction between pedestrians and vehicle. The areas were selected because they are known to have had road safety issues (and probably they still do) because of a significant amount of interaction and usage of the road space. Two geographically and spatially different areas were selected in order to evaluate the capabilities of the modelling tool where different road user behaviours were observed. This study allowed an evaluation of whether the simulations could firstly, predict if the usage of the infrastructure provided will result in road safety issues; secondly if the output could provide an indication of the type and number of safety critical events and; thirdly, if the outputs could predict changes to the number and type of incidents as a result of appropriate modifications to the road (such as the traffic calming measures considered in the first case study) and, if so, whether these changes would be comparable to published findings for similar modifications.

The outcomes of these analyses were used to develop an infrastructure safety ranking score and to draw conclusions from this about the applicability of the modelling tool to evaluate safety.

An overview of the research framework and process is provided in Figures 2a & 2b.

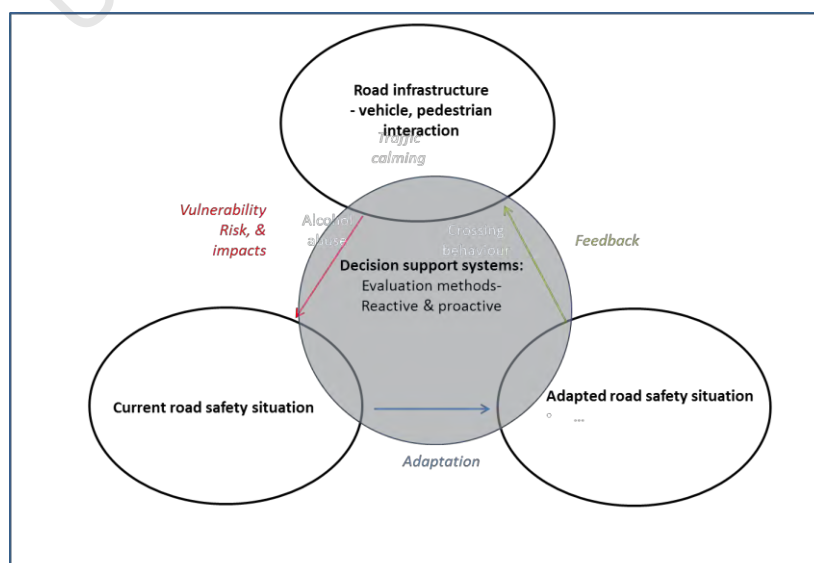


Figure 2a: Research framework

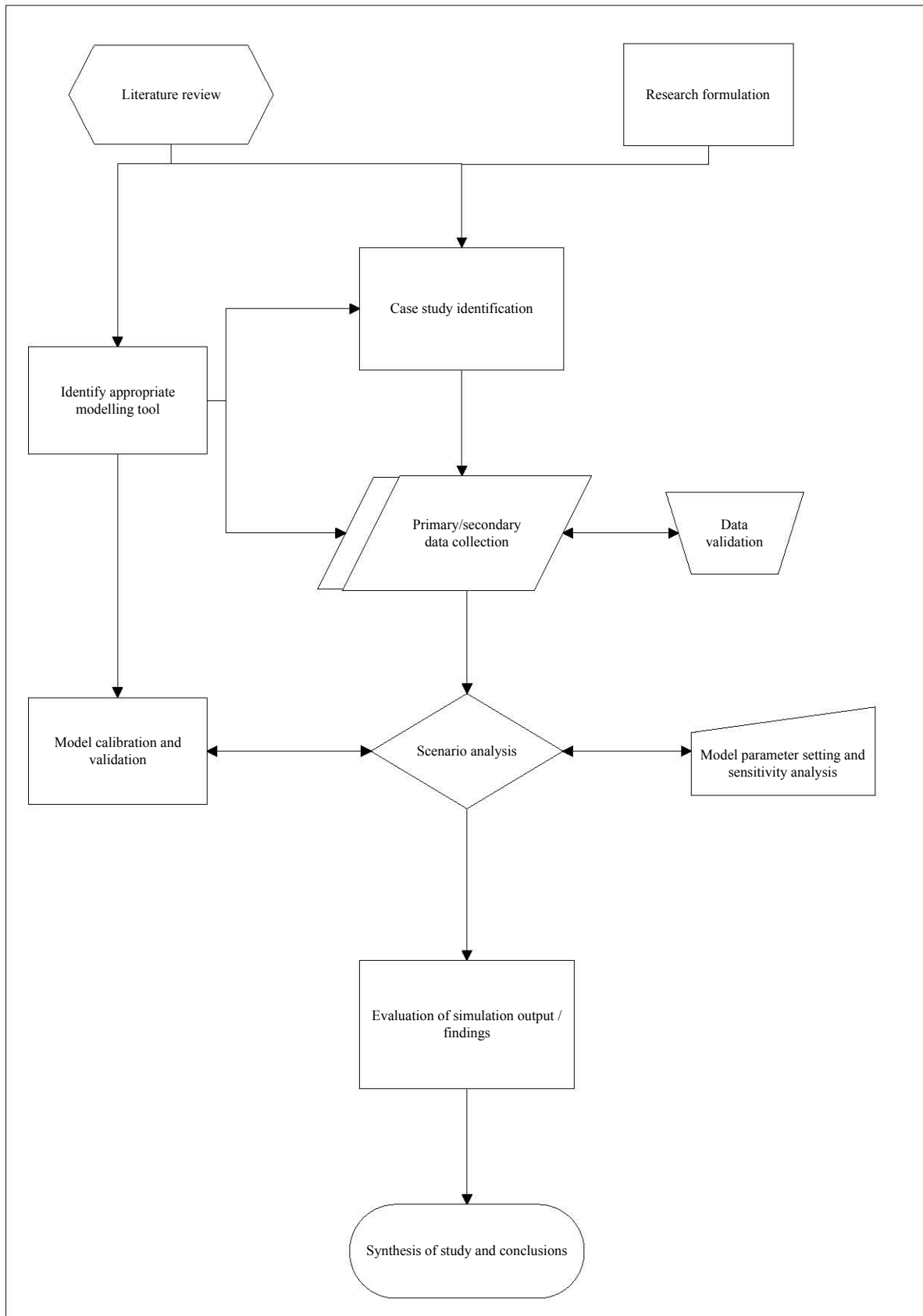


Figure 2b: Research process

1.5 Overview of dissertation

This thesis contains nine chapters detailing work that has been carried out since 2009.

Chapter 1 introduces the topic, provides some background to the research, describes the research problem and lists the research questions. It then provides the proposed research scope, its limitations and the methodology.

Chapter 2 provides a historical overview of transport planning – including policies, design guidelines and the network utilisation – in order to understand the evolution of the current cityscape from a transport perspective. It also provides a background as to the reasons why and how particular stretches of road are used and why they may have contributed to the crash record of the City.

Chapter 3 is a detailed review of historical crash data recorded for Cape Town. The details are extracted and analysed from raw data provided by both the City of Cape Town and the National Forensic Pathology Services (FPS). Out of necessity, the extractions and analyses were limited to fatalities only, as the numbers of fatalities are more manageable and the data from FPS is recognised by the City as being more reliable than police data, which contains all reported crashes. The objective here was to establish any trends in the data (numbers, which day, time of day, gender, race etc.), and to determine where crashes were most likely. This information was used to determine possible areas for case studies.

With the knowledge of where, when and how many fatalities occurred, it is important to understand what the Government's response is to the road safety problem and whether any policies, strategies or legislation will influence this record. A description of the documents and a review of their possible impact on road safety are provided in chapter 4.

There is a considerable amount of literature on the 'science' of road safety. Chapter 5 identifies some of the prominent techniques in use that allow an evaluation of, and the prediction of the potential road safety risk of any situation. From this it is concluded that although many techniques exist that could help the road safety problem in Cape Town, but that these rely upon accurate and detailed historic crash data and/or trained professionals to execute them. Micro-simulation is also identified as a potential tool. It is not often used in South Africa at present, although it is used on occasion as a traffic efficiency and provision prediction tool.

Chapter 6 provides a detailed review of micro-simulation, its requirements in terms of data, parameter setting and calibration and validation methods. The review also details the recent and emerging field of simulation modelling – pedestrian modelling, which is of particular interest to this study given the number of pedestrian fatalities and the hypothesis formulated.

Chapters 7 and 8 present the case studies that have been used to undertake the evaluation of the modelling technique. Results from each simulation analysis are presented and compared either to the findings of published reviews by others, in the case of the traffic calming measures, or to each other. A method of ranking the potential safety of a particular form of infrastructure, based on its current usage, and on appropriate changes to it, is also proposed in Chapter 8.

Chapter 9 contains a synthesis and conclusion to the study. It summarises the research findings and provides the responses to the research questions. The contribution to knowledge made is also highlighted and the chapter finishes with a reflection on the work carried out.

2 Overview of transport and land-use planning and design guidelines in Cape Town

This chapter provides a historical overview of transport planning in order to understand the evolution of the current cityscape from a transport perspective and how the legacy of planning has resulted in a population distribution that means long travel distances for the majority. It also reviews the road and public transport infrastructure currently provided as well as strategic informants and design guidelines related to the provision of transport. The aim of this section is therefore to outline the reasons why and how particular stretches of road are used and why they may have contributed to the crash record of the City.

2.1 Early Cape Town land use and planning

Located on the shore of Table Bay, Cape Town was originally developed by the Dutch East India Company as a victualing station for Dutch ships sailing to Eastern Africa, India, and the Far East. Jan van Riebeeck's arrival on 6 April 1652 established the first permanent European settlement in South Africa. Cape Town quickly outgrew its original purpose as the first European outpost at the Castle of Good Hope (Figure 3), becoming the economic and cultural hub of the Cape Colony (Figure 4). Until the Witwatersrand Gold Rush and the development of Johannesburg, Cape Town was the largest city in South Africa (http://en.wikipedia.org/wiki/Cape_Town).

Although the early Dutch town was laid out on a grid pattern, the British allowed the city to grow organically in the hands of developers. By the twentieth century, this was considered haphazard and expensive and two very different foreign influences on town planning followed. The first was the British 'garden city' movement. The second influence was a more practical, cost-effective form of building popular in America that emphasised large spaces for industry, commerce and residential areas and the use of stark materials such as concrete. It also favoured zoning areas for particular purposes, e.g. commerce or industry (<http://www.capetown.at/heritage/history>).

The main aims of Cape Town planners during the first half of the twentieth century was public health and the maintenance of social order. Racial segregation was seen as an important means to achieve these. Prior to 1927 the authority for town planning was split between different local and central institutions, and it was only once a town planning ordinance was passed (1927) and a town planning department established (1934, attached to the City Engineer's Department) that comprehensive urban zoning began in earnest (1941) (<http://www.capetown.at/heritage/history>).

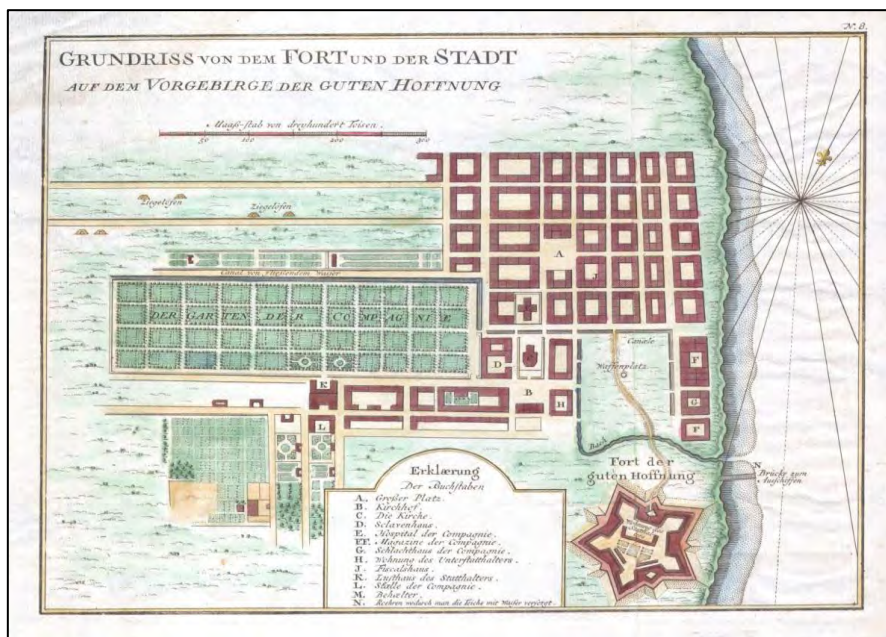


Figure 3: Map of Cape Town in 1750 by Jacques-Nicolas Bellin
 Source: J. Bellin (www. Geographicus.com)



Figure 4: An 1800's map of Cape Town
 Source: Meyers Konversations-Lexikon

2.2 Modern Cape Town: land-use and transport planning

In most South African cities land-use patterns - which characterise the form and densities of cities and influence travel distances as well as modes - are generally along the lines of historic apartheid planning which followed the principle of locating workers away from the centre of the city, resulting in a low-density 'fringe' type city. Although the majority of cities included a green buffer between the

city centres and ‘worker’ residential settlements these are now being infilled. Changes in settlement and commuting patterns over time are limited and, if anything, commuting volumes on historic paths have increased as the cities have grown over time.

Cape Town’s administrative area is roughly 2200km², although, the built-up portion occupies some 670km², mainly on the eastern periphery, known as the ‘Cape Flats’. Significant expansion has occurred recently along the northern coastal plain and into the rolling agricultural landscape to the north-east. Residential densities range from as low as 2–4 units per hectare in the wealthiest suburbs to perhaps 90–100 units per hectare in inner city areas with a significant proportion of apartment buildings. Population densities are highest in the informal settlement areas on the Cape Flats, where they may rise to between 250 and 500 people per hectare (see Figure 5). Despite extensive growth during the last four decades, the basic structure of metropolitan Cape Town continues to reflect the patterns of its development during the nineteenth and early twentieth centuries. Corridors of more intense activity and mixed land use associated with major arterial roads and suburban rail lines radiate from the geographically eccentric City centre south towards Fish Hoek and east towards Durbanville.

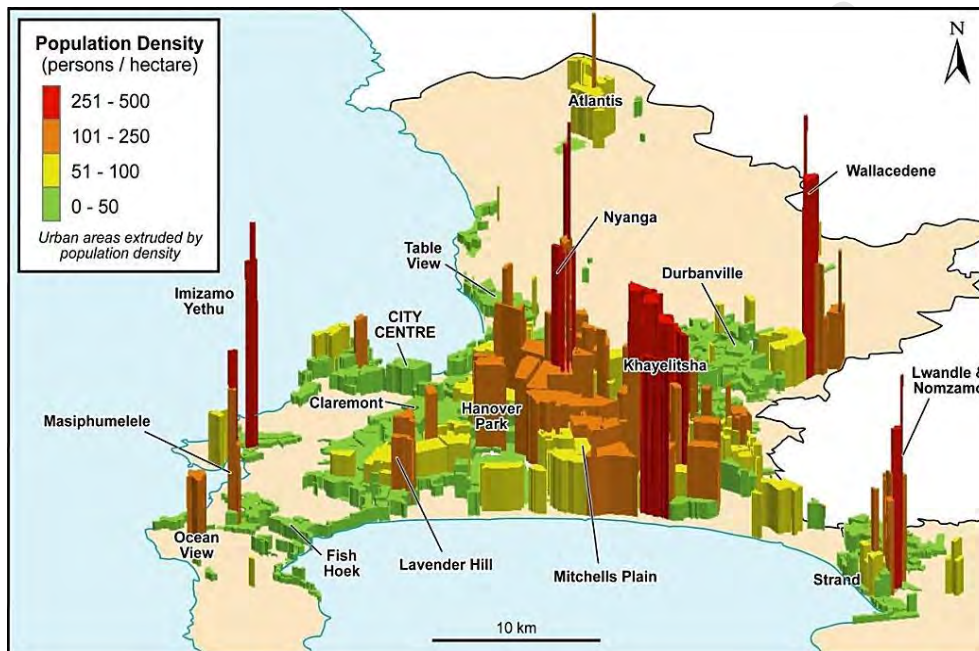


Figure 5: Cape Metropolitan Area, population density per hectare

Source: City of Cape Town, 2010

As much as 70% of the Cape Metropolitan Area’s formal employment, and higher order facilities remain concentrated along or closely adjacent to these corridors, particularly where they converge (Wilkinson, 2000). However, decentralisation of office and retail activity, as well as manufacturing and services, has been evident for some time, giving rise to the growth of important sub-centres or nodes at Claremont and Bellville. The emergence of regional shopping centres during the last 30 years, usually located near major interchanges on the city’s freeway system, has also fundamentally reshaped the city’s retail geography (Wilkinson, 2000). Despite these changes, the majority of the city’s revenue stream still emanates from the city centre (see Figure 6) and, therefore, traditional peak hour travel patterns have continued and have been reinforced to an extent where the major arteries are usually congested for several hours of the day (see section 2.5).

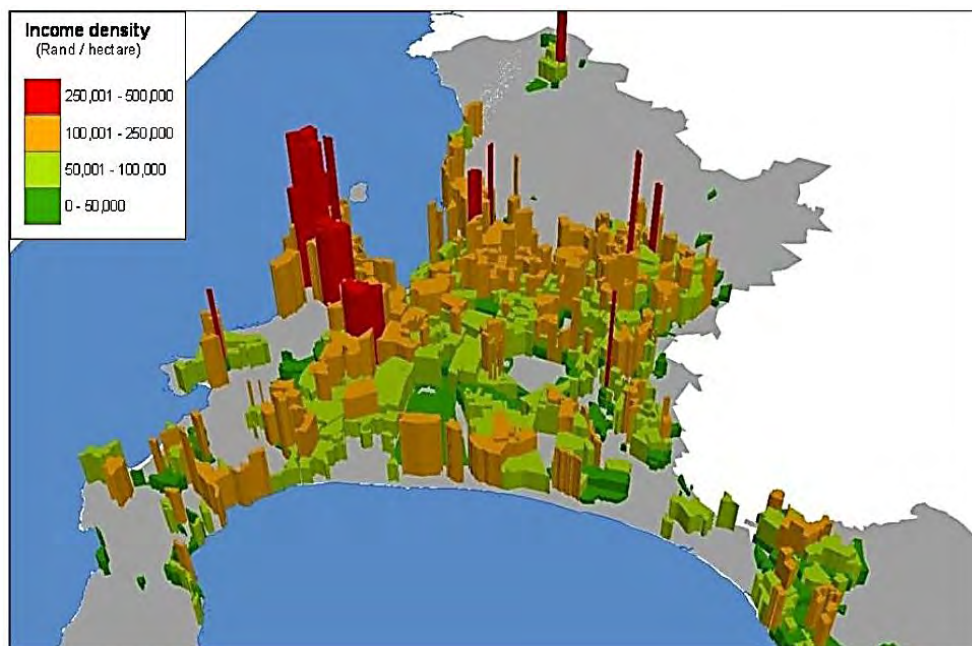


Figure 6: Cape Metropolitan Area, revenue per hectare

Source: Derived from City of Cape Town, 2010

2.3 Transport modelling

Many of the current approaches to transportation modelling are still based on the four-step or macroscopic simulation models, (the so-called predict and provide models) for medium to long term decision making. Increased computing power and software development have meant that historical uni-modal models have evolved to accommodate multiple modes and a range of horizons and scales. Essentially, four step models use the principle steps of: *trip generation, distribution, modal share and assignment*.

The first three sub-models deal with the calculation of travel demand and the fourth sub-model converts this demand to vehicle trips on the road network. These steps have seen improvements over time, but the process as a whole still relies on the prediction of vehicle and passenger volumes and corresponding infrastructure provision to meet a desired level of service. Fundamentally, therefore, the models rely on many assumptions but they still form the basis of most of the work done in traffic and transport planning. Decisions on route planning in Cape Town for many years have used this methodology, and locations are as a result of the outcomes of such models.

2.4 Transport supply

The result of historic transport planning methods/policies is the hierarchical form of road provision and control of road based traffic by segregation of pedestrians as much as possible. This so-called functional classification system (which can be traced back to the ‘*Radburn Layout*’ and the ‘*Traffic in Towns*’ publication by Buchanan in 1963) has resulted in the current format of the majority of Cape Town’s over 8,500km of public roads, consisting of various classes from freeways to secondary arterials, as shown in Figure 8 (City of Cape Town, 2009).

The extent to which road classification influences the provision of transport infrastructure cannot be understated- it is this system that has led to a focus on operating speeds and target volumes.

As it is conventionally applied, it takes much more from its theoretical underpinnings than is required to produce a generic description of the facility. Instead, it uses this theory as the basis for a more prescriptive interpretation of the function of the road. Conventionally, it concentrates on the traffic

functions of streets and the relationship between the categories developed from the scheme in terms of mobility on the network. The categorisation scheme, therefore, generates a hierarchy of levels of mobility that can be reinterpreted as parameters that define the infrastructural norms for that facility type. The nature of the categorisation system, and its interpretation in terms of mobility, means that the primary parameters that are developed are operating speeds and target volumes. The hierarchical nature of the system lends itself to restrictive norms in terms of which level of road can link to another and, by implication, the quality of service that must be provided for allowed modes (Beukes, 2011).

Significantly (from a safety perspective), this hierarchical linked system results in legal speed limits of 120km/hour on the city's freeways and expressways (except in close proximity to the city centre), and speeds of up to 100km/hour on primary arterials and many secondary arterials. Levels of service provided, especially during off-peak or inter-peak periods mean that many of these roads allow traffic speeds in excess of these limits. The remainder of the roads have posted speed limits of 60km/hour or, in the case of the poorer, less developed areas (usually referred to as townships in South Africa), there are few or no signposts indicating speed limits. In contrast to the 'better' developed areas where this formalised road classification system is prevalent, many of the township roads are much narrower with few or no sidewalks, even near schools, and many roads within these areas are unpaved. The majority of these roads are provided in a grid-like pattern with long distances between intersections, allowing high vehicular speeds.

The City's road-based public transport network comprises of an extensive formal bus service system and a licensed, (but unregulated in terms of timetables and costs) route-based, mini-bus taxi service (MBT), which operates throughout the metropolitan area. Work is also currently underway to complete the first phase of six phases of an Integrated Road-based Rapid Transit Network (IRTN). When completed the IRTN is expected to form a comprehensive network covering the metropolitan area with main lines along primary corridors, which will complement the existing 600km double track rail network, and feeder services linking adjacent areas.



Figure 7: Phases of the full Integrated Rapid Public Transport Network
Source: City of Cape Town, 2012

Most of the current road network also acts as a non-motorised network, although the extent of physical separation of the motorised from the non-motorised is not always the same, resulting in a fragmented NMT network. The majority of the formal pedestrian footpaths and sidewalks are provided mainly in the inner city areas, but the City of Cape Town (2009) recognises that: ‘There is no formal pedestrian management system in Cape Town’, and that ‘there are no programmes presently in place that aim at creating safer environments surrounding schools’. These issues are partly addressed in its NMT Strategy Document (City of Cape Town, 2005) and a comprehensive audit has been underway since 2010 (see Chapter 4).

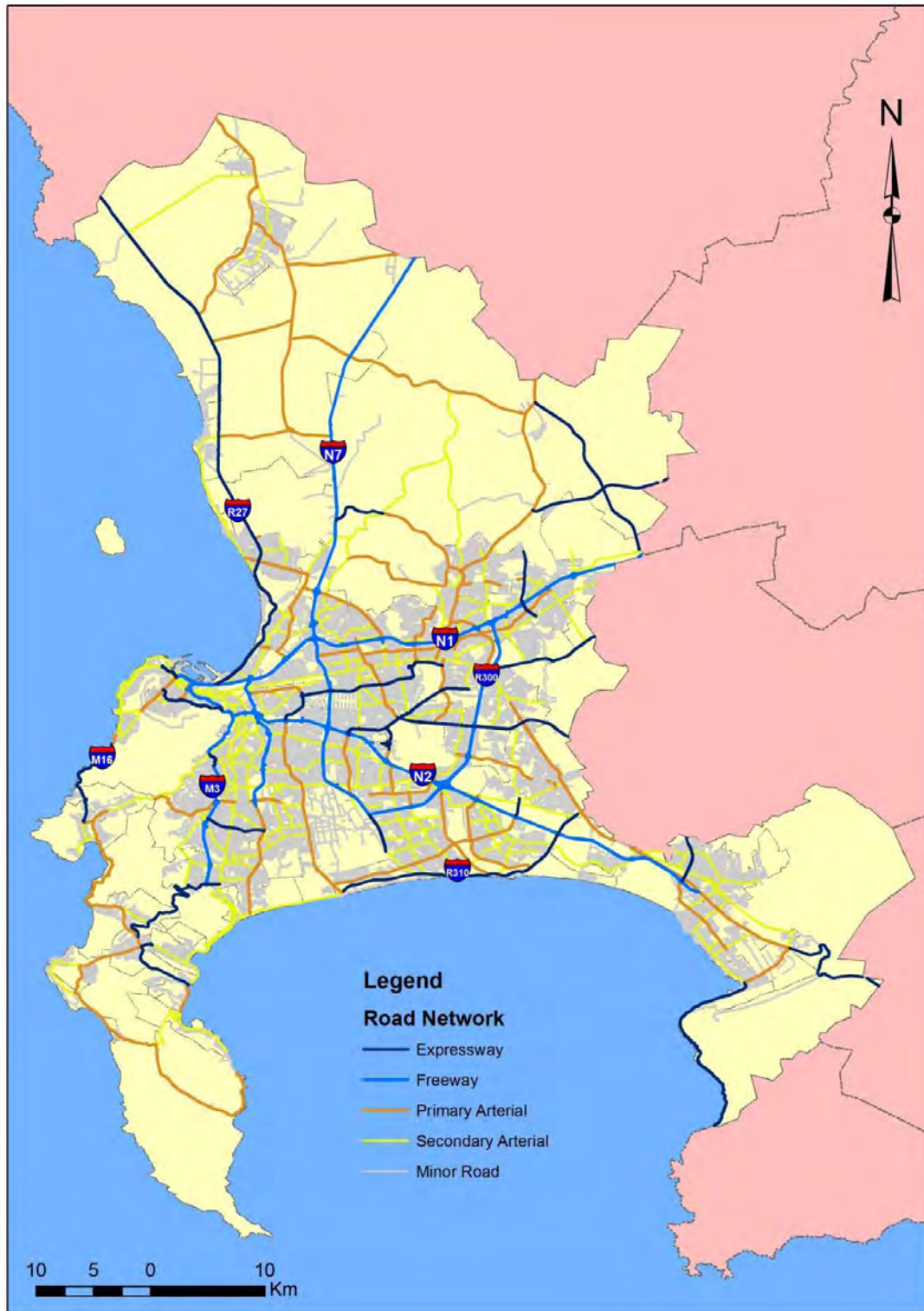


Figure 8: Road hierarchy in Cape Town

Source: City of Cape Town (derived from GIS mapping information received June 2012)

2.5 Transport network utilisation

Travel demand and mobility patterns are largely driven by socio-economic factors. Personal mobility is dependent on income levels as well as the availability, location and safety of public transport and road infrastructure.

Official records (City of Cape Town, 2009) indicate that between 2002 and 2009, the annual rate of growth in private (and licensed) vehicle ownership was 3.8%, resulting in an ownership level of 1.1million registered private vehicles in Cape Town in 2009; this equates to approximately one vehicle per four residents. Although these levels of car ownership reflect favourably with many developed nations (from a traffic congestion perspective), the geography of the city and its settlement patterns dictate that the majority of these vehicles use one of the four main routes into the city centre during the peak hours (see Figure 9). Along with the growth rate in vehicle ownership, the negative perception of public transport in terms of its safety, lack of frequency and flexibility, means that private car use forms a large proportion of the modal share (50-60%) during the peak hours and (83%) during inter-peak periods. The continued growth in GDP (see Figure 10) and the national and local government’s targeted economic upliftment of the poorer sectors of the population, means that this trend is likely to continue upwards (ASGISA, 2007).

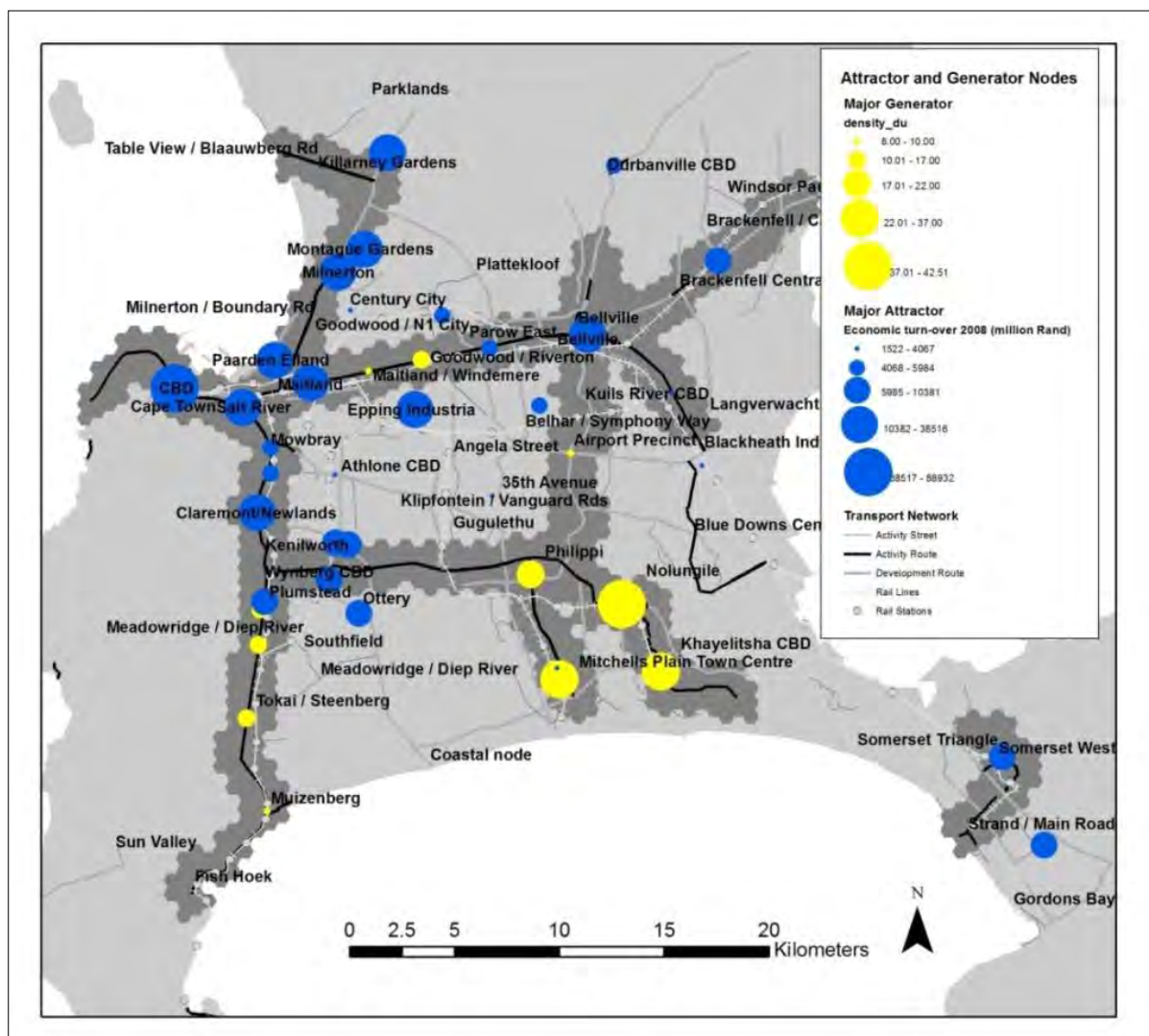


Figure 9: Cape Town - trip origins/destinations map
Source: Received from City of Cape Town, 2013

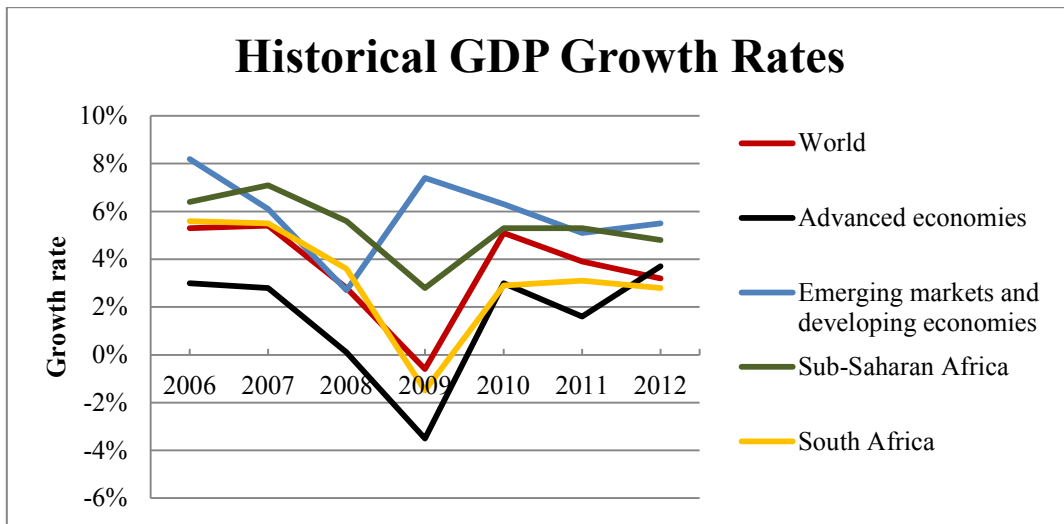


Figure 10: Historical GDP rate for South Africa compared to worldwide trends
 Source: Derived from International Monetary Fund, World Economic Outlook Database³

Furthermore, in its Integrated Transport Plan (ITP), the City of Cape Town (2009) confirms that ‘..For some years, increasing road traffic has not been matched by the necessary investment in road or public transport infrastructure’. The effect of a lack of investment in the promotion of a densification of the city and increased car ownership is clear to see on the city’s major roads - congestion, especially during the peak hours (see Figure 11). Levels of congestion have resulted in peak periods in the order of three hours rather than a single hour, and in secondary arterials experiencing higher levels of traffic as commuters seek alternative, faster routes to work, leading to inappropriate vehicular speeds and thus an increased potential for crashes, especially those which involve pedestrians.

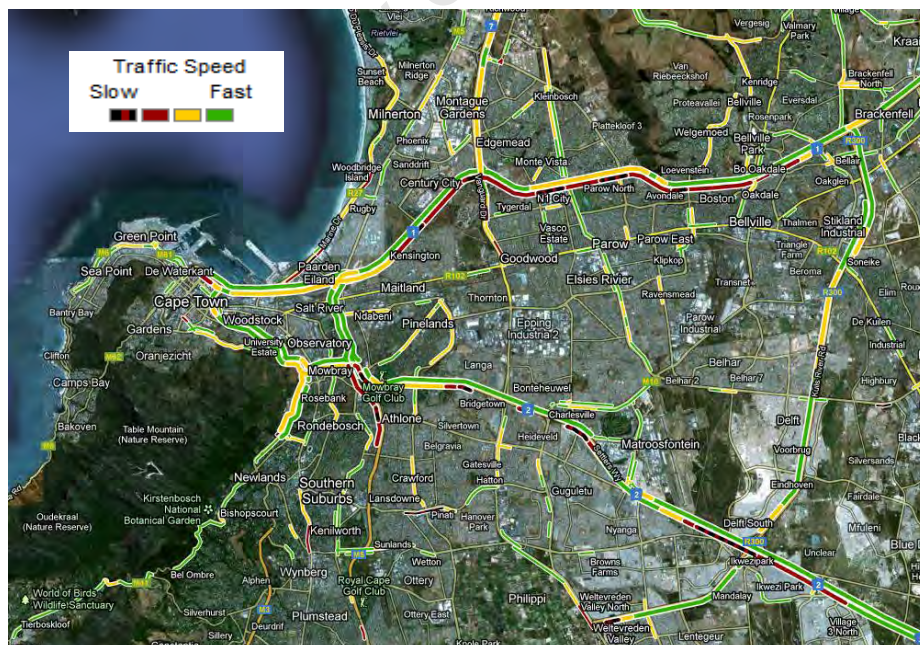


Figure 11: Cape Town - traffic demand and speeds on major routes
 Source: Google Maps (accessed May 2013)

³ Note: 2012 data is estimated by the IMF.

The recent addition to the City's public transport services of Phase 1 of the proposed IRT network, running from the CBD northwards has met with some success, in that it has captured some 10,000 commuters per day. However, the intention of the system was to integrate the various modes of public transport, and through this to reduce overall private vehicle travel demand; this has not yet been achieved as the system is in its infancy and the anticipated roll-out of the full network is expected to take up to 20 years.

2.5.1 Non-Motorised Travel

The importance of non-motorised transport (NMT) in a developing world transport context cannot be understated because of the reliance on walking and cycling for the majority of the trips made. NMT is generally recognised as a valuable component of the transportation system and the environment we live in because of the many benefits it brings such as: improved health, decreases in pollution, increased liveability and so on. It also forms part of all trips undertaken, be they commuting or recreational.

In Cape Town, despite a rate of car growth that exceeds that of population growth in recent years, a large portion of the population (51%) remains without access to private transport (Department of Transport, 2007). The transport system is thus notable for its dualistic mode of operation in terms of the supply of services to two equally sized passenger market segments. The first segment cannot afford the costs associated with vehicle ownership and is therefore captive to whatever public transport services are provided, and to walking. The second segment has higher incomes and, while presented with a choice of modes, uses private motor cars extensively (Behrens and Jobanputra, 2012).

A defining feature of the city is its inefficiency with respect to the daily transportation of people, and the burden this places on lower income groups living on the peripheries. Historic apartheid policies, such as forced removals, the creation of 'green' buffer zones between workers and employment opportunities amongst others, have contributed significantly to the current context in which the travel needs of low-income populations are not well served by the pattern and distribution of land-use activities and the transport systems that connect them. Housing and land use policies in the post-1994 democratic era have done little to remedy this inefficiency and inequality.

2.6 Strategic transport informants and guidelines

2.6.1 Transport policies

To meet the modern needs and transport challenges in South Africa, many important pieces of legislation have recently been promulgated by the Government. Of importance to road safety are – the White Paper on National Transport Policy (NDoT, 1996), the National Land Transport Strategic Framework, 2006-2011 (NDoT, 2006), the National Road Safety Strategy (NDoT, 2006a) the National Land Transport Act (NDoT, 2009), and the Municipal Systems Act (MSA) (RSA, 2000).

Pertinent details of these documents, which have shaped the sphere of transport infrastructure provision in South Africa as it is now (from a strategic and action perspective), are outlined below.

The main objectives of the Government with respect to roads and transport planning are clearly stated, and are unequivocal. They are guided by what seems to be the key piece of legislation - the White Paper on Transport Policy (NDoT, 1996) - whose mission statement is:

'The promotion of a safe, reliable, effective, efficient, coordinated, integrated, and environmentally friendly land passenger transport system in South African urban and

rural areas, and the Southern African region, managed in an accountable manner to ensure that people experience improving levels of mobility and accessibility’.

From this document, the principal focus of ‘*an equitable system for all*’ has emerged, meaning that a public transport (PT) first policy should be adopted along with integration between modes. Other key areas of focus are the integration of land use and planning of transport, travel demand management, corridor planning and the promotion of NMT. It explicitly requires the promotion of the use of public over private motorised transport (PMT), specifically setting a goal of achieving a ratio of 80:20 between public and private usage.

The centrality of NMT is confirmed by the objective of encouraging, promoting and planning for the use of NMT wherever appropriate.

Given the focus on public transport and that infrastructure provision is, largely, the end product of transport planning, the question is, how much of an impact have these policies had on infrastructure provision over the same period of time. To a certain extent, this question is addressed by an investigation of the amount of expenditure on public transport specific projects by the Provinces which, by the nature of the institutional and regulatory framework, are the executors of government policy (in this case transport). Data from the National Treasury (Figure 12) indicate that only one or two of the nine Provinces in South Africa actually met policy requirements and these are the least populous and least developed, in terms of road infrastructure.

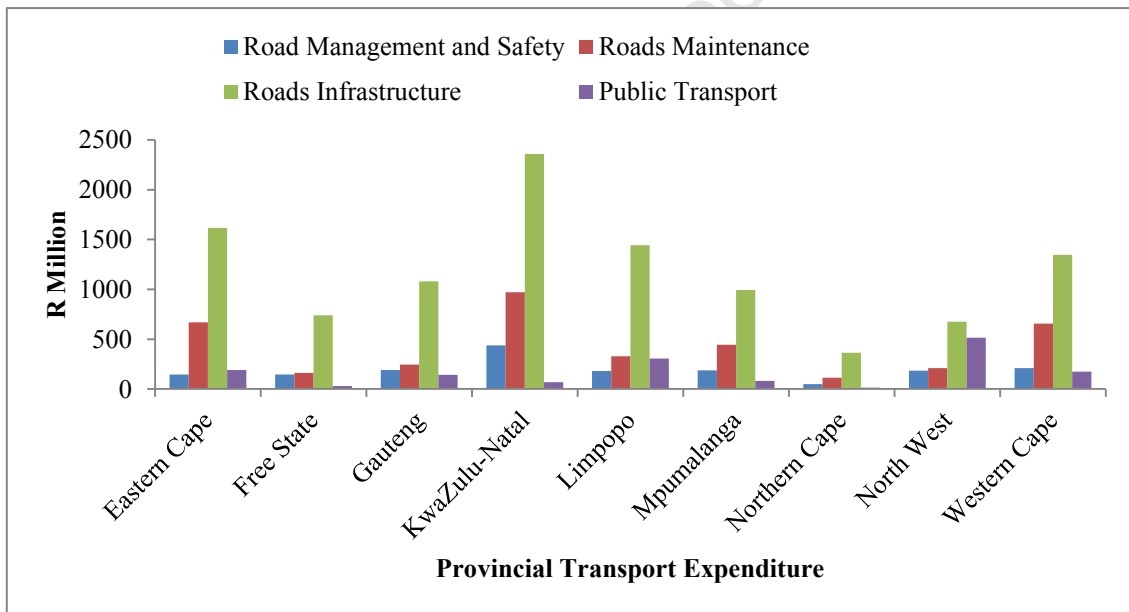


Figure 12: Provincial Roads and Transport expenditure 2007-2008.

A comparison of the expenditure on PT specific projects, road infrastructure maintenance, road upgrades and rehabilitation projects for the financial year 2007 to 2008 for each of the provinces in South Africa.

Source: Derived from (National Treasury, 2009)

It is clear that there is an insufficient revenue stream to match the twin needs of the policy objectives of public transport and the realities of the urgent requirements of road upgrading and maintenance. However, it could be argued that provincial authorities have a limited role in public transport provision, especially in municipal areas where the majority of funds are concentrated, particularly in Cape Town. The data in Figure 13 if compared to data in Figure 14 reflects this. The spike in public transport spending although seeming to indicate that that Cape Town’s strategy is now focussed on PT, and is in keeping with national policy, but this masks the fact that the expenditure was driven by

the demands of the 2010 FIFA Soccer World Cup⁴ and that it was facilitated by the promulgation of a new, better funded Public Transport Infrastructure and Systems Grant in 2006. The funds within this grant (R18.7 billion) are set such that they need to be expended by 2012 (NDoT, 2009).

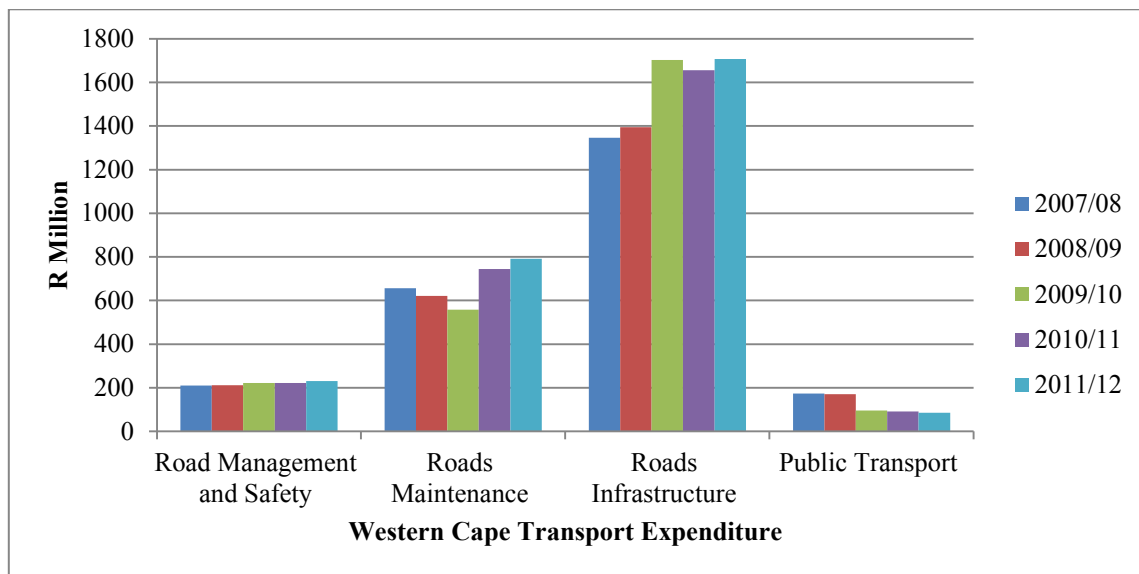


Figure 13: Completed (to 2008) and projected (2009-2012) expenditure on transport projects
 Source: Derived from (National Treasury, 2009)

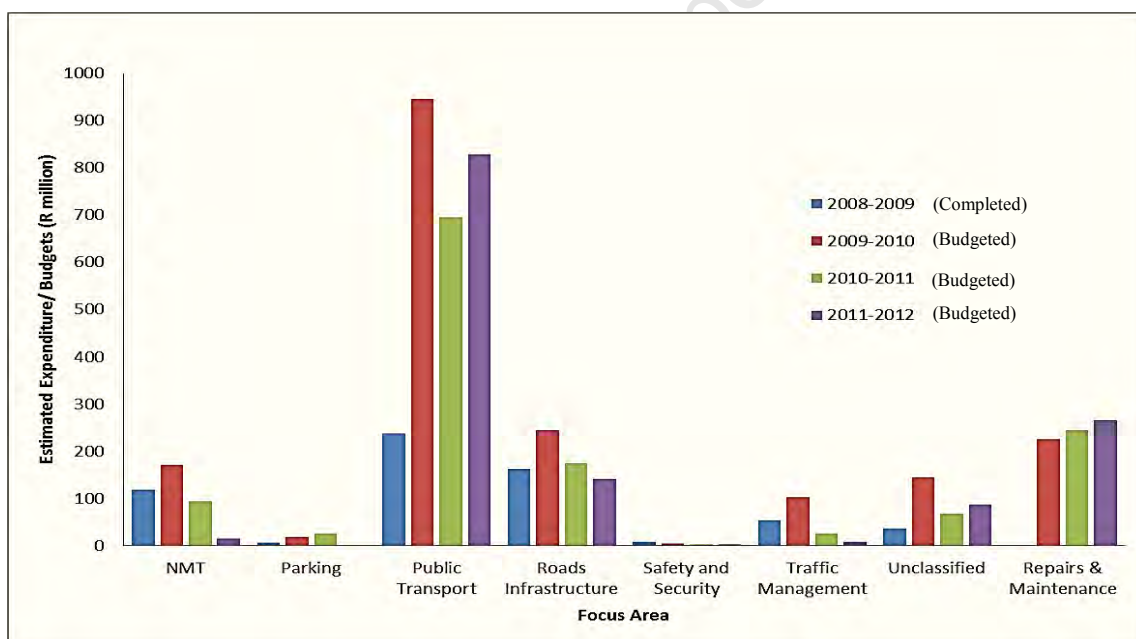


Figure 14: City of Cape Town - Completed & Budgeted Expenditure on Transport Projects
 Source: Derived from (City of Cape Town, 2009)

The MSA (RSA, 2000) requires the preparation of an ‘*Integrated Development Plan*’ which, in turn, requires input from a ‘*Spatial Development Framework*’ and an ‘*Integrated Transport Plan*’. Clearly the latter document is of greatest relevance here as its role is to detail municipal transport policy and provision objectives.

⁴ The 2010 Soccer World Cup required the provision of dedicated public transport links to and from the airport to the venue, which forced the early roll-out of dedicated bus rapid transit systems in the host cities

2.6.2 Guidelines

Policy and legislation drive the provision of transport infrastructure, in that they set the overarching national priorities, strategies and actions to be taken when planning transportation. However, these documents are only as good as their delivery mechanisms, for which purpose the relevant government departments develop a number of Guidelines. These form the basis of the best or acceptable practice that practitioners should achieve and, thus, form an integral role in the implementation of policy objectives and strategies. They should ideally, be revised or continually updated, to keep in line with national objectives.

The development of guidelines presents an ideal opportunity for a thorough investigation into the practical issues around implementing new policies, and an assessment of where current standard practice may still be appropriate. It provides practitioners with the opportunity to interrogate current thinking and systems, and identify where these must be adapted- or abandoned and replaced - if needs be, to achieve policy objectives. Guidelines, however, are developed with a level of generality. They cannot address with any degree of specificity, all the possible situations that may be encountered in practice. Their use is subject to the acknowledgement that the practitioner must apply the principles outlined in the guideline, as best as possible, to a unique situation. The overly rigorous adherence to the letter of any guideline is foolhardy, even more so when the guideline may, in some respects, be outdated.

Research findings from the academic institutions do, after a period of dissemination, peer review and debate, work their way into policies and eventually to some extent and eventually form the basis for the practical advice given in guidelines. The scientific standing, and the general acceptance of the recommendations in guidelines as being the best practice, means that they offer a measure of indemnity from professional or legal challenges to the product produced and effects thereof and generally, design which does not deviate much from the guidelines.

Complicating the issue further, many roads authorities have developed their own sets of design standards that have been based upon other guidelines (see for example: NDoT, 2003; SANRAL, 2009), and tend to require even greater compliance. This would not be so much of a problem if the guidelines that are currently in use were regularly revised to reflect the current policy objectives (Beukes, 2011). Some of the guidelines commonly used or referred to in practice are detailed below, with some discussion regarding the extent they reflect policy ideals described in the previous section.

2.6.2.1 *South African Trip Generation Rates Manual*

The South African Trip Generation Rates Manual, originally produced in 1989, provides an estimate of the number of expected trips from a range of land uses (NDoT, 1995). It was reproduced in 1995 and is still in widespread general use today despite the national economic growth over this period of time and increasing urbanisation.

In addition, the manual does not provide estimates of trip generation by mode, but provides vehicle and person trips only. There is no indication of the number of public transport trips or how the number of person trips is split by mode. Unsurprisingly, this has led to a heavy bias towards the provision for PMT. This is a poor and unsustainable case as the majority of trips undertaken in South African cities are by either foot or PT; these trips are either not considered or are underestimated by the assessment method. Furthermore, casualty rates for pedestrians in the city are particularly high, highlighting a need for particular need for NMT infrastructure provision. These biases/needs place the manual in direct contravention of transport legislation and policy.

2.6.2.2 Urban Transport Guidelines

The Urban Transport Guideline (UTG) series of documents provides recommended practice mainly for all geometric aspects of urban road design (CUTA, 1986). The guidelines are drawn mainly from British and American planning policies of the 1920s and 30s using the 'neighbourhood unit' concept, as well as the ideas about functional road hierarchies as defined in the 'environmental area' concept by Buchanan in the 1960's.

Both concepts envisage the elimination of through traffic from residential areas by means of high volume wide arterials and narrower internal networks for neighbourhood areas (preferably curvilinear). Design speeds are related to road width and PT and other modes are only dealt with superficially. In the absence of any other overall, superseding guidelines, these documents continue to be used in the industry, again in conflict with transport policy.

2.6.2.3 Guidelines for Human Settlement Planning and Design

The Guidelines for Human Settlement Planning and Design (also known as the Red Book) were published in 2000 by the National Department of Housing. These guidelines deal with roads and transport in two sections of the document. One section deals with what is termed the movement network planning (i.e. multiple modes) of settlements and the other with engineering issues around road design and construction.

Whilst the document highlights the importance of pedestrians in settlement planning and that PT and NMT is more important once the human scale is exceeded, in some places they still refer to the UTG's, giving the impression that the UTG's are still generally applicable. In essence, therefore, the guidelines have not made significant strides toward changing the one-dimensioned approach to transport planning as it still refers to the very documents that support the motorised approach. The effects of any changes as a result of the use of this document will probably only be felt in the coming years.

2.6.3 Reflection on transport planning and design guidelines

It is clear from the review in this chapter that historic land planning and settlement policies have resulted in Cape Town being a sprawling city where the majority of the population need to commute long distances to central locations to benefit from economic activity. Although the major determinants of transport provision in the city (chiefly the 5-year Integrated Transport Plan) now acknowledges the need to provide more and better integrated public transport and NMT infrastructure, the levels of investment required mean that this will take a long period of time. In the meantime, the legacy of under-investment in public transport (road and rail) has resulted in a fragmented and unreliable public transport system which is perceived to be unsafe and below standard and has led to a greater use of private vehicles.

Furthermore, national design guidelines are out-of-date and require revision to encompass the shift from auto-centric provision to more public transport and NMT provision which is more context sensitive. The transport provision requirement for new development is also guided by a historic manual which has a bias towards private vehicles and is therefore insensitive towards the majority of road users.

A change to these guidelines and manuals as well as a more rapid introduction of an integrated and reliable public transport system will go a long way in helping the road safety situation.

3 Road safety in Cape Town

Developing nations worldwide are reported to contribute the largest proportion of global road traffic mortality numbers (around 90% see for example, WHO, 2009). These nations face particular transport challenges because social inequities or transport planning paradigms imported from developed nations, usually result in inappropriate or inadequate transport planning for some; this often results in the most vulnerable users suffering the greatest travel risks and a variety of travel perceptions (see for example: Thynell, 2009). Further, the rapid increase in motorisation being experienced in developing nations, and the lack of suitable infrastructure or transport systems bring about their own set of problems. This chapter unpacks published data on road safety which shows that many of these challenges apply to Cape Town as well, due to its diverse population and socio-economic groupings (especially the number of pedestrian fatalities), and that, in comparison to other cities in the world, the record of fatality per population in Cape Town is one of the worst (see for example: Vanderschuren, 2006).

3.1 Sources of data and collection methods

Road crash data is primarily obtained from the South African Police Services (SAPS) records. The National Road Traffic Amendment Act (Act No. 8 of 1998) requires that all motor vehicle crashes that result in injury or death are recorded on a standard accident report form by either a police officer, traffic officer or an authorised person in the employ of the traffic authority or the police, but no clear distinction is made between them.

SAPS handles Accident Report (AR) forms and Quick Response forms that involve fatalities, while crashes that involve injury or damage only may be reported to the Traffic Law Enforcement Agencies or local SAPS. Insurance policies require all (insured⁵) vehicle owners to report incidents to the SAPS station closest to where the incident occurred. This information is usually captured by the duty officer present. The accuracy and level of completion is dependent on this interaction and, the process following can add to it or detract from it. The reporting and capture of uninsured vehicle incidents may, or may not, occur depending upon the seriousness of the incident. The RTMC (2010) reports that around 8% of the total number of vehicles are either un-licensed or not roadworthy⁶. The impact of this statistic on road safety is reviewed in section 3.4.2.

Completed and checked AR forms are transmitted by SAPS to the relevant transport authority (see Figure 15), after which it becomes the responsibility of the data capturing authority to verify their integrity. The submission of completed forms from police to data capturers, which happens manually, is often delayed and, in some cases, delivery notes are erroneously completed (i.e. the requisite number of AR's are not present). Incomplete forms or forms containing errors are either sent back or verified telephonically. Both methods are fraught with difficulties and errors, and are seldom corrected. Occasionally, returned forms are lost. All of this leads to long delays in the completion of records⁷, which has obvious consequences on crash investigations.

Local accident register information is forwarded to National Department of Transport for recording, (in the National Accident Register (NAR)) analysis and reporting via the RTMC.

With respect to the AR form itself, it is apparent that it has been developed after an extensive international comparison, consultation and review process (Vanderschuren and Jobanputra, 2010). It

⁵ It is not a legal requirement for a vehicle to be insured in South Africa.

⁶ A roadworthy certificate is a legal requirement when a vehicle reaches 3years of age or greater and on transfer of ownership.

⁷ At the time of writing, the last publicly produced crash records for the City of Cape Town are from the year 2005.

contains all fields necessary for good reporting of incidents which should enable a detailed review process post-incident, but AR forms are seldom complete, reliable or accurate.

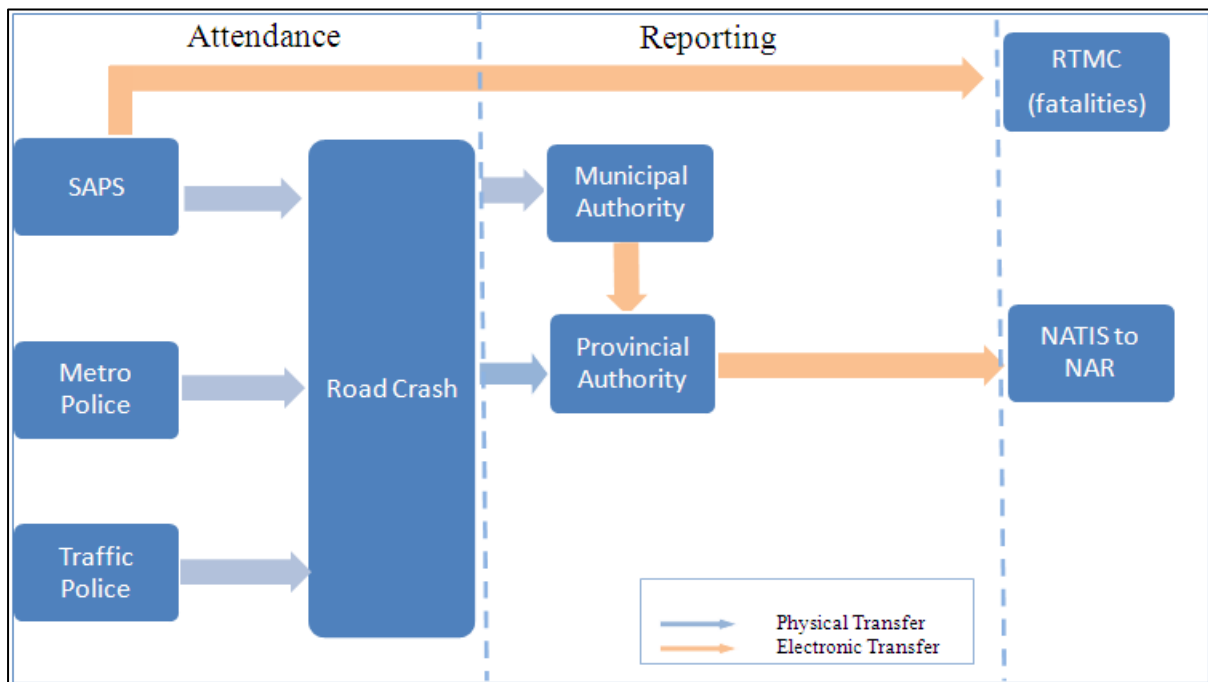


Figure 15: Road crash data collection and transfer process

Source: Jobanputra and Vanderschuren, 2010

The number of fatalities received by National Traffic Information System (NaTIS) is checked by RTMC against the number of fatalities recorded on the Quick Response forms and the National Accident Register.

Besides the RTMC database, various other organisations also record road incident related data such as: the Medical Research Council's database of hospital records (the Forensic Pathology Service), the National Injury Mortality Surveillance System (NIMSS), vehicle insurance databases, claims lodged with the National Road Accident Fund and, in Cape Town, records of incidents logged by the City of Cape Town's Traffic Management Centre (TMC) on its freeway and arterial system.

NIMSS produces information on non-natural deaths from 37 mortuaries in six provinces. In essence, this system involves the active collation and centralisation of routinely kept data. Although this data is currently skewed by the number of urban mortuaries (36 out of 37), it is reasonably representative of the national picture, and probably more accurate, as the majority of autopsies are dealt with at urban rather than rural mortuaries. The NIMSS is being expanded annually, and will eventually process information from all mortuaries performing medico-legal post-mortems.

Again, in Cape Town, the City's TMC, (which monitors the major urban freeways and arterials within the metropolitan area in real-time) logs all incidents. Data is compiled regularly and a monthly report is generated for general use; however, officials have not yet integrated/correlated this data with the annual crash statistics captured for the City.

Data from insurance companies or the Road Accident Fund is not readily available to the public for obvious reasons.

From a review of the results in the various data sources above it is apparent that there is a degree of inconsistency, and that publicly available data is underreported. Government is aware of this, but

despite attempts to put adequate procedures in place to collect and record crash data, it is clear that data collection methods - from the initial incident attendance to AR completion and subsequent data capture - are not satisfactory and require a complete methodological review. They would certainly benefit from automation, a process which is now becoming commonplace in many countries (see Jobanputra and Vanderschuren, 2010).

3.1.1 Reliability of Road Safety Data

Reliable road safety data is needed to ensure an accurate understanding of the state of road safety in the locations concerned, factors influencing road safety, to monitor trends, describe problems and to identify targets for interventions. The consensus in the literature is that, in general, there is a problem with data quality (see for example: WHO, 2004) because of incomplete and inaccurate reporting and under-reporting of road crashes especially those involving pedestrians and cyclists, worldwide. South Africa is clearly not an exception given the quality of the AR form; nevertheless, the data available locally is sufficient to evaluate overall trends and significant safety issues.

3.2 General Trends

By most international standards, South Africa, and by proxy, its cities, has one of the worst road safety records in the world at around 30 fatalities per 100,000 population every year (see IRTAD, 2009; OECD, 2011; RTMC, 2010).

In Cape Town, crashes increased by 16% from 2005 to 2007 but there is a gradual downward trend to 2010. Fatal crashes remain at around 5% of the crashes involving injury over the same time period⁸ (see Figure 16) .

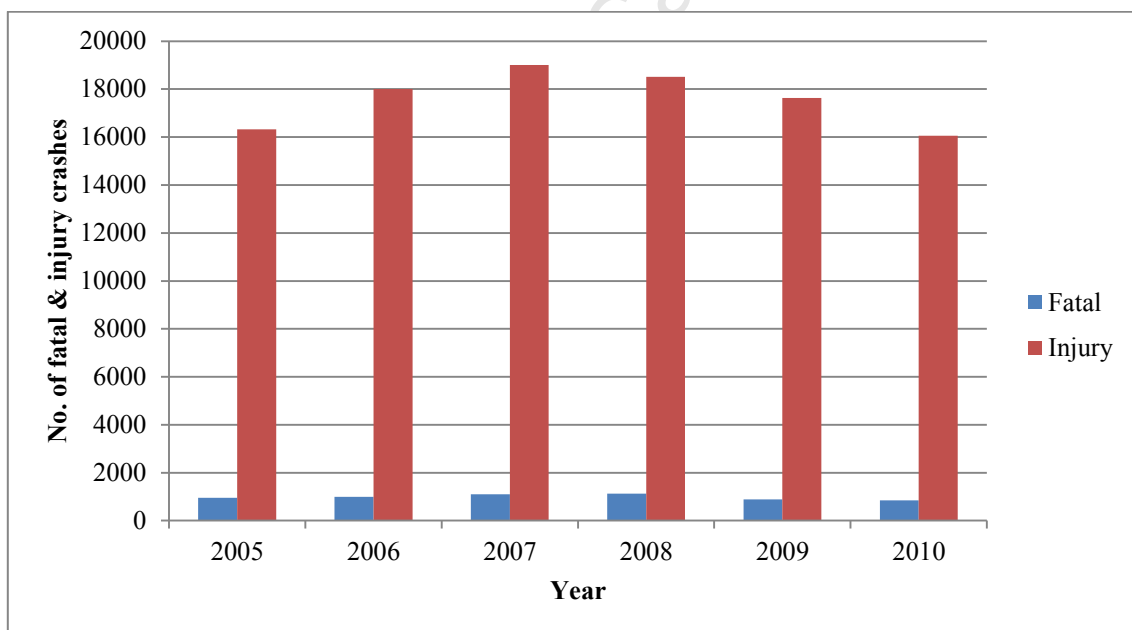


Figure 16: Trend in Number of Fatal & Injury Crashes, Cape Town

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

Moving monthly averages show that monthly crash rates were marginally higher in winter when the roads are wet with reduced visibility (Cape Town experiences rain during winter, unlike other areas within South Africa). The Friday evening peak period, as well as the holiday periods, are when most vehicular crashes occur, whereas, Saturday evening is generally when most pedestrian incidents

⁸ Fatal crashes are defined as those which result in death immediately or over a period of up to seven days

occur. The majority (74%) of all fatal crashes occur in the dawn/dusk/night period as do the majority of all fatal pedestrian crashes (80%). Of the known crash types, head/rear vehicular crashes are the most common.

Data from the NIMSS, shows that the following patterns were characteristic for transport related deaths - a high percentage of male deaths (70-80%), a high percentage of pedestrian deaths (55 - 60%) and high alcohol-relatedness of deaths among both drivers and pedestrians (> 50% of deaths); there are distinct peaks over weekends among adults and in the mornings and early afternoons among children of school going age (MRC, 2007).

3.3 Detailed analysis of road crash records

The following analysis is limited to fatalities and, where pertinent, on crashes resulting in serious injuries; there is little by the way of reliable data on crashes that are of a minor nature or property damage only.

3.3.1 All crashes

Between 2007 and 2011, the City of Cape Town data reports show that a high number of pedestrian deaths (>50% of the total number of people killed) as well as pedestrian casualties (>30% of the total number injured) were characteristic (see Figure 17 for fatalities). The level of pedestrian fatalities compares poorly with the national level for the years 2009 and 2010, at around 33% of the total fatalities (RTMC, 2010), and even more unfavourably with the OECD's 26 member countries – which range between 8% and 37% of all road fatalities (ITF, 2011).

The data also shows that an average of 35% of the fatalities are attributed to the 'motor vehicle' group and of these the split between drivers and passengers is fairly even. Between 1-3% of the total fatalities were cyclists although they account for only 0.8% of all trips (NDoT, 2005).

These data clearly indicate the problems faced by non-drivers (i.e. NMT users) and point to a general lack of safe infrastructure for them.

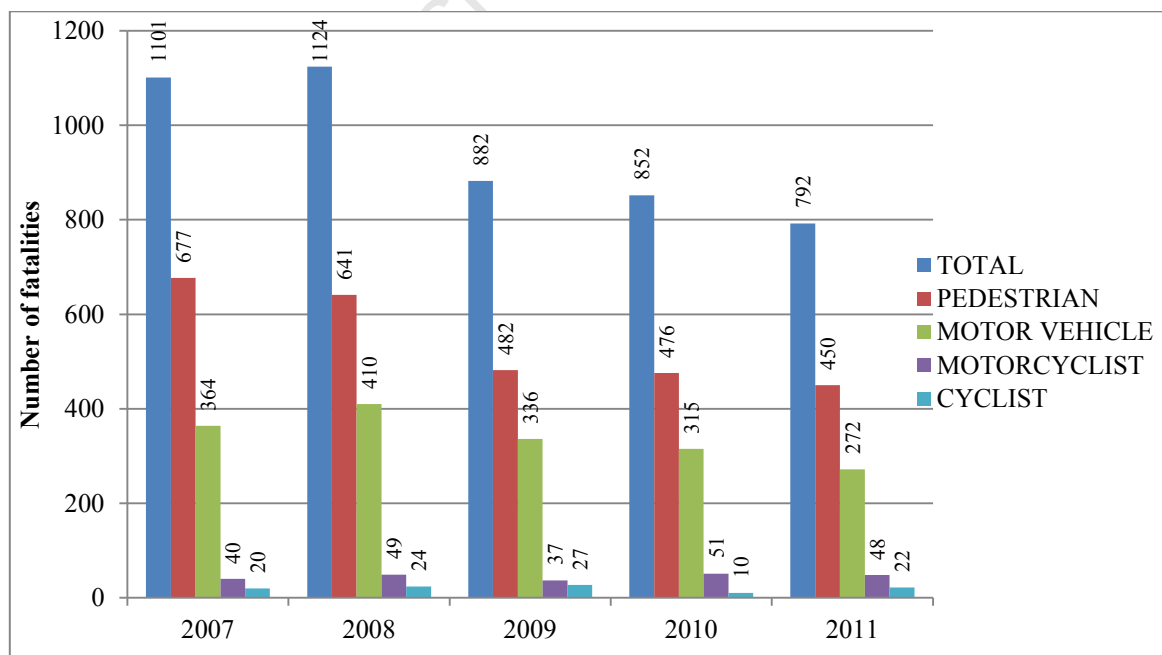


Figure 17: Breakdown of fatality data for Cape Town

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

3.3.2 Person type analysis

The City of Cape Town data between 2007 and 2011 shows that, of the known ages of those killed, persons between the ages of 22 and 35 are most at risk of being killed in road crashes (at approximately 30% of the total, see Figure 18), and that the majority of persons killed are from the ‘coloured’ or ‘black’ race groups (see Figure 19). Neither of these results are surprising as persons between the ages of 22 and 50 are the most economically active, and would consequently be exposed to safety risks the most, and the ‘coloured’ or ‘black’ race groups form the majority of the population in Cape Town.

The statistic confirms the generally held belief that the younger section of the population is prone to more risky road use behaviour (see for example: WHO, 2004).

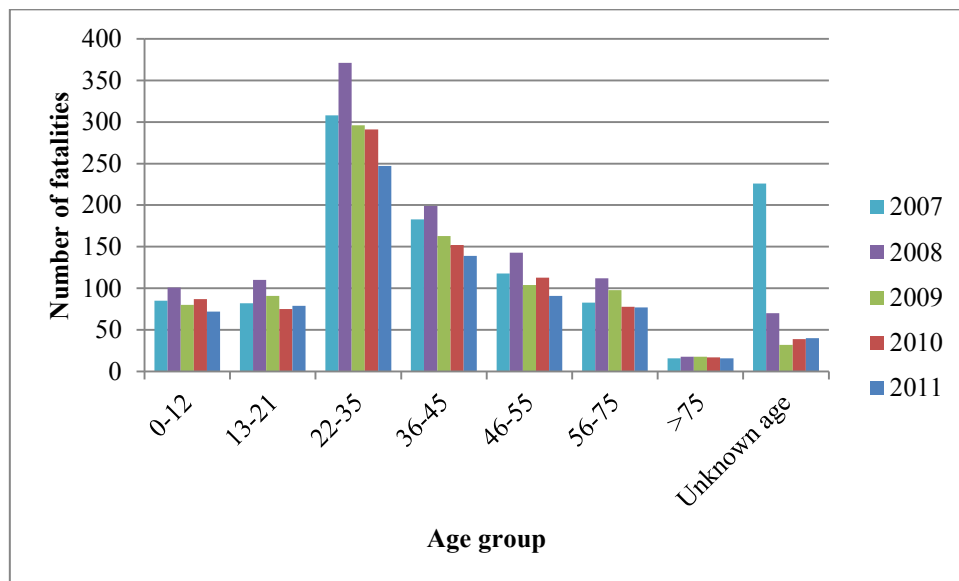


Figure 18: Age groups of fatalities between 2007 and 2011

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

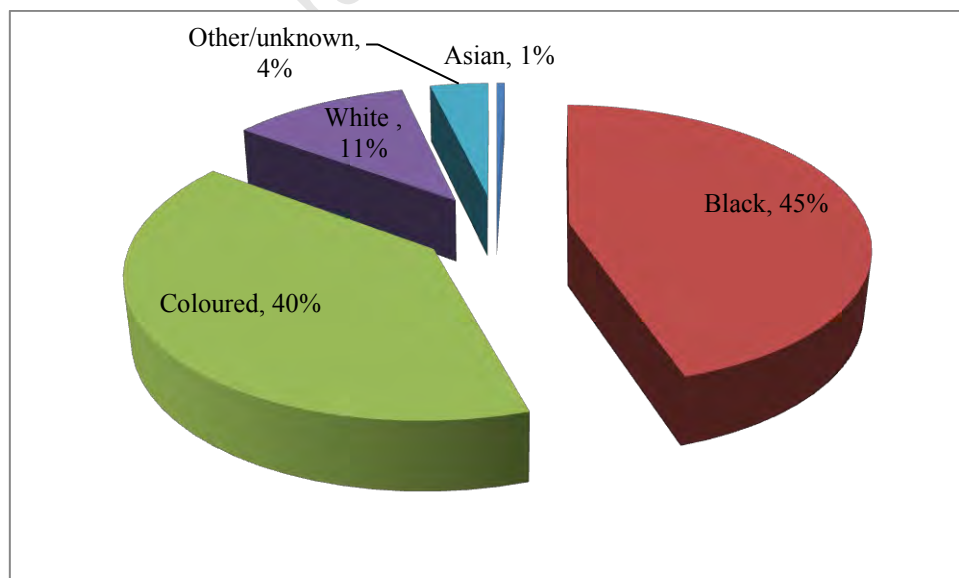


Figure 19: Categorisation of race for fatalities between 2007 and 2011

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

The gender data (Figure 20) indicates that for every female killed, there are approximately three males killed. Data on respective driving distances, vehicle ownership and walking habits are not readily available, so it is difficult to draw any firm conclusions from this result, apart from the general assertion that it is the younger, and possibly more aggressive males, who are at most risk of fatalities from road incidents.

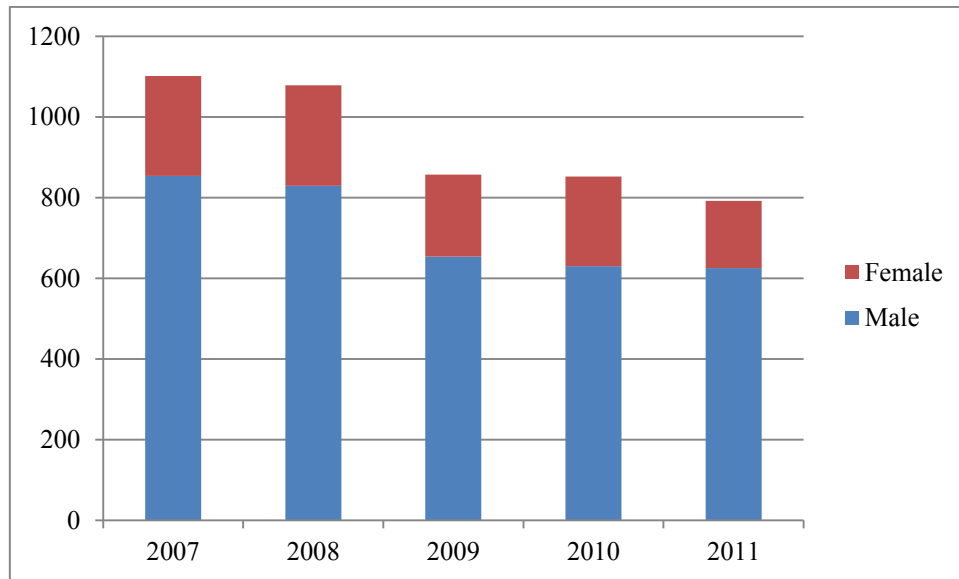


Figure 20: Categorisation of gender for fatalities between 2007 and 2011

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

Pedestrians in the 26-40 age groups (again) appear to be at most risk of fatality from road crashes - they form around 43% of the total pedestrian fatalities recorded. The age group between 41 and 74 is the next largest group. Of concern, though, is that of the total number of pedestrians killed in the data sets examined, between 14-17% were children aged 14 or less.

Details on the nature of and reasons for pedestrian fatalities are either sparse or unreliable. However, it is likely that behavioural factors that reduce the road users' ability to act safely, such as the result of alcohol and substance abuse, aggressive driving, the use of cell phones and fatigue, have a large part to play. Also, given the diversity of culture in South Africa, different driving and pedestrian behaviours and perceptions prevail within the traffic mix (Vanderschuren, 2006), which can be witnessed on a daily basis and clearly exacerbates safety issues.

3.3.3 Crash Types

Details in Figure 21 show that crashes involving pedestrians, resulting in both serious⁹ and fatal injuries, form the largest proportion of the known crash types. Figure 21 also details the significant number of 'other' and 'unknown' crash types which is symptomatic of the data capturing and recording issues discussed in Section 3.1. Apart from these two categories, the remaining crash types are quite common worldwide, the only other exception being the 'Accident with Animal' type which would be rare, if not unheard of, in developed cities and, which further underscores the duality of the city.

⁹ A serious injury is defined as one where a person has sustained injuries to such an extent that hospitalisation is required (<http://www.arrivealive.co.za>).

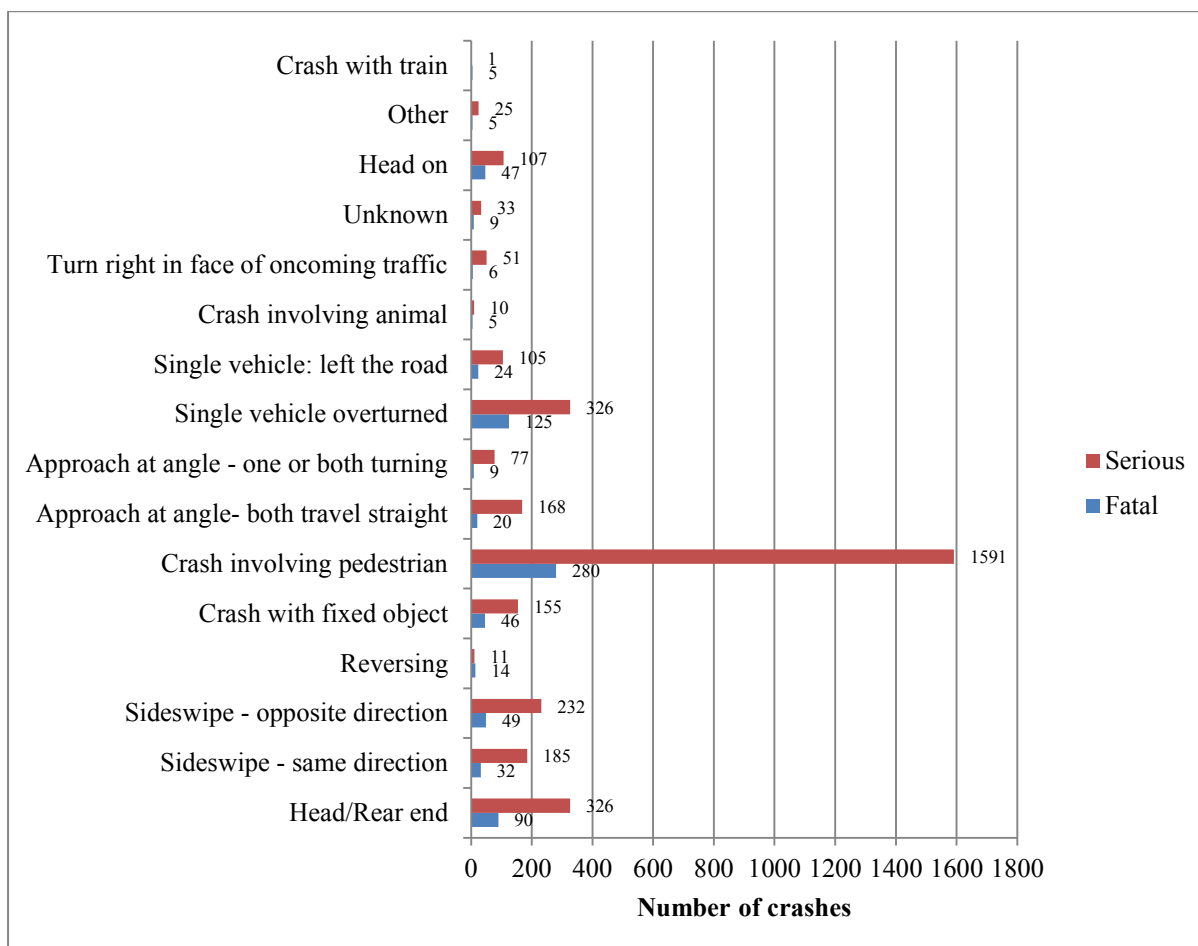


Figure 21: Serious and fatal crash types in 2010

Source: Adapted from City of Cape Town and Forensic Pathology Services (received January 2013)

3.3.4 Hazardous crash location analysis

Figure 22 provides details of the worst known locations and number of crashes involving pedestrians within the city limits for individual corridors over a period of three years. Similarly, Table 1 shows the results of an analysis carried out to compile a list of the 15 worst known road sections for pedestrian incidents by Equivalent Accident Number (EAN¹⁰), calculated using the World Bank's recommended weighting¹¹ and Severity Index¹² using 2008 data detailed in a report by the CSIR (2012).

Although these analyses and diagrams only record the worst known road sections and intersections where pedestrians were involved in crashes, the picture that emerges is quite clear – they both show that other than Vortrekker Road, all of the incidents took place on routes that are classified as arterials, expressways or freeways and that, when they occur, they will have a high degree of severity. All of these roads carry high volumes of fast moving traffic, through or beside low income neighbourhoods for substantial sections of their lengths; these are neighbourhoods where there are poor NMT facilities and where the majority of travellers are captive NMT/Public Transport users. Examples of studies that reinforce these assertions follow.

¹⁰ Equivalent Accident Number is used to compare locations in terms of the number and severity of crashes that took place there. The score is calculated by weighting fatal and injury crashes by factors of 12 and 3 respectively. Weights are calculated in relation to the generalised cost of different levels of crashes.

¹¹ http://www.worldbank.org/transport/roads/saf_docs/haz_locs.htm

¹² Severity Index = EAN divided by the total number of crashes

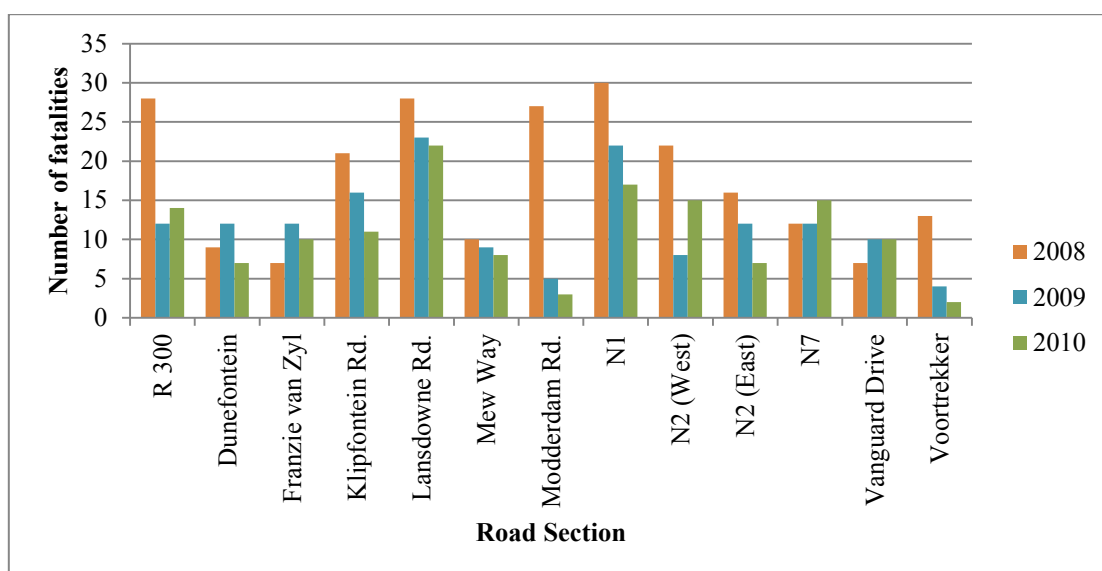


Figure 22: Worst known road sections in Cape Town for pedestrian fatalities

Source: Extracted from Forensic Pathology Reports (received January 2013)

Table 1: Top 15 worst known all-crash locations for pedestrians in 2008, Cape Town.

Road Section	Fatal	Serious	Slight	Total	EAN	SI
Lansdowne Road	28	203	325	556	945	1.70
Voortrekker Road (Maitland)	11	78	274	363	366	1.01
Kuils River Freeway (R300)	28	45	53	126	471	3.74
Mew Way	10	50	96	156	270	1.73
Klipfontein Road	22	38	84	144	378	2.63
N2-West	22	29	63	114	351	3.08
Vanguard Drive	7	21	84	112	147	1.31
N7 – North	12	26	61	99	222	2.24
Spine Road	8	30	68	106	186	1.75
Modderdam Road	27	34	67	128	426	3.33
N2 – East	17	29	37	83	291	3.51
Van Riebeeck Road	4	26	71	101	126	1.25
N1 North	30	15	36	81	405	5.00
R44	4	26	65	95	126	1.33
AZ Berman Drive	4	29	56	89	135	1.52

Source: Based on CSIR, 2012

Behrens (2005) has observed that both the mean and 95th percentile walking trips in South African cities are considerably longer than those conventionally assumed in practice (800m is assumed in traditional road hierarchy philosophies), and that a significant proportion exceed conventional parallel arterail or distributor frequencies of 1.5km. Many of these trips are undertaken on routes with, at best, poor and poorly connected footpaths to and from housing complexes (including informal settlements) and to/from informal trading places which are usually located within the road reserve (Ribbens et al., 2008). A study conducted by CSIR (2008) stated that these informal trading practices located within the road reserve ‘... are leading to cognitive overload of drivers and therefore not recognising/seeing pedestrians in time’.

Another critical issue in terms of pedestrian safety was highlighted by an international study (CSIR, 2012) which showed that when a large population group in cities is afflicted by malnutrition, impoverishment, social exclusion and discrimination, ill health and poor housing conditions, as well as restricted access to land and basic infrastructure; increasing levels of criminal violence, lack of

safety and general fear in the use of public space were often observed. This results in people socialising within the road reserve where they are within public sight, which is not necessarily conducive for road safety in general, and safety and security in particular.

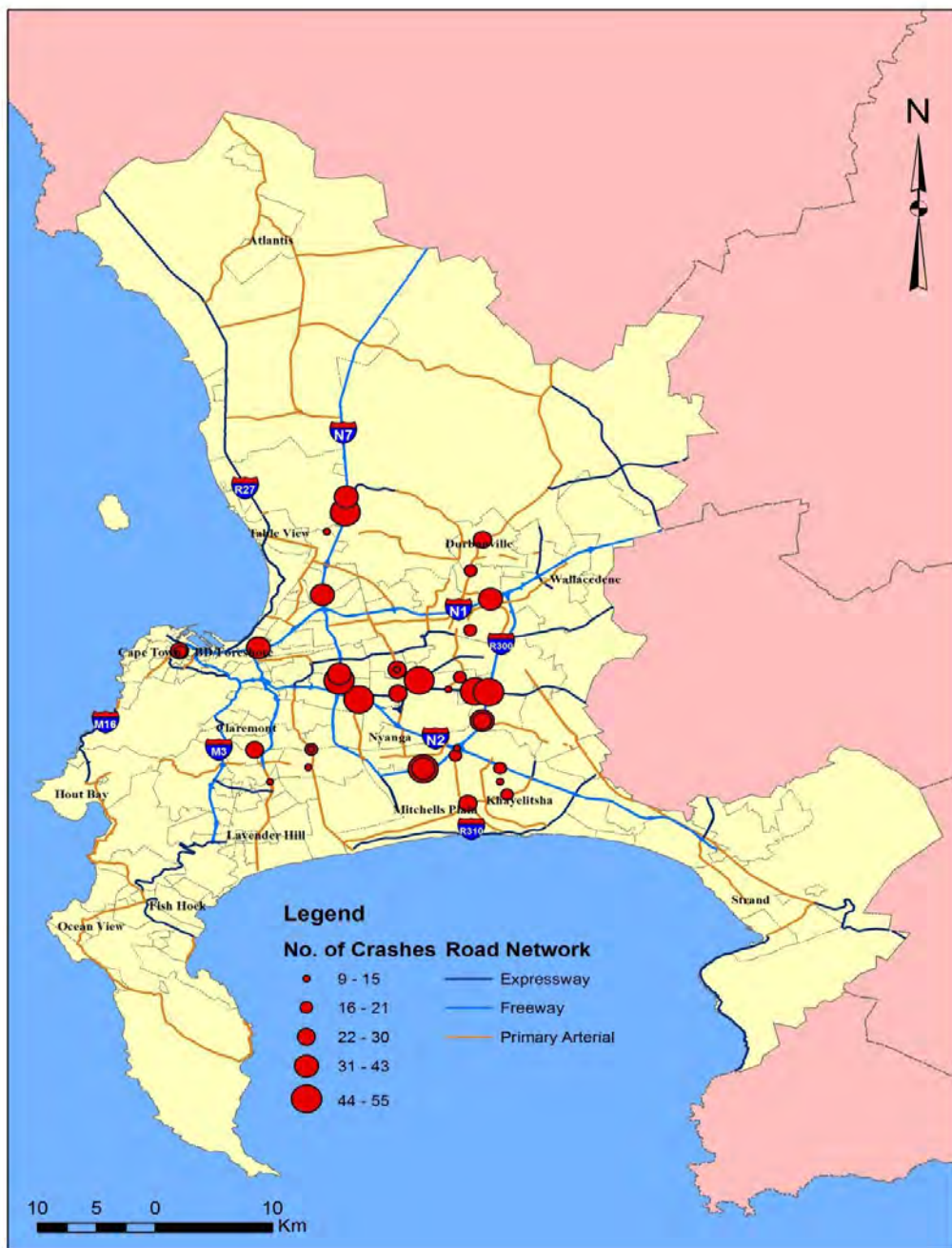


Figure 23: Fatal crashes at intersections

Source: Derived using (CoCT, 2005) and general City of Cape Town GIS mapping information



Figure 24: Fatal crashes along road corridors

Source: Derived using (CoCT, 2005) and general City of Cape Town GIS mapping information

3.3.5 Economic Cost of Crashes

The economic cost of road crashes in the City of Cape Town was estimated to be in the region of R2.7 billion for 2005 using data from a study commissioned by the National Department of Transport in 2000. With inflation alone (i.e. excluding the effect those costs outside the basket of goods and services that comprise official inflation figures), this cost could be as much as R3.5 billion, which equates to around 2% of the City's Gross Geographical Product for 2009 – i.e. a significant cost to the economy (<http://www.capetown.gov.za/>). In comparison, the WHO (2004) estimates the cost of road crash injuries to be approximately 1% of the gross national product in low-income countries, 1.5% in middle-income countries and 2% in high-income countries, whereas Connelly and Supangan, (2006) estimate the cost of crashes in Australia range from between 0.62 to 3.63 of Gross State Product.

3.4 Factors attributed to crash causation

The WHO states that road traffic crashes ‘...result from a combination of factors related to the components of the system comprising roads, the environment where the crash occurs, vehicles and road users and their respective interaction. Some factors contribute to the occurrence of a collision

and are therefore part of crash causation; some aggravate the effects of the collision and thus contribute to trauma severity and some may not appear to be directly related to road traffic injuries. Some causes are immediate, but they may be underpinned by medium-term and long-term structural reasons. Crashes are, therefore, unpredictable events, but identifying the risk factors that contribute to them is important in identifying interventions that can reduce the risks associated with these factors (Mohan et al., 2006).

3.4.1 Human Factors

According to the RTMC (2010), ‘.95% or more road traffic crashes occur as a direct result of traffic offences or non-compliance with prescribed norms and standards’. By implication, these crashes happen as a result of some measure of either driver negligence or ignorance, and it speaks to the efficacy of traffic policing in South Africa, something that is regularly highlighted as a major contributory factor to the high crash rate (see Matzopolous et al., 2008; Mohan, 2008; Mohammed and Labuschagne, 2008).

The two main causes of crashes occurring nationwide reported by the RTMC (2010) are: speeding and jay walking (40% and 32% respectively of the total attributable to this factor). In the Western Cape it can be deduced that 75% of all road crashes occur on roads with a 60km/h speed limit; but for fatal crashes, only 40% occur on roads with a 60 km/h speed limit; 30% on roads with a 120km/h speed limit; and 16% on roads with a 100km/h speed limit. In Cape Town, 20% of the fatalities occurred on roads with a 120km/h speed limit; 4% on roads with a 100km/h speed limit; 7% on roads with an 80km/h speed limit and the remaining on roads with a speed limit of 60km/h and below. It should be noted that there are very few roads with a speed limit less than 60km/h within the city and although the majority of crashes occur on roads with a speed limit of 60km/h it can be seen from Figure 24 that most of them occur on arterial roads, most of which are dual carriageways where speed limit signage is haphazard and there is usually little in the way of law enforcement .

To exacerbate matters (and to possibly complicate road safety investigations), although jaywalking is, strictly speaking, an offence in South Africa, it is rarely, if ever, punished because of the sheer numbers of pedestrians who commit the ‘offence’ (due to widespread ignorance of this law) and because of the legacy of spatial planning which created barriers between work places and workers living areas which, in some cases, involves significant detours (up to 1km) to comply with the law.

Continuing with the theme of non-compliance, post-mortem tests carried out by the Medical Research Council showed that 61% of pedestrians and 55% of drivers killed in road crashes had a blood alcohol content greater than the legal limit (Matzopolous, 2005).

3.4.2 Vehicle Factors

National information provided by RTMC (2010) on vehicles, shows that tyre bursts due to smooth or worn/damaged tyres (36%), faulty brakes (25%) and faulty steering (24%) were the main contributory vehicular factors to road fatalities in this category

In the Western Cape Province, records show that approximately 25% of all minibus-taxis and 12% of all buses have at least one smooth or damaged tyre (RTMC, 2010). Over 3,800 tyre bursts were recorded as contributory factors to crashes between 1999 and 2012. Of note is that in 4% of these cases, they occurred in mini/midi-buses (which usually carry more than their allotted number of passengers (i.e.12)), and in 1% of the scheduled bus fleet (which carries in excess of 50 passengers in the peak periods). The consequences of either of these modes being involved in crashes would, clearly, be far more severe than tyre bursts on motor cars.

In addition, according to the RTMC (2010) around 3% of the Province’s vehicles are not roadworthy (this does not necessarily imply that the vehicles are unsafe – a ‘roadworthy’ vehicle requires registration and a test certificate when they are sold second-hand. In many instances this does not happen; however, it remains possible that many of these vehicles were not properly maintained and could have contributed negatively to the crash data). Partly because of the number of un-roadworthy vehicles and the lack of requirement of an annual vehicle check, the RTMC (2010) estimate that vehicular defects contribute to 9% of the annual national road fatalities.

3.4.3 Road environment factors

Traditionally reporting of the contribution of the road environment on crashes usually indicates that it is fairly insignificant. However, in general, most South African cities have road environments that allow high speed on their road networks, which, given the low levels of adherence to regulations described previously, are used to speed excessively. In addition, most cities are characterised by (many) informal settlements located close to, or next to arterials or major highways, in order to gain easy access to transport and thus, employment nodes. Despite some recent upgrades, many of these settlements/townships still lack proper road and pedestrian infrastructure; street lighting is poor and there is a lack of paved footways (Ribbens, et al., 2008). Furthermore, the infrastructure that is provided for the more vulnerable road users does not provide safe and integrated routes; and, where it is most needed – at transport nodes where there is a high concentration of pedestrians crossings to catch buses or trains usually in the early morning and at night – the problem of inadequate provision, safe provision and lighting issues are prevalent.

At the national level, the RTMC (2010) indicates that sharp bends (27%), poor road surface conditions (20%) and poor visibility (15%) were the main reasons for crashes attributed to the road environment and that its total contribution to road fatalities was 8%. Clearly these attributes have a role to play in what may be termed human errors that have led to crashes. The analysis of all crashes per road types in Cape Town (Figure 25) confirms the RTMC’s findings in that sharp bends and poor visibility are more likely to be found on single and dual carriageway roads.

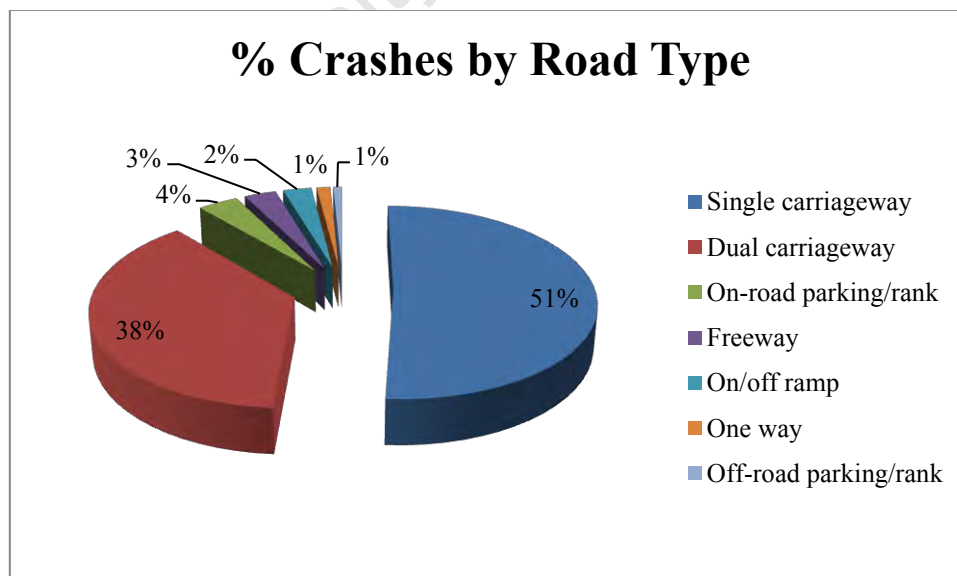


Figure 25: Crashes per road type in 2010

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

Although it could be argued that these fatalities are mainly as a result of road-user error, the concept of integrating non-motorised and motorised traffic was initially developed in the Netherlands through the ‘woonerf’ concept and later ‘Verkehrsberühigen’ in Germany and subsequently adapted in many

European cities (Ribbens, 2008) to create safer residential precincts that allowed shared road use by initially adopting a ‘walking speed’ limit and subsequently a speed limit of between 20 and 30km/h, as ‘walking speeds were rarely attained, and by the use of measures generally referred to as traffic calming measures. Through these, it has been shown that infrastructure provision does, indeed, have a role to play in contributing to road safety through its interaction with human and vehicular behavioural factors as a result of its ‘readability’.

Despite the successes of these concepts and the reasonably obvious infrastructural measures that need to be implemented to create similar zones as well as roads without sharp bends or visibility issues, road environmental factors still continue to pose safety risks in South Africa, possibly because of the legacy of a huge backlog of infrastructural deficiencies.

3.4.4 Other factors

The crash records broken down to provide a day-to-day frequency indicate that the numbers of crashes per day are reasonably consistent but that the weekend period seems to be a problem (see Figure 26).

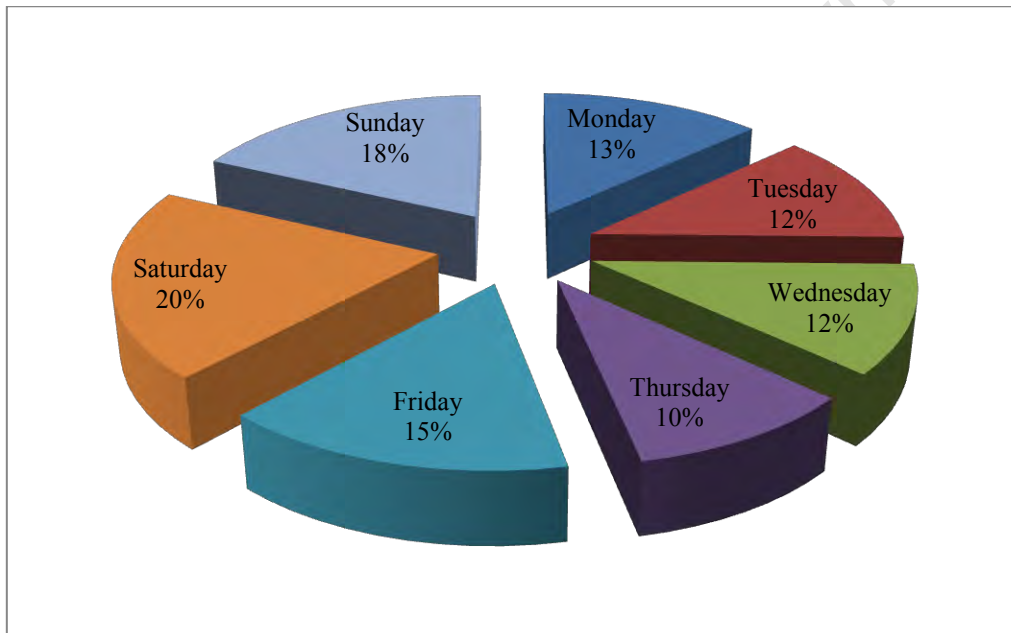


Figure 26: Crashes by day of week (2008-2011)

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

The temporal profile of crashes (see Figure 27 and 28) indicates that the dusk to evening period, usually associated with work to home trips and the period thereafter (probably at weekends given the indications in Figure 26), is clearly a problem time period, either because of light conditions or because of behavioural issues. Seasonal variations in crash rates are limited with the exceptions being during the months of December, the start of the Cape’s winter (June/July, because of the onset of heavy rains) and the Easter period (usually end March/early April).

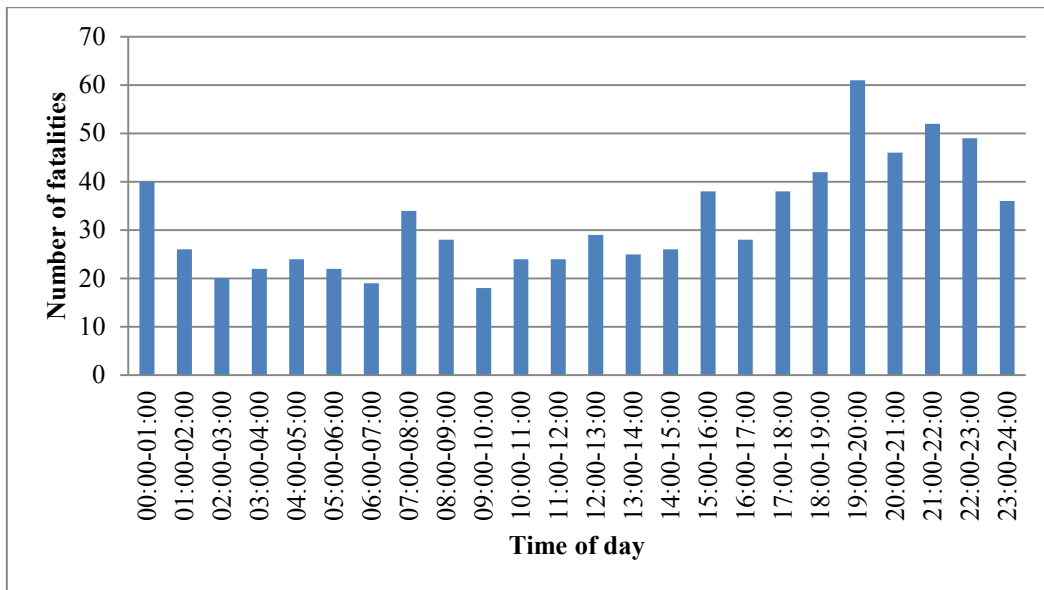


Figure 27: Crashes by time of day (based on weekly total)

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

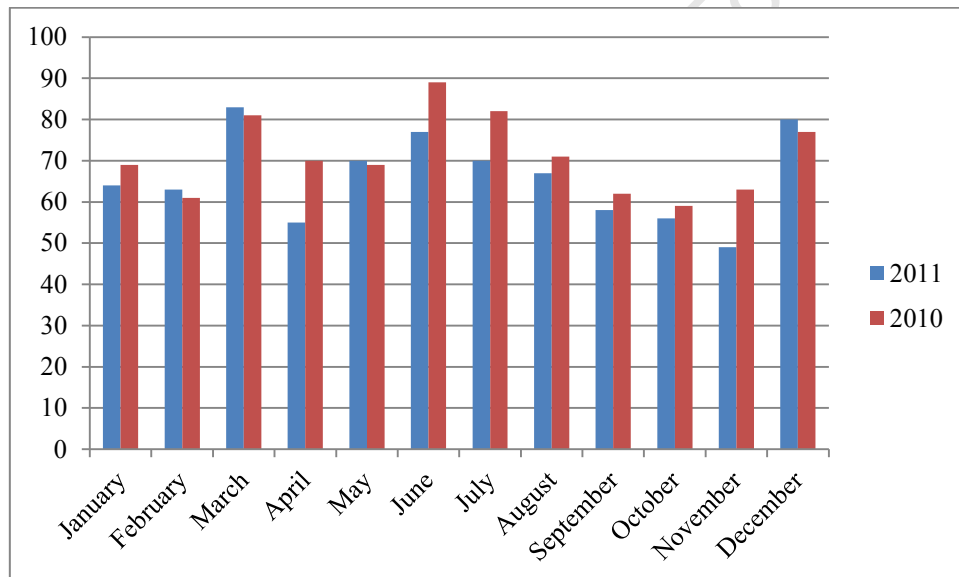


Figure 28: Crashes by month of the year

Source: City of Cape Town and Forensic Pathology Services (received January 2013)

A similar temporal profile can be observed from the data for pedestrian fatalities, with the addition of a significant peak between midnight and 1a.m. on Saturday and Sunday, strongly indicating the possibility of alcohol or substance abuse.

In comparison and by way of enriching the data presented, research carried out using national forensic data from 2001-2005 by Mabunda et al. (2008) distinguished the following three categories of pedestrian fatalities using a multiple correspondence analysis (see Figure 29): (1) *night-time male pedestrian fatalities characterised by excessive BACs*; (2) *daytime female and elderly pedestrian fatalities that occurred in the morning hours between 6 AM and midday and wherein a minority tested positive for alcohol concentration*; and (3) *weekday children, adolescents, and young adult-related pedestrian fatalities that occurred between 18:00 and 23:00 h (40%) and 12:00–17:00 h (28.7%)*.

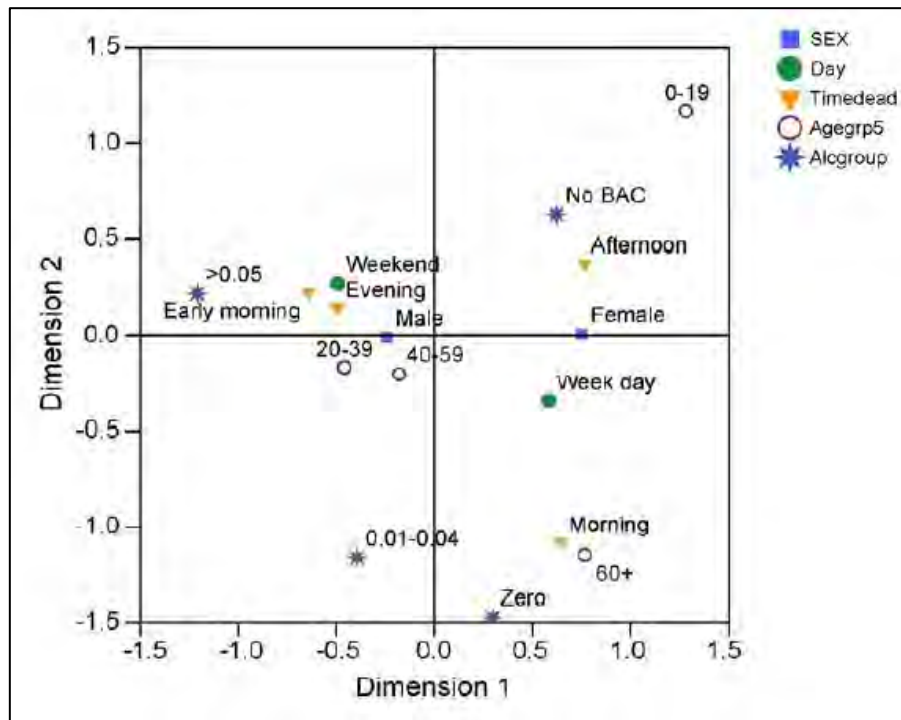


Figure 29: Multiple Correspondence Analysis of pedestrian fatalities in South African cities

Source: Mabunda, et al., 2008

The conclusion of this study and other literature (see for example: Sukhai et al., 2004 and Ribbens et al., 2008) is that rapid urbanisation in South Africa, particularly in cities like Cape Town, has resulted in environments with high population densities and inadequate separation of people and vehicles. These studies have also emphasised the need for road safety planning to be integrated into the initial stages of all town planning and civil engineering projects; and that pedestrians and cyclists are a particularly vulnerable group of road users whose safety requires specificity.

4 The national responses to the road safety issue

The previous chapters have identified transport and land-use planning policies that have contributed to (and continue to contribute to) the significant road safety challenge - particularly the disproportionate level of pedestrian fatalities. This challenge exists not only in Cape Town, but throughout South Africa. All tiers of government have recognised road safety as a societal responsibility and have agreed on plans, with targets, to reduce the level of fatalities (halving road fatalities by 2014) in accordance with the Millennium Development Goals (MDG) goals initially and subsequently through the 'Moscow Declaration'. This chapter presents a review of government's action to these challenges, and a critique of the responses in order to establish whether government's actions are likely to result in changes that will alleviate the road safety problem in any way.

4.1 Policies and Strategies

Legislation and regulation (see chapter 2) regarding South Africa's roads is comprehensive and compares favourably with other countries (see for example Watson, 2007). National government also regularly publishes road safety strategies, which include recommendations from the World Health Organisation and best practice drawn from around the world. A more detailed review of policies and strategies with an emphasis on road safety follows.

4.1.1 National Road Safety Strategy 2006 Onwards

The National Department of Transport has initiated a programme for improving road user safety through a National Road Safety Strategy (NRSS), which cites '*...the need for a reduction in the unnatural causes of death*' with MDG targets agreed for the transport sector as its aims (NDoT, 2006a).

The focus of the NRSS is on service delivery through the principles of '*Batho Pele*' (people first) across all spheres of transport. It suggests that several factors cause of the high rates of traffic fatalities in the country, among these are: poor driver behaviour and attitude; the existence of a "culture of impunity" in respect to payment of traffic fines; the average age of most vehicles being over 10 years (and poorly maintained), the minibus taxi fleet being over 13 years old; widespread fraud and corruption in all sectors of the industry; first class, high-speed roads, travelling through informal settlements and rural areas where pedestrian activities are high but pedestrian facilities inadequate.

A number of strategies are put forward to address safety problems:

1. A general improvement of road traffic law enforcement measures and visibility.
2. An improvement in gathering and maintenance of data for research and development of road safety programmes.
3. Capacity development at various levels of oversight over road traffic matters.
4. Proper coordination of road traffic matters across all spheres of government.

A lead government agency, the Road Traffic Management Cooperation (RTMC) was established in 1999¹³, for the co-operative and coordinated strategic planning, regulation, facilitation and law enforcement in respect of road traffic matters instigated by the national, provincial and local spheres of government. Unfortunately, there have been many issues with this organisation since its inception (see section 4.4).

¹³ The Road Traffic Management Corporation (RTMC) was established in terms of Section 3 of the Road Traffic Management Corporation (RTMC) Act, No. 20 of 1999, and commenced with the preparation of a Business Plan and Strategy for its operationalisation in April 2005 (see: <http://www.arrivealive.co.za>).

An internationally recognised road safety strategy based on the 4E's of road safety (enforcement, education, evaluation and engineering measures), as well as co-operation and coordination between role-players, is stated in the NRSS as being required to improve the situation. Presumably, based on this, 15 priorities for implementation are recommended:

1. To **transfer further functions to the RTMC** - the lead agency created to coordinate road traffic activities nationally.
2. Possible changes to law enforcement functions in all provinces from Transport Departments to dedicated Community Safety Departments.
3. *'Development of a **calendar of strategic activities** for enforcement and communication, concentrating on a single behaviour at any one time with priorities of speed reduction, reduction in drink-driving rates, seat-belt wearing, moving offences and vehicle road worthiness and legality'*.
4. *'Implementation of high-tech solutions to prevent speeding, particularly at hazardous locations. This includes development of the national fleet as well as **installation of static speed calming** devices such as cameras on main roads, and the eventual development of Electronic Vehicle Identification with "readers" to measure speed over long distances, e.g. between toll plazas'*.
5. *'Use of video and other equipment to ensure that overtaking and other moving violations are dealt with. 17% of deaths result from unsafe overtaking'*.
6. *'The implementation of a year-round "traffic checking" or "**mini-road block**" activity (with a target of 1000 activities daily, nationally) to deal with legality of drivers and vehicles, vehicle condition, safety and security, seat belt infringements, and drinking and driving offences.'*
7. *'**Comprehensive emotive advertising** and public relations campaigns to support enforcement and to gain public support for projects'*.
8. *'Improvement of fine collection and penalties through the implementation of the **Road Traffic Infringement Agency** and implementation of the Administrative Adjudication of Road Traffic Offences Act 1998. This will include development of a national contravention register, and easier fine payment through banks and post-offices as well as a points demerit system'*.
9. *'Discussions with the **Department of Justice** on stronger and more effective sentencing, and an assurance of the availability of courts and sufficient personnel to deal with traffic crime'*.
10. *'**Reduction of speed limits in areas of high pedestrian activity** to the internationally accepted 30-40km/h, and stricter enforcement of red traffic lights to save lives of both pedestrians and motorists. Education activities to support these initiatives'*.
11. Develop **training courses and practical tests for Professional Driving Permit drivers**, 'to ensure improved skills in defensive driving, and continue negotiations with Department of Labour in respect to driving hours.
12. *'Introduce a **probationary period** for all drivers, during which time there is a zero-tolerance attitude to speeding, alcohol use and other serious violations of the law'*.
13. *'Further investigation into the declaration of Traffic Enforcement as an essential service to enable officers to work during evenings and weekends, when most crashes occur'*.
14. *'Introduce system of driver re-training and testing after serious crashes or repeat violations.'*
15. *'Regular measurement and review of the strategy in terms of both outputs and outcomes to refine projects and define successes. Cost benefit studies where appropriate'*.

The NRSS concludes: *'..to be successful, Road Safety strategies need to be comprehensive and holistic, to address the challenges on several levels'*.

Using these priorities to inform action plans, national government has recently undertaken several campaigns to reduce the burden of road crashes. Notable amongst these have been the *'National*

Rolling Enforcement Plan, which involved the stopping and checking of more than 1.5million vehicles in 2011; and the *'Think Pedestrian'* campaign, which was aimed at stabilising, then reducing pedestrian fatalities through intensive awareness and education programmes for drivers and pedestrians. Campaigns along similar lines were also undertaken by Provincial Governments. Details of some achievements by the Western Cape Provincial Government are outlined in section 4.5.

4.1.2 National Land Transport Strategic Framework

The National Land Transport Strategic Framework (NDoT, 2006b) for the period 2006 to 2011 gives guidance on transport planning and land transport delivery by national government, provinces and municipalities.

Key Performance Indicators (KPIs) are identified for policy areas (among others, traffic safety and enforcement) and defined for customer based KPI's relating to each policy area. For traffic safety, customer based KPIs are defined as numbers of road fatalities for vehicles and pedestrians and the number of road traffic fatalities per 100 million vehicle kilometre per vehicle type.

Annual reports for road fatalities are produced by the RTMC which provide measurable performance indicators.

4.1.3 Global Plan for the Decade of Action for Road Safety 2011-2022

The 'Moscow Declaration' issued by ministers and senior officials from 150 countries, including South Africa, underlines the importance of protecting all road users, in particular those who are most vulnerable such as pedestrians, cyclists and motorcyclists (www.who.int/roadsafety).

The Global Plan provides an overall framework for activities that may take place in the context of the Decade of Action. The categories or 'pillars' of activities are: building road safety management capacity; improving the safety of road infrastructure and broader transport networks; further developing the safety of vehicles; enhancing the behaviour of road users; and improving post-crash care. Indicators have been developed to measure progress in each of these areas. Governments, international agencies, civil society organisations, the private sector and other stakeholders were invited to make use of the Global Plan as a guiding document for the events and activities they will support as part of the Decade of Action (www.who.int/roadsafety/decade_of_action).

Many activities that would fall within the 'pillars' of capacity building and road infrastructure improvement are common to those outlined in the NRSS and are therefore being addressed. Behavioural changes are difficult to measure accurately; and post-crash care levels in terms of their comparative before and after benefits are also problematic. In the case of vehicle safety, apart from changing testing regimes, there is little the South African Government can do, and apart from some tightening up on offenders, little done has been in this arena.

4.1.4 Draft National NMT policy, 2008

To start to address the NMT issues of accessibility and safety, the National Department of Transport produced a Draft National NMT Policy document in 2008 (NDoT, 2008a). The policy document is intended to provide a single framework and enabling environment for all government transport departments and stakeholders to address the challenges inherent in NMT. Its primary objectives are: *to increase the role of NMT as one of the key transport modes, integrate NMT as an essential element of public transport, and provide a safe NMT infrastructure and allocate adequate and sustainable funding for the development and promotion of NMT.*

The document is still in draft form but it has possibly helped local authorities in that it provided an enabling environment for their current policies and strategies. In the Western Cape, Provincial

guidelines have been produced, also in draft; the documents produced by the City of Cape Town are detailed in Section 4.1.5.

4.1.5 City of Cape Town NMT Policy and Strategy

The City of Cape Town's 'NMT Strategy Document' (City of Cape Town, 2005), recognising the inequities of past planning policies, states that: until now, the City has not had 'a comprehensive plan guiding the planning and implementation of programmes and facilities to respond to the multiple needs of NMT users'. It has planned to address this shortcoming through policy accompanied by a set of objectives and strategies for an improved NMT environment. Its vision statement for NMT is:

'Cape Town will be a city where all people feel safe and secure to walk and cycle, NMT is part of the transport system, public space is shared between all users (NMT, special needs people and motorised users) and everyone has access to urban opportunities and mobility.'

An important goal in realising this vision is to: *'Increase cycling and encourage walking by creating a safe and pleasant bicycle and pedestrian network of paths to serve all the citizens in the Cape Town Area'*.

To achieve this vision, the City undertook a process of identifying existing NMT routes and strategic gaps in 2010. Key areas for implementation of recommended improvements ranked by technical, operational, environmental, socio-economic and financial criteria have been derived from this process. The municipal area was split into four areas to simplify the process. An example of the analysis for the southern area of the City is illustrated in Figure 30; however, the basis of assigning priorities is unclear from supporting documents. In addition, the City has produced a citywide Bicycle Masterplan (Figure 31). To date there has been little in the way of improvements on the ground.

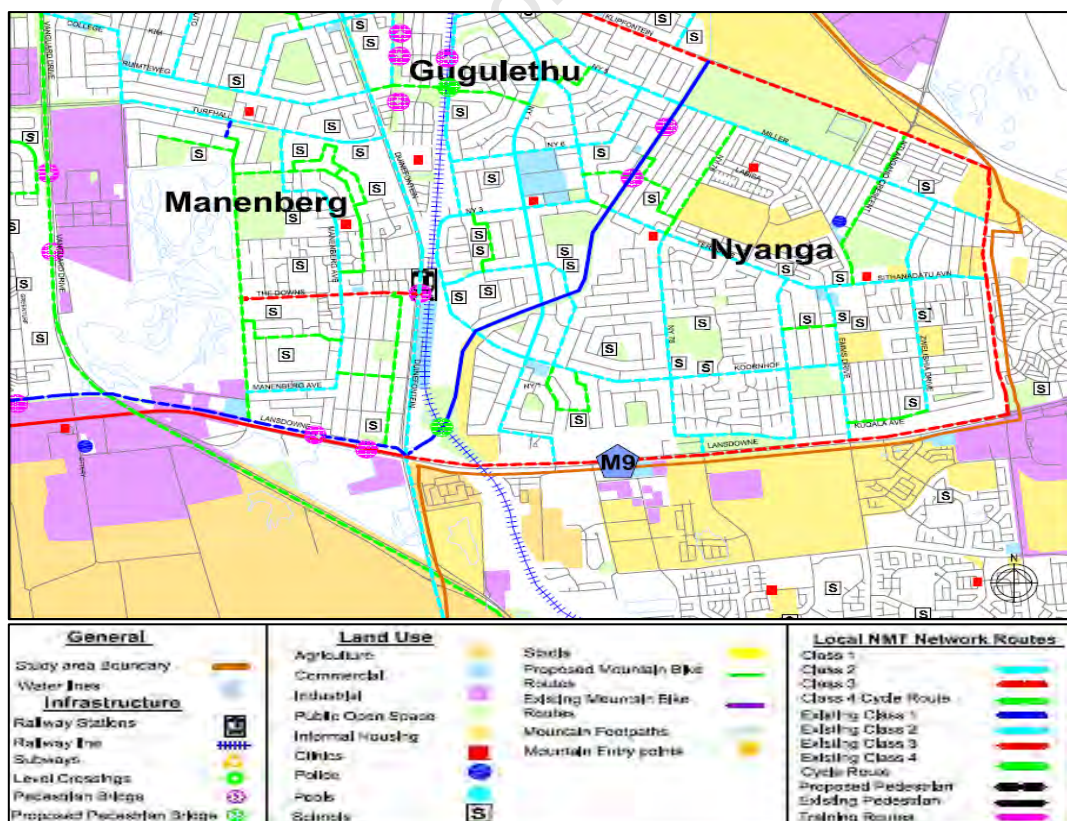


Figure 30: Extract from the City of Cape Town's NMT Strategy Plans (Southern Region)

Source: Adapted from City of Cape Town, 2010 (received, December 2012)

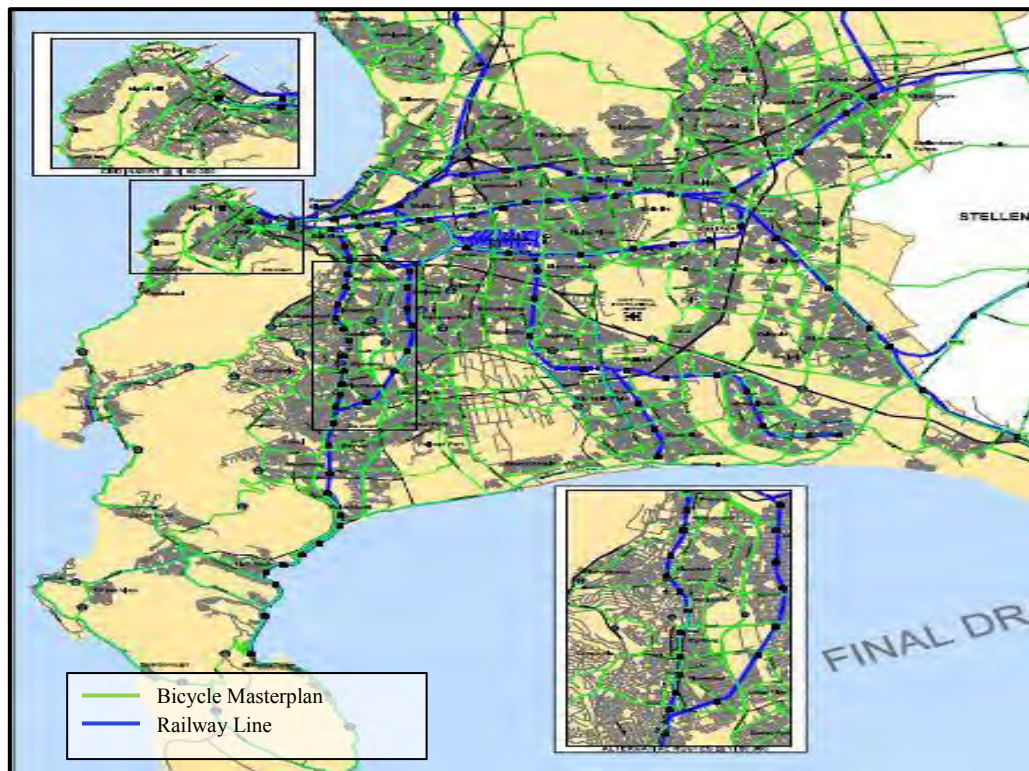


Figure 31: City of Cape Town - Bicycle Masterplan

Source: City of Cape Town (received January 2013)

4.1.6 Local strategies

The Western Cape Government's Safely Home initiative, led by the Minister for Transport and Public Works, is aimed at reducing the number of people killed on the province's roads by 50% by the end of 2014. Safely Home is based on the 4E's of road safety which are as described above. The programme recognises that the Western Cape has among the most dangerous roads in the world and strives to fulfil the UN Decade of Action's goals to reduce road carnage.

The campaign reports that since 2008 there has been a reduction of 28%, (regularly updated on <http://www.safelyhome.westerncape.gov.za>) in lives lost from official statistics recorded in 2008. This figure includes fatalities in Cape Town and shows that a coordinated and active response to the issue with a champion at governmental level can achieve better road safety.

4.2 Engineering responses

Apart from the functional classification of roads in the UTG's and the Red Book (and therefore speeds and widths), there is little more in any guidelines in relation to road safety, nor is there a requirement to carry out audits of existing or proposed designs. In fact, although road safety audits are unequivocally considered to be an important aspect of road safety management internationally and they have been shown to be a contributor to the reduction of incidents, they are not mandatory in South Africa (Grosskoff, et al., 2010). There is some level of safety audit carried out institutionally during the draft design stages, but formal audits seem to be left up to the practitioners and very little pro-active auditing of existing roads is carried out. All of this is despite the fact that a draft road safety guideline was drawn up in 1999 by the Committee of Land Transport Officials (called the South African Road Safety Manual).

Practitioners and the industry do recognise the need for formal road safety audits of not only all new proposals, but also of some existing facilities, to help drive down the appalling crash rate in South Africa. Resistance to the adoption of an accepted guideline comes from the perception of a lack of

sufficient resources, capacity, funding and time constraints (Grosskoff, et al., 2010), but given the government's longstanding desire to reduce the crash rate, and the payback of such an initiative, it must surely warrant more serious consideration.

In terms of the engineering counter-measures and road design opportunities for improving road safety, the National Road Safety Strategy (NRSS) document has the following to say (see NDoT, 2006b):

'There is not a single site in South Africa where more than 1% of crashes occur. Therefore, even if that site is remediated by engineering methods, only a maximum of 1% of crash reduction will occur. Putting effort into behaviour and attitude change is, therefore, more beneficial.

Identification of hazardous locations (stretches of road) are, however, still a priority, so that enforcement activities can be concentrated on those areas, during the most dangerous times of the day, and engineering solutions can be explored'.

It is clear from this statement that road safety investigations – the causes of crashes which are traditionally aggregated under human, vehicular and environmental factors - will continue to be carried out retrospectively based on historic crash data with a focus on identifying so called 'black-spots' or hazardous locations. Appropriate engineering responses are developed as a result of these investigations.

Each document mentioned in this chapter cites traffic calming as one of the most effective ways of addressing the safety issue. However, local municipal policies preclude the use of traffic calming on any road other than lower order roads (City of Cape Town, 2011). The method recommended for speed control of primary and secondary arterials is via traffic law enforcement. Therefore, barring any major road engineering changes, enforcement is the only remedial method that can be considered in the City to reduce crash numbers on arterials.

A number of traffic calming schemes have been implemented on the minor roads in the City in the recent past but details of their impact on road safety are not available. Despite this, the degree of their success should be reflected in the crash statistics which, as shown, are minimal.

4.3 Law enforcement

Traffic law enforcement can be defined as the area of activity aimed at controlling road user behaviour by preventative, persuasive and punitive measures in order to effect the safe and efficient movement of traffic.

In general, the preventive effects of police enforcement depend on the subjective chance of being caught, the certainty of punishment, the punishment rapidly following the offence, and the social acceptance of the usefulness and necessity of the traffic law involved (in other words, public support). Each of these elements is a link in the chain of traffic surveillance. For example, if the subjective chance of being caught is small, the penalty, certainty of being punished, and speed of punishment will not make much difference in preventing offences. To increase the subjective chances of being caught, it is important that controls are accompanied by the necessary publicity, and regular surveillance takes place; in addition, the chances of being caught must be unpredictable, clearly visible and difficult to avoid (SWOV, 2008). The actual policing activities of traffic law are therefore of pivotal importance.

Even though the relationship between policing and traffic law compliance has an impact on road safety, the actual relationship between levels of policing and crash rates is neither straightforward nor is easy to establish. Elliot and Broughton (2005) hypothesise this relationship as being non-linear,

with the highest levels of crashes expected at zero-enforcement and drivers gradually modifying their behaviour (i.e. reducing violations) at a certain point of enforcement (see Figure 32). They further posit that although violation rates could, arguably, fall to almost zero, crash rates would not fall to that extent as they are influenced by a multitude of other factors.

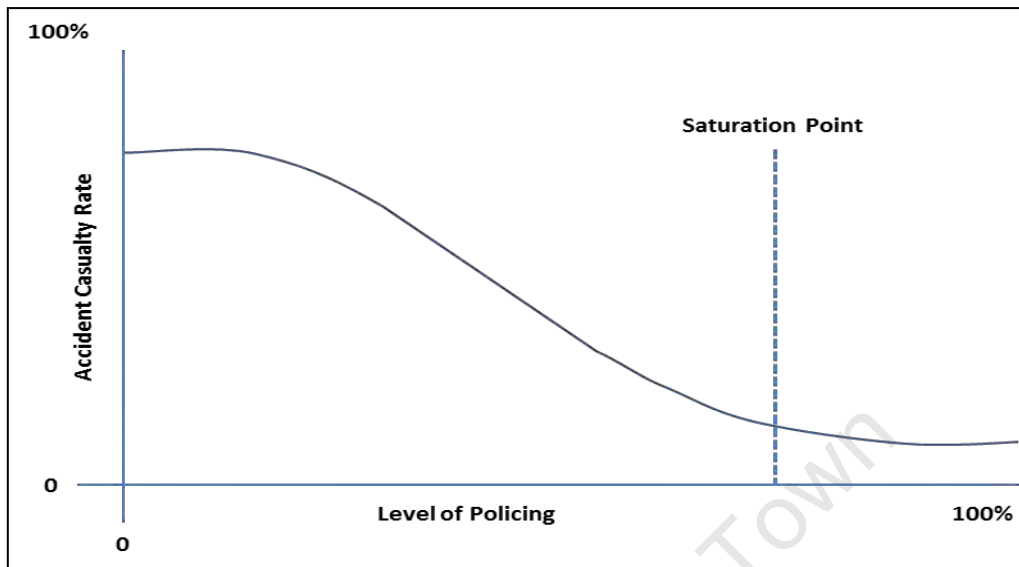


Figure 32: Theoretical relationship between level of policing and accident/casualty rates

Source: Elliot and Broughton, 2004

The point at which levels of policing and enforcement bring about meaningful changes in the road safety situation is also difficult to establish as it may vary from region to region and, for example, with levels of road usage. Little research has been carried out on this particular aspect in South Africa (Mohammed and Labuschagne, 2008). However, the literature and other publications have many examples of the levels of the non-compliance of road users, most of which clearly influence the road safety situation in urban areas. For example:

- The NRSS reports that around 17% of drivers exceed speed limits, 4.3% of drivers exceed the legal alcohol limits, 28% of drivers commit red-light violations, 15% of professional drivers (i.e. those allowed to drive a public service vehicle) do not hold a valid permit and 21% of vehicles have defective tyres. (These data, especially speeding, are probably under-estimated. For example, live data from Western Cape Government (http://mis.pgwc.gov.za/mis/mis_web_reports.main) show that between 25 and 55% of the traffic on Western Cape's provincial roads exceed the speed limits and that the 85th percentile speed is normally considerably in excess of the speed limit).
- Currently, only about 20% of South African traffic fines are paid annually, according to the Road Traffic Infringement Agency, indicating a general lack of punishment (www.lexisnexis.co.za/media/).
- *'Cape Town taxi bosses have started paying their outstanding traffic fines with some association revealing that they owe the city close to R1million'. The sudden change of heart of the defiant taxi bosses could be due to the newly introduced "100 Worst Taxi Drivers programme", - an initiative launched jointly by the City of Cape Town and the Provincial Department of Transport and Public Works (<http://westcapenews.com/>)¹⁴.*

¹⁴ The 100 Worst Taxi Drivers programme was primarily an education programme and involved a series of meetings with the South Africa National Taxi Council (Santaco) and taxi associations informing them about the consequences of not paying traffic fines (warrants of arrest and possible cancellation of operating licenses (<http://westcapenews.com/>))

- Being asked to pay a bribe to a traffic official is the most common form of corruption in South Africa, according to a Statistics South Africa crime survey. More than half (52.8%) of those who were victims of corruption were asked to pay a bribe to a traffic official to avoid traffic fines (www.iol.co.za/news/crime-courts/).
- Results of surveys undertaken by the Medical Research Council showed that an overwhelming majority of adolescents are not complying with the legal requirements of always using seat belts. More than one in three learners (37.6%) rode with a driver who had been drinking alcohol; 25.9% drove after drinking alcohol themselves; 18.1% had walked alongside a road after drinking alcohol; 7.5% had walked alongside a road after taking dagga; 7.6% had walked alongside a road after taking other drugs and one in two learners (52.8%) had been driven by someone who was smoking cigarettes in the car. The fact that learners under the legal driving age of 18 years responded to questions regarding their driving behaviour, implies that there are learners driving illegally (MRC, 2010).

The study by Mohammed and Labuschagne (2008) does not conclude on actual levels of law enforcement required, but it does conclude, *inter alia*, that improved systems of police enforcement, monitoring and evaluation will help to develop solutions to the current road safety problem.

4.4 A critique of the effectiveness of the responses to the road safety issue

The crash records in Chapter 3 indicate that although the road safety record in Cape Town is improving, it remains at unacceptably high levels in comparison with most other cities; the situation in the remainder of the country is reported to be even worse (see for example: RTMC, 2009). It is therefore possible to surmise that the problem is either systemic, there is a lack of funding to institute appropriate changes, or that the problem is simply not being adequately dealt with.

The review of Government policies and strategies shows that, in general, Government is aware that road safety is a concern and that something needs to be done about it. Legislation and regulation covering South Africa's roads is comprehensive and compares favourably with other countries and road safety strategies are published regularly mostly in-line with recommendations from international best practice.

The RTMC (which was essentially run as a business with yearly funding from the National Department of Transport), has been under investigation for maladministration of its funds and its performance; the government appointed task team '*unearthed problems including mismanagement, a lack of skilled personnel, inadequate or absent controls, and the abuse of supply chain procedures*' (<http://www.fin24.com>). Clearly, if the corporation formed to deal with strategic planning of road safety and law enforcement requires investigation by its own creators for maladministration, then it cannot be expected that issues on the ground are being properly dealt with.

With reference to the quote from the NRSS (Section 4.2), considering that more than 14,000 people are killed on South African roads each year, if there was a single location that accounted for 1% of these fatalities, or even 1% of fatal and non-fatal crashes, it would surely be a cause of major concern, and possibly legal inquiry leading to some kind of recrimination. Surely the benchmark for considering the possibility of a design flaw cannot be that a location must account for more than 1% of all crashes, or even 0.1% of all crashes. Possibly, the document is referring to the local context where single locations can, and do, account for more than 1% of all crashes (see Table 1, fatal). Notwithstanding this, the NRSS also seems to dismiss the potential of road design to effect a change in road user behaviour and to pro-actively limit the number of fatalities that occur. The implication is that there is very little wrong with the way roads are planned or designed, instead, the problem lies with the way roads are used (or misused). In contrast, international evidence of the beneficial effects

of traffic calming and the notable successes of strategies such as Sweden's 'Vision Zero' indicate that the opposite is in fact the case (see section 7.4 and 5.4.1 respectively)

Legislation that introduces a probationary period for all newly qualified drivers for a period of one year has recently (2012) been included in proposed amendments to the National Road Traffic Act. The amendments also propose a roadworthy test every two years for vehicles over 10 years old. Both of these, if approved, will have an impact on the road safety situation over time.

The UN's 'Decade of Action for Road Safety', to which South Africa is a signatory, clearly implies that developing and enforcing legislation regarding limiting speed, reducing drink-driving and use of seatbelts are key risk areas where actions are needed (see: WHO, 2011). The review in Section 4.3 suggests that the authorities charged with dealing with traffic law enforcement are failing to provide sufficient and effective enforcement which has a direct and negative implication on road safety levels. The fact that statistics of law breaking are included in the NRSS seems to indicate a general acceptance that it will occur and it is part of South African culture.

The Western Cape Province has had a Community Safety Department for over 10 years now. It functions in line with good practices as advocated by the WHO for example. It is responsible for civilian oversight over the police, traffic management and crime prevention and community police relations in the Western Cape and is seen as a successful example to be followed by other provinces in the country. Furthermore, it has oversight over speed-over-distance cameras on routes with particularly poor safety records as well as year-round mini-road blocks (www.safelyhome.westerncape.gov.za) on, what seems to the public, to be a random selection of roads and random in nature, but is more likely to be a coordinated calendar based strategy given their commitment to the reduction of road fatalities. Table 2 provides a summary of the Provincial enforcement statistics, for the period from the start of January to the end of June 2012.

Table 2: Western Cape Province enforcement statistics 1 January to 30 June 2012.

Total Number of Vehicle Checks for the above Period	880,992
Number of Drivers Under the Influence of Alcohol (DWI) for the Period	620
Number of Speed Offences and Highest Speed Arrests	147,835
Number of Un-Roadworthy Vehicles	812
Number of Vehicles Screened for Overloading (March 2011 to April 2012)	631,000

Source: Department of Community Safety and Provincial Traffic Management (<http://www.safelyhome.westerncape.gov.za>)

The problems identified in section 4.3 occur even despite the levels of enforcement shown in Table 2. This indicates that more law enforcement is needed and that the lack of culpability also needs to be addressed from a systemic perspective and also a behavioural one. It is interesting that in countries in the EU - where road fatality rates are at their lowest worldwide - the ETSC (2011) reports that where data is available, up to 30% of drivers exceed speed limits on motorways and up to 80% in urban areas. The ETSC (2011) also reports that less than 2% of journeys were made under the influence of alcohol but that the EC estimates that at least 25% of all road deaths are alcohol related. Figures of the number of drivers found to be above the limit at roadside alcohol breath tests in this report vary considerably from 0.9 to 17.4%. It is also notable that the number of respondents who view speeding as a serious safety risk is over 75%, and worryingly in some member states, only 5% of the driving population know their respective legal blood alcohol limit. What is clear though is that the level of compliance checking is much more extensive and enforcement of punishments seems more stringent (ETSC, 2011).

On a more positive note, the Western Cape Provincial Government's official campaign, Safely Home has yielded positive results and is an example that needs to be followed by the rest of the country.

At City level, the translation of the national guidelines for NMT has resulted in the formulation of an NMT strategy for the City of Cape Town. Although the reasons for the choices of improvements and whether each section of work will form an integrated or connected system are not clear, this, along with the policy emphasis on public transport should result in an improved NMT environment and a reduction in fatalities and injuries, in time. However, it can be seen that road design guidelines, especially at the urban level and those recommended for settlement areas, are at odds with the NMT and public transport first objectives as they are still based on historic hierarchical concepts imported from a car-oriented era. From a road safety perspective, this issue is compounded by the fact that it is not mandatory to carry out a road safety audit prior to implementation of any new infrastructure, despite the fact that road safety audits have been shown to reduce the potential of crashes of not only new but also existing infrastructure (ETSC, 2005)¹⁵.

From a crash investigation and countermeasure perspective, the crash records provide general locational details of the majority of fatal crashes for most urban incidents (albeit mostly related to the nearest intersection). From these records, it can be seen that the majority of pedestrian fatalities occur on roads that allow high speed differentials (i.e. speeds in excess of the legal limit due to enforcement issues), but records relating to the reasons why pedestrian crashes occur, the nature of the crash and its accurate location are either sparse or unreliable, making safety evaluation difficult.

As stated, the results of the safety investigations are aggregated under human, vehicular and environmental factors, but their interaction is seldom investigated and, safety strategies, initiatives and infrastructure retro-fits continue to be derived mostly from this focus on historic data, usually only for 'black-spots' or clusters of incidents.

Despite the intuitive link between road safety and observed crashes, research by Peltola, (2009) suggests that 'black-spot' analyses have the disadvantage that, although these locations have peculiarities which lead to high numbers of incidents, crashes are random events and can occur anywhere given a certain set of antecedent conditions and at any time. They may, therefore, be an unreliable method for future incident prediction. Evidence from some highly motorised countries shows that an integrated approach to road safety through a good understanding of the sequence of events prior to the crash, along with detailed crash investigation, provides a more rational basis for the development of engineering counter-measures, and that this has produced a decline in road deaths and serious injuries (see Trinca et al., 1988 and Lonero et al., 2001). But the practical realisation of an integrated systems approach (as advocated by Haddon, 1983) remains the most important challenge for road safety policy-makers and professionals.

Worldwide, the issues related to 'black spot' data, data availability in general, its reliability, as well as methodological challenges posed by the random nature of crashes, have fostered many complementary approaches to improve road safety assessments, many of which have been extremely successful¹⁶. Given South Africa's continuing poor safety record, the limited successes of its policies and safety strategies, the fact that policies relating to NMT and PT will take time to come to fruition and the lack of success from its road safety investigation approaches so far, some additional/complementary methods of assessing road safety would yield better results, especially those that do not rely upon historic data as a basis of proposed interventions.

¹⁵ A study of immediate benefits in UK, revealed a reduction of about 1 accident per site per year for audited schemes, compared with the schemes that were not audited.

¹⁶ For example the UK achieved a 10% reduction in fatalities over the last year (<https://www.gov.uk/government/publications>) and the EU-24 countries have averaged a reduction of 3.4% in the number of fatalities between 2000 and 2010.

5 Road safety concepts, indicators and predictive modelling

Having established that government response to the road safety issue is somewhat lacking and that techniques used to evaluate and address areas with road safety issues may be inappropriate, this chapter reviews some prominent road safety concepts and complementary safety evaluation and predictive modelling techniques available from the literature. The aim being to assess the feasibility and adaptability for use in Cape Town

5.1 Introduction

Road safety studies are dependent upon how safety is defined and measured. The traditional methods of representing safety through empirical studies based on observed crashes assume that individual crashes are unpredictable but that groups of crashes can produce a reliable statistical pattern. However, analyses using groups of crashes can be unreliable due to temporal issues and because in-depth crash data is rarely available to determine the true nature of crashes.

To evaluate and suggest alternatives, this chapter reviews some fundamental concepts related to the way road safety is defined and measured; the main elements of crash causation (to understand the processes related to crashes); safety indicator concepts which do not rely on historic crash data, along with techniques which use these indicators. From these reviews it is concluded that predictive modelling in the form of micro-simulation would be an appropriate tool to use in the analysis of road user safety on urban infrastructure.

5.2 Crash data and the dimensions of road safety

Historical data is used for many different types of models and modelling approaches to define safety risk. A useful descriptive model has been proposed by Rumar (1988) to highlight the relationship between what he referred to as the 'three basic dimensions of traffic safety'- risk, exposure, and consequences (i.e. crash outcomes). Each dimension is considered relevant given the fact that changes in any one particular dimension will have an influence on the overall traffic safety situation as represented by the total area in Figure 33.

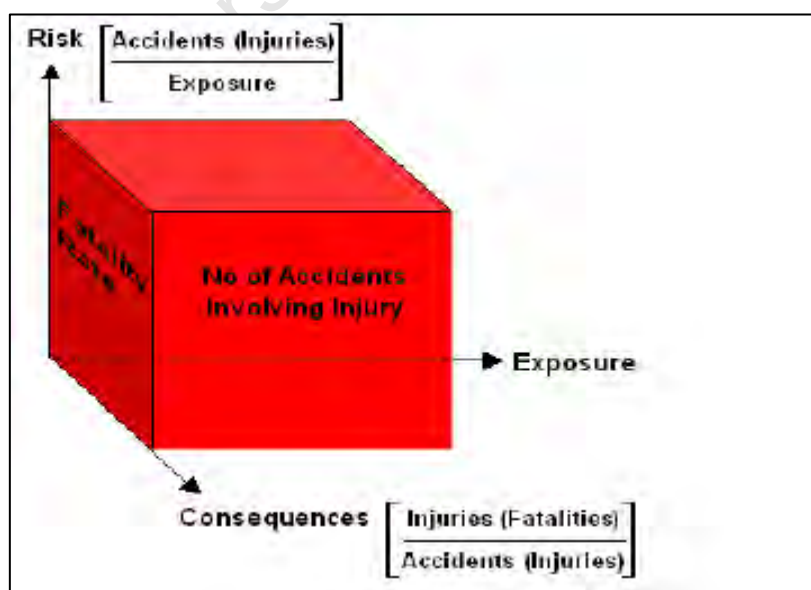


Figure 33: The three dimensions of traffic safety

Source: Adapted from Rumar, 1988

The relationship suggested by Rumar (1988) is indicative of the fundamental principles used in descriptive analysis which are based on historical crash and exposure data, and are commonly used to express meaningful comparative measures of risk at the international and national level. Typical examples of traffic safety risk indicators include:

- *Health risk in traffic* – Number of fatalities/injuries per million hours in traffic;
- *Crash risk* – Number of crashes per 100,000 population or, per million kilometres travelled per person;
- *Injury risk* – Number injured per 100,000 population or, per million kilometres travelled per person;
- *Death risk* – Number of fatalities per 100,000 population or, per million kilometres travelled per person;
- *Accident ratio* – Number of accidents per million kilometres travelled per vehicle;
- *Injury ratio* – Number injured per million kilometres travelled per vehicle;
- *Death ratio* – Number of fatalities per million kilometres travelled per vehicle;
- *Vehicle/accident ratio* – Number of vehicles involved in crashes per million kilometres travelled per vehicle;
- *Injury consequence ratio* – Number of injured per police reported accident;
- *Death equivalence ratio* – Number of fatalities plus number of serious injuries plus number of minor injuries.

Risk indicators can provide a useful, descriptive and comparative analysis for any situation.

The majority of safety studies found in the literature, report on the above indicators using police recorded crash data - the main advantages of this type of reporting is the quantity of data and the inclusion of objective measures of failure in at least one of the three major components of the transport system.

Unfortunately, there are a number of widely reported problems with police recorded data, such as low reporting rates, incomplete and missing data, errors in data entry and its use in road safety assessments poses statistical challenges due to the inherently rare nature of crash occurrences. There are also a number of differences in reportability criteria between different jurisdictions (let alone nations), different legal requirements and, in many cases, crashes are not reported due to the risk of higher insurance premiums or because some drivers do not have insurance or a valid license. The development of risk indicators using this data without some kind of validation of the data is thus unwise.

5.3 Safety Continuum

The notion of safety for road users while in the transportation system can be hypothesised as a series of time-dependent events that range from undisturbed passages to actual collisions as a result of the interaction between road users. This interaction can be described as a continuum of safety related traffic events (see Figure 34).

The number of events corresponding to the relative class of occurrence can be visually determined from this diagram. It shows that the events on which safety analyses and estimates (i.e. crashes and serious events) are based on, are few and exceptional. This theoretical concept provides a bottom-up and more rational approach to safety research compared to the traditional concerns with the occurrence of traffic crashes and their consequences. Crashes are exceptional in the sense that they occur due to a collection of events where all alternatives to handle the situation safely have vanished

one by one (Svensson and Hyden, 2006). They are stochastic events that can occur anywhere given a certain set of antecedent conditions.

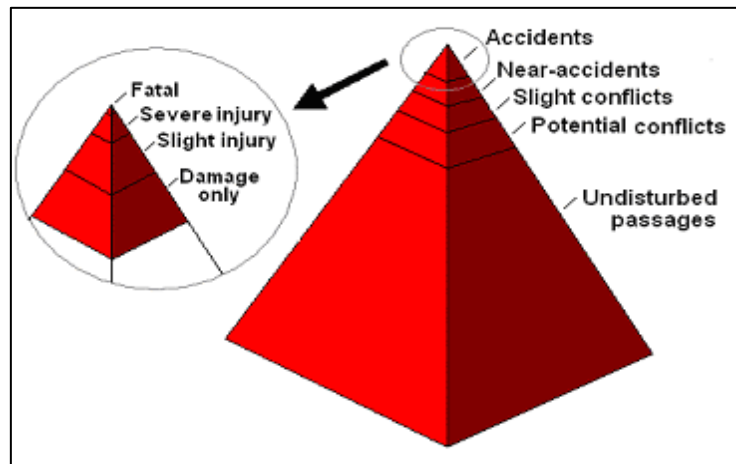


Figure 34: The interaction between road users as a continuum of events

Source: Hyden, 1987

Further, it is clear from published data that, while the extremes of the pyramid are promptly detected (crashes and undisturbed passages), intermediate events lack objective definitions and thresholds, as well as, effective procedures for their measurement. Therefore, a more comprehensive understanding of the connection between behaviour and safety by considering both unsuccessful and successful interaction is required. Unsuccessful interactions (crashes) as well as successful interactions can be investigated via proximal, near miss, surrogate safety or complimentary methods of potential safety risk analysis.

5.4 Causes of crashes

The process of obtaining empirical evidence for crashes is difficult, as police reports rarely provide a detailed account of the chain of events that led to the crash (see Chapter 3). Nevertheless, the 'cause' is usually assigned to one of the three responsible parties - the road, the road user or the vehicle - without much further investigation. The close interaction between the three 'parties' makes it difficult to isolate a single cause for a crash, although in-depth crash investigation or accident reconstruction does attempt to provide this background information through the use of experts with different disciplinary backgrounds and in accordance with a theoretical reference frame. Such systems type investigations seem to be more routinely carried out in most developed nations, but in South Africa, they are not - they seem to take place only for the most severe or politicised cases.

Typically, these analyses treat events as three temporally separated phases: '*pre-crash*,' '*crash*' and '*post-crash*,' based on the systems approach developed by Haddon, (1983). The knowledge gained from such analyses can be usefully employed for safety counter-measures for each of the component factors of the road system and their interaction, which is dynamic and often complex, and the reason why causes (faults) are split into these component parts.

Table 3: The Haddon Matrix.

PHASE		FACTORS		
		HUMAN	VEHICLE AND EQUIPMENT	ENVIRONMENT
Pre-crash	Crash Prevention	Information Attitudes Impairment Police enforcement	Roadworthiness Lighting Braking Handling Speed management	Road design and road layout Speed limits Pedestrian facilities
Crash	Injury Prevention during the crash	Use of restraints Impairment	Occupant restraints Other safety devices Crash protective design	Crash protective roadside objects
Post-crash	Life Sustaining	First-aid set Access to medics	Ease of access Fire risk	Rescue facilities Congestion

Source: Haddon, 1983

5.4.1 Crashes related to the road environment

The underlying causes of crashes within the traffic system are often suggested to be exogenous rather than endogenous. Authors such as Flahaut (2004); Martin (2002); and Shankar et al. (1995) indicate that road geometrics and roadside features are significant in explaining road crashes (see also Appendix A), implying that the make-up and complexity of the system will, at certain times and places, exceed the perceptual and cognitive capacity of the road user and will result in errors leading to crashes (see Section 5.4.3.1 relating to the driving task). From a socio-technical perspective, this implies that the system, at that point, is inappropriately designed (and/or built) with regard to the limitations of the road user.

A concern with attributing the cause of crashes to exogenous factors, such as the complexity of the system, is the variability of the perception of complexity among users and, therefore, the design of systems tend to be based on generalisations of abilities and behaviours of the user, engineering properties of materials, vehicles etc. Traffic control devices help to standardise the behaviour of users, as much as possible, and additional roadside signs (such as variable messages) and in-vehicle technologies have assisted in increasing awareness and making safer environments.

Despite these advances, externalities are sometimes still implicated as the causes of crashes. In recognition of this, Sweden for example has assigned the responsibility of achieving traffic safety goals between the road users and the system owners (i.e. those responsible for the road infrastructure, vehicle manufacturers, designers and authorities with an involvement and interest in safety). Sweden has adopted the ambitious long term target of zero fatalities as a consequence of road traffic incidents. Amongst the strategic principles to achieve this goal, termed '*Vision Zero*', are that the traffic system must be adapted to take better account of the needs, mistakes and vulnerabilities of road users by appropriate design, and that speed is the most important regulating factor for safe road traffic (SNRA, 2003). The Dutch '*Sustainable Safety*' approach is a similar, multi-faceted error management system (SWOV, 2010).

5.4.2 Crashes related to vehicular factors

Without doubt vehicle defects play a role in crash causation as is evident from Chapter 3 and the raft of vehicle technical specifications, legislation, regulations and standards of manufacturing requirements (see for example: ETSC, 2001). The WHO (2004) state that vehicle design can have

considerable influence on injuries, and its contribution to crashes is around 3% in high-income countries, about 5% in Kenya and 3% in South Africa.

As a comparison, a later study by Moodley and Allopi in 2008, of vehicular factors leading to crashes in South Africa, indicated that the contribution of vehicle defects to fatal road crashes varied between 5% and 17%. These data were based upon details obtained from a specialised 'Accident Response Unit' of the police service rather than nationally published data. Furthermore, the report indicated that from a survey of 438 vehicles, the authors found that 24% of vehicles checked had defective tyres (i.e. with a tread depth of below 1mm or tears, holes etc.), 11% had defective lights (i.e. broken lens covers, missing bulbs etc.), 2% had window/windscreen defects and 7% of the vehicles had two or more defects¹⁷. While the relative numbers of vehicle defects and unroadworthy vehicles do not necessarily correspond to the numbers of crashes, the differences in contribution reported between high income countries (where there is a high degree of vehicle compliance testing) and lower income countries indicates that there is a link.

Other vehicular factors that influence crashes and crash severity include: inadequate in-vehicle protection, inadequate vehicle safety standards and the lack of protective in-vehicle safety systems. Vehicle engineering improvements for safety can either be achieved either by modifying the vehicle to help the driver avoid accidents, or by modifying the vehicle to provide protection against injury in the event of a crash. Although much can be done to prevent some accidents from happening, it is clear that for the foreseeable future the majority will continue to occur. A recent European Union study (ETSC, 2001) in one Member State reviewed the effectiveness of casualty reduction measures nationally since 1980 and demonstrated that the greatest reduction was from vehicle crash protection (15%) compared to drink/drive measures (11%) and road safety engineering measures (6.5%). It also states that '*...Reducing the risk of injury in accidents is and will remain a priority and the single most effective way of achieving this is by improving the safety of cars*'.

The improvement of vehicle safety standards and the data above clearly implies a causal relationship between vehicle age and risk of a car crash. Further, an independent study carried out in Australia shows that occupants in cars manufactured before 1984 have approximately three times the risk of a car crash injury compared to occupants of newer cars (Blows et al., 2003). Driving assistance systems, based on stand-alone technologies such as: radar, cameras, ultrasonic sensors and the like, are increasingly being deployed in luxury and medium range cars (Page, 2012). These technologies provide drivers, and possibly other road users, detection systems that address drivers and motorcyclists perception failures by screening obstacles in the vehicle vicinity (mainly ahead of the equipped vehicle), or action failures by correcting false, incorrect or bad wheel/brake actions in emergency situations (Page, 2012).

The Dutch 'Sustainable Safety System' also recognises the role of vehicular factors in crash causation and states that: '*A sustainable and safe traffic system has as part of it: vehicles fitted with facilities designed to simplify the task imposed on the driver and constructed to protect the human body as effectively as possible from the violent impact of crashes*' (SWOV, 2010).

¹⁷ The percentage of reported unroadworthy vehicles in December 2010, in South Africa stands at 4.6% of the total vehicle parc (RTMC, 2010). However, a vehicle with tyres of less than 1mm tyre tread depth is considered un-roadworthy which, given the survey by Moodley and Allopi above, indicates that there is an institutional problem with the recording of roadworthy data and possibly, that vehicle defects have a more significant impact on road crashes than reported.

5.4.3 Crashes related to the human element

Not surprisingly, within such a complex socio-technical system, human error has consistently been implicated as the major causal factor in road traffic incidents. Literature from the field of road safety and psychology indicates that the scale of attribution of cause of crashes to human or driver error ranges from 75% (see for example: Abbas, 2004 and Salmon et al., 2005) to as much as 95% (see Rumar, 1990 and RTMC, 2010).

Human factors include level of experience, fatigue or attention, and combine with the inadequacy of the variables characterising the other components (road layout, vehicle environment) to produce *'human errors'*.

Possibly the most widely quoted definition of human or driver error is that of Reason (1990). He defined human error as *'a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency'*.

Humans are of course by nature subject to errors. But 'error' should not be confused with, or be regarded synonymous with, *'fault'* – which leads to a loss of any possible solution, apart from law enforcement (Van Elsande et al., 2008). Recognising this, some driver behaviour questionnaires identify the types of driver error made by different driver groups and provide a focus on person and systems perspectives. An example is a study conducted at the Virginia Tech Transport Institute (2002, in Salmon et al., 2005), which investigated the nature and causes of driver error and their role in crash causation; as a result, they developed driver error taxonomies as well as recommendations for improvements in traffic control devices, roadway delineations and accident reporting forms.

As a consequence of the limited amount of investigation of (and thus data on) different errors made by road users and their associated causes, there is limited information available on this particular aspect. An error management approach may well contribute to a better understanding of the causes of crashes.

5.4.3.1 The driving activity/task

Driving is regarded by behavioural researchers as a highly complex task, requiring continual adaptation to meet the needs and demands of the prevailing traffic situation. Its complexity increases from initial control (to maintain desirable alignment and speed), to guidance (the interaction with the road environment) and navigation (the process of planning and executing the trip). An idea of the relative level of complexity is suggested in a study carried out by Hakkinen & Luoma in 1991¹⁸. According to this study, based on data from Finland and the United States (see Table 4), an average driver could be responsible for 30 errors in one hour as a result of 7,200 observations and 1,800 actions; and there is a possibility of a crash once every 7.5 years preceded by 75,000 driving errors. Clearly, these statistics are contingent on the degree of complexity of the originating environment.

Perceptual and cognitive research in relation to the driving task is now a predominant area of multidisciplinary research in Human Factors and Human-Machine Interface (HMI) design. The information-processing approach emerged with the advent of cognitive psychology in the 1970s and has identified and quantified many different limitations in relation to human perception and cognition, and the propensity for different types of human error to occur as a result of these limitations (Archer, 2005a).

¹⁸ The report is originally in Finnish. These results are presented here based on an interpretation by Archer (2005).

Table 4: Events and complexities of driving tasks

Event	Frequency per time unit	Frequency per kilometre
Pieces of traffic information	5 in 1 second	300 per km
Driver observations	2 in 1 second	120 per km
Driver decisions	40 in 1 minute	40 per km
Driver actions	30 in 1 minute	30 per km
Driver errors	1 in 2 minutes	1 per 2km
Risky situations	1 in 2 hours	1 per 120 km
Near crash	1 in 1 month	1 per 2000 km
Crashes	1 in 7.5 years	1 per 150,000 km
Injury crash	1 in 100 years	1 per 2 million km
Fatal crash	1 in 2000 years	1 per 40 million km

Based on an average driver, travelling at an average of 60km/h and an annual mileage of 20,000km.

Source: Modified from Archer, 2005a

The human information processing approach is also recognised by the Swedish National Road Authority (SNRA, 2003) which has identified human functions/error mechanisms that are critical for safe driving. These functions include:

- The timely detection of relevant information;
- The identification and selection of information for decision-making;
- The interpretation of relevant information;
- The ability to turn decisions into correct action;
- The evaluation and modification of actions taken;
- The evaluation of own abilities and limitations;
- The evaluation of vehicle performance and limitations; and,
- The motivation to drive safely.

In a report aimed at identifying ways through which the ‘*Vision Zero*’ could be achieved, the SNRA (2003) identified stress and strain, tiredness, alcohol, and medication, as factors that can have a significant negative effect on driver performance. They also identified inexperience and incorrect attitudes (i.e. behaviour) as potential problem areas with regard to safety.

5.4.3.2 Acceptable Risk

In contrast to the SNRA, but along the lines of the motivation to drive safely, Wilde (1998), states that the factors that influence the level of accepted (driving) risk can be: macroeconomic, cultural, social, or psychological. And, ‘*In general, the amount of risk that people are willing (in fact, prefer) to take can be said to depend on four utility factors...*’. These are:

1. The expected benefits of risky behaviour alternatives (examples: gaining time by speeding, fighting boredom, increasing mobility).
2. The expected costs of risky behaviour alternatives (examples: speeding tickets, car repairs, insurance surcharges).
3. The expected benefits of safe behaviour alternatives (examples: insurance discounts for accident-free periods, enhancement of reputation of responsibility).
4. The expected costs of safe behaviour alternatives (examples: using an uncomfortable seat belt, being called a coward by one’s peers, time loss)?

The level of risk at which the net benefit (the difference between benefits and costs) is expected to maximise is called the target level of risk. The theory realises that people do not try to minimise risk

(which would be zero at zero mobility), but instead attempts to optimise it. Risk homeostasis theory posits that people at any moment of time compare the amount of risk they perceive with their target level of risk and will adjust their behaviour in an attempt to eliminate any discrepancies between the two. Each action carries a certain level of injury likelihood (either because of their own behaviour, or because of the behaviour of other road users that cannot be predicted) - such that the sum total of all actions taken by people over one year explains the crash rate for that year. This rate, in turn, has an effect on the level of risk that people perceive, and thus upon their subsequent decisions.

With experienced drivers the motivating factors are usually so thoroughly internalised that most people, most of the time, are not consciously aware of them. Thus, the target level of risk should not be viewed as something that people arrive at by explicitly calculating probabilities of various possible outcomes and their respective positive or negative values. There may be cases in which risk is deliberately pursued, but most risks that people incur are rather more passively accepted as the inevitable consequences of their deliberate choice of action.

Supporting data for the theory, primarily developed and validated in the area of road safety, can, for example, be found in the documented change over from left to right side traffic by Sweden in 1967. This change was followed by a marked reduction in the traffic fatality rate, which Wilde says was due to perceived risk being higher than the target level of risk. However, after some time, the fatality injury rate returned to previous levels, indicating a decrease in the perceived level of risk.

Similar studies by SWOV (2012) but specifically related to speed choice, confirm that some reasons for exceeding the speed limit are: haste, pleasure and adapting to other traffic.

5.4.4 Longitudinal Studies

In the 1980s in Leeds, UK, a comprehensive study of the underlying causes of crashes for 1,254 crashes over a period of one year for roads with a speed limit of 40mph or less, was undertaken to determine the '*chain of factors*' leading to incidents (Carsten, et al., 1989). In addition to police reports for the crashes, questionnaires were administered and sites were visited to gain as much relevant information as possible regarding the incidents. In contrast to the approach in South Africa, the study used four levels of factors for determining crash causation: '*immediate failures that precipitated an accident,*' '*failures that increased the likelihood of an accident,*' '*road-user behaviour or lack of skill leading to a failure,*' and '*explanation for failure or behaviour,*' in an attempt to segregate mechanisms and thereby provide a more focused analysis for potential countermeasures.

Many other studies focus specifically on particular issues to develop a classification system that can be used by decision makers in order to reduce common types of incidents. For example, a study by Retting et al. (1995), using police reports of traffic safety problems particular to the urban environment found that the most common types of incidents could be resolved by a combination of better signal timing, increased visibility of road furniture, reduced speeds near intersections, red-light cameras, or intersection redesign.

5.4.5 Systems Theory

Although the approaches to identify components of the road user system that can be addressed individually and, in the case of the Haddon matrix approach, temporally, to interpret crash data, they tend to produce typologies that mix up disjointed phenomena. For example these approaches put manoeuvres, processes, factors, consequences and types of collisions on the same level. To improve the way crash data is analysed, researchers need to rely on crash production theory not only because of the complex human component in the analysis (Van Elslande, et al., 2008), but because it is impossible to consistently predict behaviour within the human-vehicle-environment (HVE) triptych

which makes the system complex and non-deterministic. This unpredictability is because human functions are strongly involved in crash causation. Furthermore, at each stage of a trip, there is a need to perform some function within the system (such as perception, interpretation, anticipation, action etc.), which generates transformations (new situation, new purpose etc.); these in turn require new functions – an endless loop which means that errors cannot be identified exhaustively.

The systemic approach is opposed to reductionism and assumes that real systems are interacting with their environments and that they can acquire qualitatively, new characteristics through emergence and continual evolution (Bertalanffy, 1969). Rather than reducing an entity (in this case road safety) to the features of its parts or elements (e.g. road or vehicle), a systemic approach focuses on the relationship between the parts, which connect them into a whole. In other words, the systemic approach assumes that to handle a complex behaviour, it is fundamental to make a connection between the three components of the system in a manner that: defines the system, what it does, what it becomes and its goal (i.e. the safety of the HVE system). From this point of view, a crash is the result of an incorrectly adjusted interaction between the system components. The cause of a crash should therefore not be seen as a problem in one component or the other, but in the defective inter-component interaction (Figure 35).

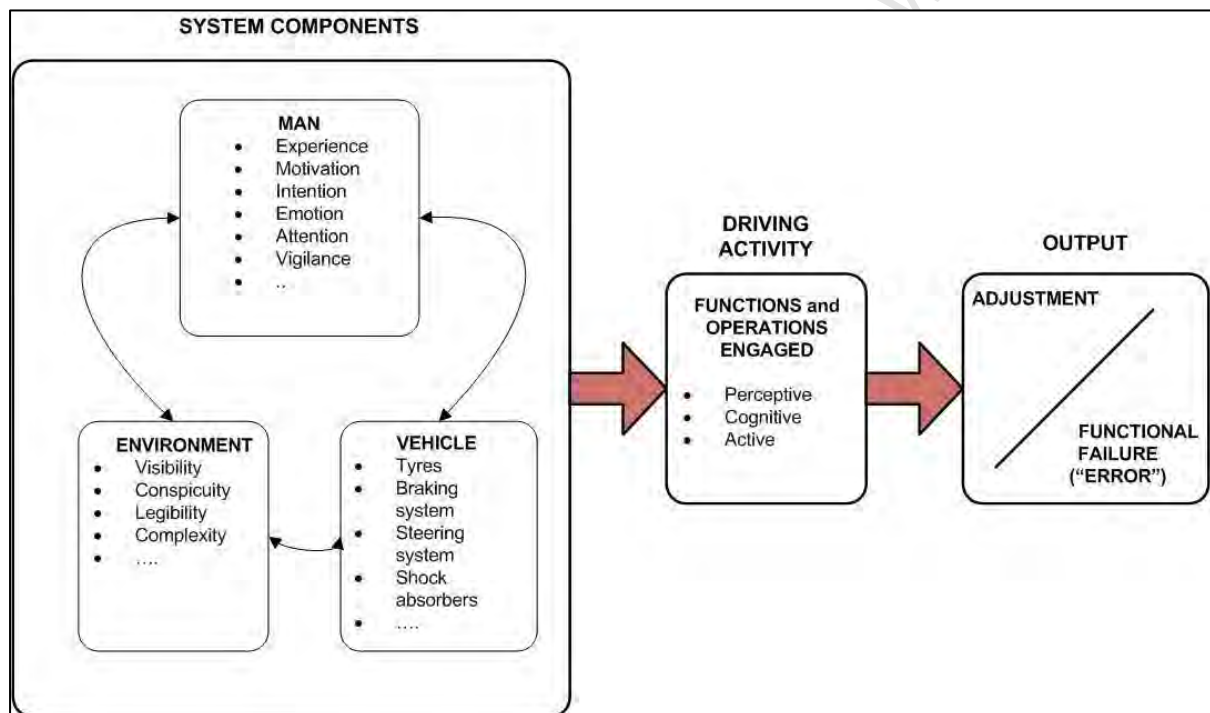


Figure 35: Interaction within the Human-Vehicle-Environment system

Source: Adapted from Van Elslande et al., 2008

5.4.6 Recent advances in road safety research

Recent advances in road safety have seen the adoption and adaption of many of the Dutch ‘Sustainable Safety’ systems and the Swedish ‘Vision Zero’ concept. The principles of these systems are broadly similar - they focus on the prevention of (serious) crashes where possible, and prevention of severe injuries when a crash occurs (SWOV, 2010), i.e. a systems approach. The systems are characterised by a pro-active approach which means that black-spots are dealt with generically.

The Dutch system adopts *man as the measure of all things* to achieve this goal. Man's measure is determined by physical vulnerability as well as psychological characteristics: human beings,

irrespective of background, education and motivation, do make errors and do not always abide by the rules; that is why the human being is an important cause of crashes (SWOV, 2010).

‘Sustainable Safety’ aims to prevent these errors and offences as much as possible or to mitigate their consequences by designing the traffic system according to the human measure. It states that: first of all, the surroundings, such as the *road* and the *vehicle*, should be tuned to man's capabilities and should offer assistance and protection. In addition, information and education campaigns need to prepare people for the traffic task, and, finally, man’s traffic behaviour must be checked for safety (SWOV, 2010).

5.5 Safety indicators

5.5.1 Traffic speed

The relationship between speed and road crashes has been studied extensively. Higher driving speeds provide less time to in which to process information and to act on it, the braking distances are correspondingly shorter and, therefore, the possibility of avoiding a crash is lower (SWOV, 2012). In short, high driving speeds increase the possibility of being involved in a crash and, the results of the crash are likely to be more severe. However, the relation between speed and crash rate is much less direct and much more complicated than the relation between speed and crash severity. The injury severity of the vehicle occupants in a crash, for example, is not only determined by the collision speed, but also by the mass difference between the vehicles and by the vulnerability of the vehicles/road users who are involved. In a crash between a light vehicle and a heavier one, the occupants of the lighter vehicle generally are considerably worse off than the occupants of the heavier vehicle. This case is even more pronounced for pedestrians, cyclists and moped riders in crashes with (much) heavier motor vehicles. Recently published studies (see for example: US DoT, 2005; Elvik, 2009 and Rosen and Sander, 2009) summarised the relationship between impact speed and the probability of sustaining an injury of a specific level of severity (in terms of the Abbreviated Injury Scale) by means of a set of logistic functions. For passenger car occupants the best fit for fatal injuries was:

$$\text{Probability of fatal injury (\%)} = 100 * \frac{e^{0.1524i - 8.2629}}{1 + e^{1.1524i - 8.2629}} \quad (1)$$

Where e is the exponential function and i the impact speed (in miles per hour). Whereas, Rosen and Stander (2009) found the following relationship:

$$\text{Probability of fatal injury (\%)} = \frac{1}{1 + e^{(6.9 - 0.090v)}} \quad (2)$$

Where e is again the exponential function and v is the impact speed.

Figure 36 shows the two functions together indicating that the risks of fatality for pedestrians and vehicle occupants are surprisingly close, although Rosen and Sander (2009) suggest that age would be an influencing factor to the level of risk. As expected, the curves fitted to the raw data indicate a higher fatality risk for the same level of speed. However, the results for pedestrian risk are considerably better than previously suggested risk levels by, amongst others, the WHO (2004), where it is suggested that pedestrians have a 90% chance of surviving a crash at 30km/h or below but less than a 50% chance of surviving a crash at 45km/h. A study by Richards (2010) comparing Rosen and Sander’s data with historic and current UK data found similar results, but that approximately half of the pedestrian fatalities occurred at 30mph (48km/h) or below. All of the data and conclusions

indicate the importance of keeping impact speeds as low as possible, especially within urban areas where most crashes occur.

In contrast, the relationship between speed and crash rate of a given severity, is generally accepted as being best described by a power function: the crash rate increases more rapidly when the speed increases and vice versa, depending on the initial speed (Nilsson, 2004; verified by Elvik, 2009).

According to Nilsson's (1982) calculations, the effect of a change in the average speed on a road on the number of injury crashes could be expressed by the formula:

$$LO_2 = LO_1 \left(\frac{v_2}{v_1} \right)^2 \quad (3)$$

Where LO_2 is the number of injury crashes after the change in speed, LO_1 is the initial number of injury crashes, v_1 is the average speed before the change, and v_2 the average speed afterwards. The same formula could be used to describe the effect on the number of crashes with severe injury, but to the power 3, and for fatal crashes its effect was to the power 4. These power functions have largely been validated using newer data (see Nilsson, 2004; Hauer and Bonneson, 2006; Elvik, 2009).

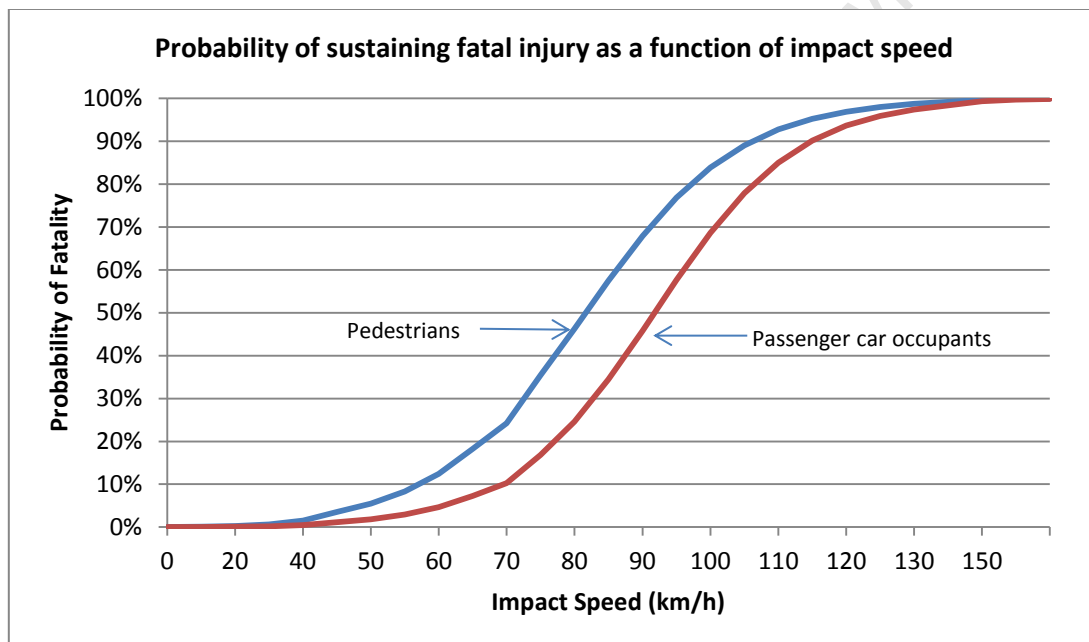


Figure 36: Probability of sustaining a fatal injury as a function of impact speed.

Source: Derived from U.S. DoT 2005 and Rosen and Stander 2009

The study by Elvik (2009) made it possible to refine this quantitative relationship by, among other things, making a distinction between different road types. The study showed that the effect of an increase or decrease in driving speed on rural roads is relatively greater than the effect on urban roads. For example an absolute increase or decrease of 1km/h has a greater effect on rural than on urban roads. Table 5 details the exponents of the power functions for these two road categories and for different crash severities. The consistency of the exponents was tested by Elvik (2009) using Norwegian crash data. His results indicated a high degree of consistency despite the existence of a couple of exponents that are uncertain. His report also acknowledges the possibility that the initial speed of vehicles has an impact on the crash rate and therefore the need for 'low-speed' and 'high speed' power models.

Table 5: The Power Model relationship between changes in speed and changes in road safety

Crash or injury severity	Summary estimates of exponents by traffic environment					
	Rural roads/freeways		Urban/residential roads		All roads	
	Best estimate	95% reliability interval	Best estimate	95% reliability interval	Best estimate	95% reliability interval
Fatal crashes	4.1	(2.9, 5.3)	2.6	(0.3, 4.9)	3.5	(2.4, 4.6)
Fatalities	4.6	(4.0, 5.2)	3.0	(-0.5, 6.5)	4.3	(3.7, 4.9)
Serious injury crashes	2.6	(-2.7, 7.9)	1.5	(0.9, 2.1)	2.0	(1.4, 2.6)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(0.8, 3.2)	3.0	(2.0, 4.0)
Slight injury crashes	1.1	(0, 2.2)	1.0	(0.6, 1.4)	1.0	(0.7, 1.3)
Slightly injured road users	1.4	(0.5, 2.3)	1.1	(0.9, 1.3)	1.3	(1.1, 1.5)
Injury crashes - all	1.6	(0.9, 2.3)	1.2	(0.7, 1.7)	1.5	(1.2, 1.8)
Injured road users - all	2.2	(1.8, 2.6)	1.4	(0.4, 2.4)	2.0	(1.6, 2.4)
PDO - crashes	1.5	(0.1, 2.9)	0.8	(0.1, 1.5)	1.0	(0.5, 1.5)

Source: Adapted from Elvik, 2009

Using Nilsson's formula - adjusted by the exponents from Table 5, and acknowledging that the risk linked to speed varies across road types - a sound rule of thumb is that, on average, a 1% reduction in the mean speed of traffic leads to a 2% reduction in injury accidents, a 3% reduction in severe injury accidents and a 4% reduction in fatal accidents (Aarts and van Schagen 2006, based on Nilsson 2004). It follows from the high risk associated with speed, that reductions in driving speeds (even minor ones) will make an important contribution to reducing the numbers of road traffic deaths and injuries (see Figure 37).

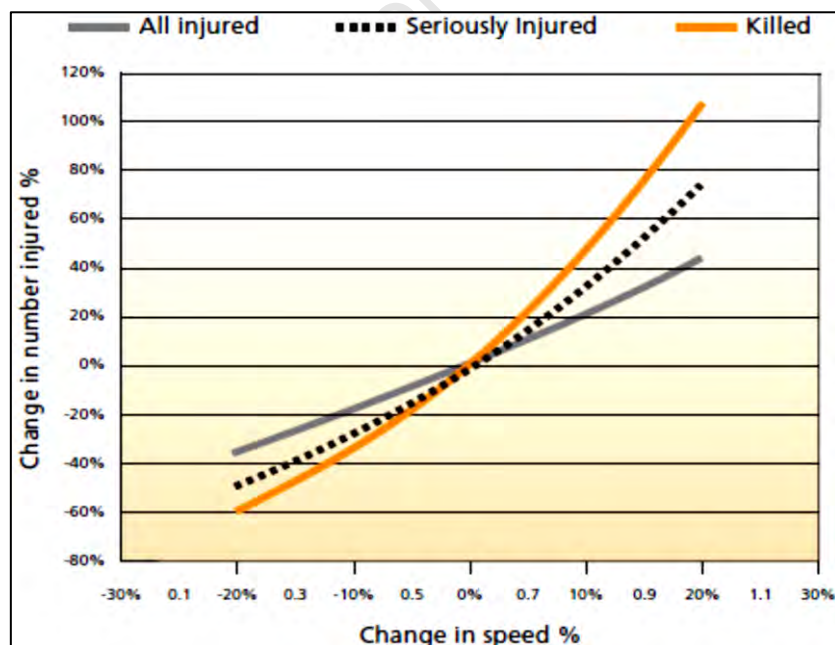


Figure 37: The relationship between speed and number killed or seriously injured

Source: Nilsson, 2004

As further corroboration of the effects of speeds on crash rates, a report by Grundy et al (2009), examines the 399 zones with 20mph (32km/h) speed limits that have been installed in London, UK, gradually since 1990 (see Figure 38). They evaluated the effects of these zones on crashes, injuries and deaths occurring within the zones and on their periphery. They found that after controlling for the

underlying downward trend in crashes, a significant reduction in crashes of 7.4% was observed on the periphery of the calmed zones.

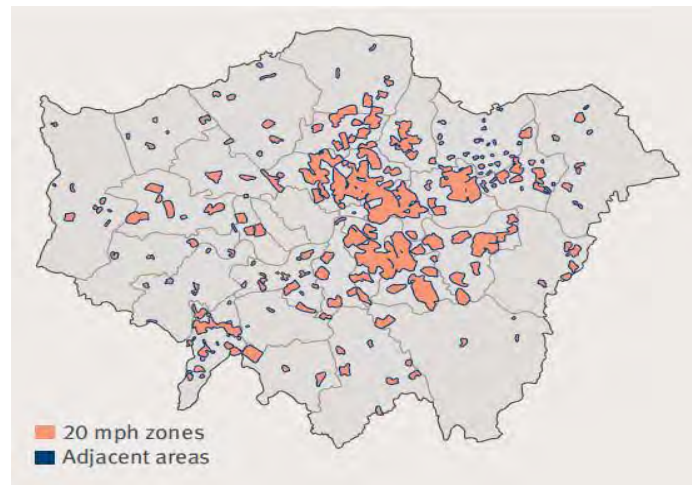


Figure 38: 20m.p.h. zones and adjacent areas in London

Source: Grundy et al., 2009

In addition to absolute speeds, studies show that the speed differences between vehicles also have an effect on the crash rate (see for example: Aarts and Van Schagen, 2006). These studies mostly conclude that roads with a large speed variance are less safe; that vehicles that drive faster than average on that road have a higher crash rate; and that vehicles that drive slower were found not to have an increased risk.

5.5.2 Traffic flow and composition

Studies of relationships between crashes and traffic flow indicate that they are not straightforward. These studies generally conclude that reduced congestion and smoothed traffic flow are likely to improve safety, although there is some evidence that increased congestion leads to reduced speed and therefore reduces the risk of crashes (see for example: Golob et al., 2004). Intuitively, it can be noted that increased travel increases exposure and thus, the level of risk increases.

Aggregate studies of flows for specific time periods or spaces, provide compelling evidence that crashes are not simply a linear function of traffic volume. Several aggregate studies underpin the research reported here by identifying the relationships between different types of crash rates and the three main traffic flow parameters: traffic volume, speed, and density.

Based on vehicle miles travelled and peak hourly flows, these studies show that:

- Single-vehicle crashes decrease at a decreasing rate as a function of flow, and multiple-vehicle crashes increase with flow, usually at an increasing rate;
- They are observed to vary for day, night and for weekday (Ceder and Liveneh, 1982 and Martin, 2002; in Golob et al., 2004);
- Peak crash rates do not occur at peak flow, they tend to increase with increasing density, reaching a maximum before the optimal density at which flow is at capacity (Garber and Subramanyan, 2001);
- Crash rates involve an interaction of variation in speed and flow, with crash rates being an increasing function of the standard deviation of speed for all levels of flow (Garber and Ehrhart 2000); and,

- Crash rates are higher under congested conditions (see for example: Ceder ,1982; Sullivan, 1990 and Persaud and Dzbik,1992)

In addition, an EU project to evaluate road infrastructure related safety measures, found that traffic volumes and road lengths were the most important explanatory variables in their Accident Prediction Model but that the parameters of the model can vary considerably with road types due to changes in user behaviour (Eenink et al., 2008).

In summary, despite the variations presented, the literature confirms the evidence of strong relationships between traffic flow conditions and the likelihood of traffic crashes.

5.5.3 The Built Environment

Much of the research investigating the influence of built environment on pedestrian activity and pedestrian–vehicle collision occurrence has tended to focus on identifying road features, such as signalised intersections, that increase or decrease crash risk (Cho, et al., 2009). Built environment research includes land use types, road network connectivity, transit supply and demographic characteristics. Other research (see for example Wier et al., 2009; and Miranda-Moreno et al., 2011) as studied the more complex relationship between the built environment, pedestrian activity and incident occurrence. Among other results, these studies found that the built environment in the proximity of an intersection has a powerful association with pedestrian activity but a small direct effect on pedestrian–vehicle collision frequency.

Clifton et al (2009) found that within the built environment, policy variables, transit access and greater pedestrian connectivity (such as central city areas), are significant and negatively associated with injury severity Similarly, LaScala et al (2000) found that pedestrian collisions occurred more often in areas with higher population and cross-street densities. They also found that alcohol availability in neighbourhoods or regions affects the pedestrian and bicycle crashes especially in areas with greater bar densities and higher population numbers.

From a population density perspective, after controlling for VMT and location, Clark and Cushing (2004) found that state population density was a moderately strong predictor of rural but not urban traffic mortality rates.

5.6 Predictive Modelling

5.6.1 Observational Analysis

Most models that predict levels of safety use inferential statistics applied to historical crash data for a given traffic site, through observational analysis. Through these analyses, researchers have continually sought ways to gain a better understanding of the factors that affect crash probability in the hope that they will be able to better predict the likelihood of crashes and provide direction for policies and counter-measures aimed at reducing crashes (Lord and Mannering, 2010). Unfortunately, the detailed driving data (acceleration, braking and steering information, driver response to stimuli, etc.), pedestrian data and crash data (for example what might be available from in-vehicle video recorders) that would enable better identification of cause and effect relationships are typically not available. As a result, researchers have framed their analytic approaches to study the factors that affect the number of crashes occurring in geographical space (usually a roadway segment or intersection) over some specified time period (week, month, year, number of years). Such an approach handles the spatial and temporal elements associated with crashes, and ensures that adequate data are available for the estimation of statistical models (in terms of measurable explanatory variables). This results in crash-frequency data that are non-negative integers, and suggests the application of count-data

regression methods or other approaches that can properly account for the integer nature of the data (Lord and Mannering, 2010).

Lord and Mannering (2010) also state that: *‘Important data and methodological issues have been identified in the crash-frequency literature over the years. These issues have been shown to be a potential source of error in terms of incorrectly specifying statistical models which may lead to erroneous crash-frequency predictions and incorrect inferences relating to the factors that determine the frequency of crashes’*. Their summary is reproduced in Appendix B.

Clearly, if the issues of data and their methodological challenges are not adequately addressed, the statistical validity of an analysis could be compromised. A wide variety of methods have therefore evolved over the years, each of which addresses issues pertinent to their particular analysis (see Appendix B for a summarised form).

Sayed and de Leur (2008) state that: Crash Prediction Models (CPM) *‘..can facilitate the accurate and consistent quantification of safety performance at all stages of highway planning and design. Traditional safety performance measures of collision rates and collision severities provide very little information concerning the safety of a location and cannot accurately reflect the future potential safety benefits of road improvements. Conversely, CPMs can be used either alone or in combination with collision modification factors (CMFs) to accurately assess and predict the safety of planned highway improvements’*.

The literature shows many examples of different CPM’s (see Lord and Mannering, 2010 for a comprehensive listing). They usually analyse different effects for different types of roads and intersections, and only for vehicular traffic. The fundamental difference between these models is the length of roadway segment that needs to be included either as an independent variable or accounted for by the dependent variable (such as the expected number of crashes per year).

An example developed for British Columbia by Sayed and de Leur (2008) in its general form is:

$$\text{Segment Model Form: } E(\Lambda) = a_0 V_1^{a_1} L_1^{a_2} \quad (4)$$

$$\text{Intersection Model Form: } E(\Lambda) = a_0 V_1^{a_1} V_2^{a_2} \quad (5)$$

Where, $E(\Lambda)$ = collision frequency
 L = section length
 V = section average annual daily traffic (AADT)
 a_0, a_1, a_2 = model parameters

The model parameters were estimated by the authors using five years of volume and collision data for various forms intersections and highway segments and the predictions refined into property damage only (PDO) and severe incidents. For example for a rural two-lane highway, 1.1km in length with an AADT of 12,000, using Equations 4 and 5, they predicted the collision frequency per five years to be 7.3 PDO and 5.34 severe collisions. This was refined by using an Empirical Bayes method to give the expected number of collisions at a location by combining the predicted and the observed collision frequency to give estimates of 7.8 PDO and 5.68 injury collisions. The authors go on further to identify collision prone, or hazardous, locations using existing data and an Empirical Bayes (EB) adjustment to define such locations at a certain confidence level. (For the example above, they derive a value of 11.9 collisions/five years as being a value needed to be observed to consider that section of highway as being collision-prone). The study also evaluated the measure of effectiveness of site-

specific safety modifications using before-and-after collision rates and the EB method to avoid regression to the mean bias.

Using broadly the same techniques, the US Highway Safety Manual (HSM), has developed a Crash Prediction Methodology (CPM) and methods to identify collision prone sites and to measure the effectiveness of remedial measures (AASHTO, 2010). The recommended general equation for predicting crashes is:

$$N_{\text{predicted}} = N_{\text{spfx}} \times (\text{CMF}_{1x} \times \text{CMF}_{2x} \times \dots \times \text{CMF}_{yx}) \times C_x \quad (6)$$

Where:

$N_{\text{predicted}}$ = predicted average crash frequency for a specific year for site type x;

N_{spfx} = predicted average crash frequency for base conditions of the Safety Performance Function (SPF) developed for site type x;

CMF_{1x} = crash modification factors specific to site type x and specific geometric design and traffic control features y

C_x = calibration factor to adjust SPF for local conditions for site type x.

Safety Performance Functions are equations that estimate expected average crash frequencies as a function of various road characteristics such as traffic volumes, number of lanes etc.

With the incorporation of CPMs in the HSM, their use is expected to become the foundation of safety practices for many road authorities.

Using Elvik's (2008) analysis of the Empirical Bayes method to evaluate 'before and after' situations in Finland, Peltola (2009) outlined three different crash prediction models - a '*Complicated Model*', a '*Pre-set Model*' and a '*Simple Model*'.

These are described by the following:

$$E = 0.156 \times A_1 \times A_2 \times A_3 \times A_4 \times A_5 \times A_6 \times \text{Mileage} \quad (7)$$

where E is the expected number of injury accidents per year, A1 is a factor dependent on speed, A2 is a factor dependent on street lighting, A3 is a factor dependent on sight distance, A4 is a factor dependent on per cent heavy vehicles, A5 is a factor based on the number of intersections per kilometre and A6 is based on the width of pavement.

$$E = 0.1315 \times B_1 \times B_2 \times B_3 \times B_4 \times B_5 \times B_6 \times \text{Mileage} \quad (8)$$

Where B1 – B6 are based on the same categories as A1-A6 but are developed with pre-set effect of '*important factors*' based on before and after studies.

$$E = 0.0173 \times \text{Mileage} \quad (9)$$

Peltola's study (2009) compared the three models using previous crash data for vehicles on paved rural roads outside junctions. His main conclusions from this study were that the number of crashes during one year cannot be predicted well; that motor vehicle mileage is the main explanatory variable; and that the simple model is just as good as the complicated model; however, this does rely on an accurate assessment of miles travelled.

The field of predictive modelling also extends to the efficiency assessment of road safety measures (see for example OECD, 2012). In one of many approaches, the European Commission, Perandones

and Ramos (2008), used the approach of road safety audits, infrastructure assessments, black-spot analysis and the like, to develop a Road Safety Index (RSI).

The approach of the RSI is proactive and aimed at preventing future road incidents where road infrastructure might be improved. A web based tool named the 'e-book' is a product of this study - it allows the user to find which type of potential accident can occur in their specific situations and to then find the relative countermeasures.

A number of other techniques to predict safety that appear less frequently than CPMs and the Empirical Bayes method in the literature, include the use of contingency tables, log-linear analysis, logit models, tree-based regression, artificial neural networks, among others. As with the above-mentioned techniques, the majority are developed using their local context and have a reliance on accurate and statistically representative data.

5.6.2 Naturalistic driving and simulators

Naturalistic driving is a fairly recently developed method for investigating driver behaviour and road safety using video cameras and sensors installed in participating vehicles. The participants drive the instrumented vehicles for a period of time with limited or no intervention from investigators. The benefit of naturalistic data is that precise vehicle kinematic data (i.e. acceleration/velocity/position) and driver behaviour and performance (as viewed using continuous video) data is collected. This continuously recorded data for crashes, near-crashes, and normal driving allows for far more sensitive analyses than those conducted using other crash data. While naturalistic driving studies provide unique data, there is a practical limitation to the number of vehicles that can take part and this, in turn, limits the number of actual crashes captured. This number is still far smaller than that available from crash databases or actuarial analyses. Also, when parsing several hundred crashes to answer specific research questions (e.g. analyses investigating driver fatigue in run-off-road crashes), the number of resulting crashes can be quite limited (Guo et al., 2010).

To help overcome this limitation researchers have proposed the use of near-crashes¹⁹ in combination with actual crash events as, by association, near crashes have many of the same characteristics of a crash and should provide insight into the risk associated with driver behaviour and environmental factors in combination with crashes. Using this as a basis for a study from 100 instrumented cars, one of the US DOT's main conclusions was that using near-crashes as surrogates can significantly improve the precision of estimates of crash risk (Guo et al., 2010).

5.6.3 Pedestrian safety estimation

Of equal importance to the overall road safety picture is the reduction of pedestrian fatalities, especially in developing nations. Here, the traditional method again relies on recorded fatalities and the identification of hazardous sections of roads or areas. The techniques used to estimate the potential number of vehicular crashes can similarly be applied to pedestrians, i.e. statistical approaches using before and after data or estimation based on safety assessments such as conflict analysis.

¹⁹ Near-crashes are defined here as: any circumstance that requires a rapid, evasive manoeuvre by the participant vehicle, or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. A rapid, evasive manoeuvre is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities (Guo et al., 2010)

From a comprehensive review of published predictive safety models for pedestrians, the NCHRP (2008a) indicates that the most common form of predictive model uses the negative binomial structure and adopted the following general functional form for its predictions:

$$N_{ped} = \exp(\beta_0 + \beta_1 ADT + \beta_2 PedVol + \beta_3 X_3 \cdots \beta_n X_n) \quad (10)$$

where, $\beta_0 \dots \beta_n$ are coefficients to be estimated. N_{ped} is the expected number of pedestrian crashes, ADT is the Annual Average Daily Traffic, PedVol is the annual average daily pedestrian volume, and $X_3 \cdots X_n$ represent other site characteristics such as proportion of left-turn volume, number of lanes, speed limits, absence/presence of crosswalk and absence/presence of a median.

Collectively, the studies which mainly investigated intersections concluded that an increase in total traffic and pedestrian volumes led to higher pedestrian crashes, but that the relationship between pedestrian volumes and pedestrian crashes was non-linear. From the form of the function, the median type, number of lanes and marked/unmarked crosswalks are also associated with pedestrian crashes (NCHRP, 2008a).

The NCHRP (2008a) study concludes by developing a prediction methodology for vehicle-pedestrian collisions at signalised intersections based on the above-mentioned function with '*Accident Modification Factors*' (AMF). The cited advantage of these predictive models is that they can be readily applied to conventional intersections with minimum data but, on the other hand, their primary weakness is the limitation of the availability of crash data to generate a good model that can explain observed variations.

In another study, Ulfarsson et al. (2010) analysed four years of police-reported crash data from North Carolina, US, using a multi-nomial logit model in a study which allocates fault to vehicle-pedestrian collisions. Their results show that pedestrians are at fault in 59% of crashes, drivers in 32% and both in 9%. This model was used to further break down probable causes in each category. Although the locations and many other factors are dissimilar, these results offer a comparison with the findings reported in Section 3.4.1 for Cape Town (70% of fatalities attributed to speeding and jaywalking (RTMC, 2010), and 61% of all pedestrian fatalities attributed to blood alcohol over the legal limit (Matzopolous, 2005)).

5.7 Surrogate or proximal safety techniques and measures

The usefulness of historical crash data for general work in traffic safety is beyond question - there is a clear need for this type of data to, for example, analyse issues with particular types of infrastructure, engineering measures or different types of road users. However, the use of statistical techniques to predict road safety on the basis of historical data is questionable, especially when there are known data deficiencies such as recording, quality and reliability issues (as shown in Chapter 3). Furthermore, statistical analyses require several years of reliable data in order to reasonably assess impacts which means that they are not really suitable methods to analyse the safety effects of recently implemented infrastructure.

The result of these issues has been a move towards more proactive safety analysis and planning, i.e. analysis that uses observable near-crash traffic events and other surrogate safety data instead of being entirely based on historical accident data. This move has also been prompted by the fact that near-crashes occur far more frequently than crashes and have similar underlying processes, which gives them key advantages for their use in safety analysis. Safety indicators are also a more resource-efficient and ethically appealing alternative for effective safety assessment and the methods available

can be used as a research tool to establish the link between behaviour and risk, and for safety diagnosis (i.e. the problem at a site or series of sites).

Commonly accepted criteria for transport safety applications put forward by Tarko et al. (2009) are that surrogate measures should satisfy two basic conditions: *'(1) A surrogate measure should be based on an observable non-crash event that is physically related in a predictable and reliable way to crashes, and (2) There exists a practical method for converting the non-crash events into corresponding crash frequency and/or severity'*.

The first condition emphasises the crucial aspects of crash surrogacy that enable meeting the second condition: the development of a method of converting the surrogate outcomes into the meaningful outcome – frequency and severity of crashes.

Traffic volume meets the first condition of a good surrogate measure - vehicles must be present on the road for crashes to happen. However, this measure has a limited use as it seldom meets the second condition because, with the exception of traffic calming measures, most safety treatments do not affect traffic volume.

Speed is proposed and used by some authors as a safety surrogate measure. It is an important component of a surrogate event definition, but its use as a standalone surrogate measure may be difficult due to the complexity of the speed-safety relationship. Other surrogate measures of safety proposed include: traffic conflicts, critical events, post-encroachment time, time-integrated time-to-collision, headways, shock-waves and deceleration-to-safety time, with traffic conflicts being the most prevalent measure considered by highway safety engineers (Tarko et al., 2009).

In each of these measures the main analytical concerns surround the lack of a consistent definition (for example: for 'high-risk' or 'near-miss'), predictability and reliability of the surrogate measure with safety outcomes in addition to the physical relationship with safety.

5.7.1 Traffic Conflict Technique

Safety studies using traffic conflicts conducted by Perkins and Harris (1968) identified safety problems related to vehicle construction. The adopted approach - to observe and record unsafe interactions between vehicles, determined by the use of evasive action to avoid a potential collision – is now used as an alternative approach to overcome some of the issues found in the observational traffic safety studies. The potential of this technique was received enthusiastically by researchers in different parts of the world who sought to find ways to establish the relationship between conflicts and crashes.

Safety studies use traffic conflicts not only because they occur more frequently than actual crashes²⁰, but because the mechanism involved in both types of events is reasonably comparable. As a consequence, traffic conflicts are deemed to produce reliable short-term safety studies which address many of the statistical issues linked to the frequency and recording of actual crashes. In addition, such an approach is more inclusive than records of actual crashes since it considers the collision mechanism from a somewhat broader perspective.

The Swedish Traffic Conflict Technique is generally accepted as a de facto standard in many other countries. It defines a conflict as *'an observable situation in which two or more road users approach*

²⁰ In a study by FHWA (FHWA, 2008), it was found that the ration of traffic conflicts to actual crashes was approximately 20,000 to 1.

each other in space and time to such an extent that there is a risk of collision if their movement remains unchanged' (Amundsen and Hydén, 1977). The point at which the evasive action was undertaken determines the point where observers begin to estimate the value of Time-to-Accident (TTA).

TTA is calculated using estimates of speed and distance for vehicles involved made by conflict observers or by video analysis. As the measure is based on the point at which evasive action was undertaken, it does not take driver reaction time into account (see for example Figure 39). The severity of a given traffic conflict is graphically estimated from TTA and speed differential values obtained for the vehicles involved. An illustration of the function separating serious and non-serious conflicts is provided in Figure 40.

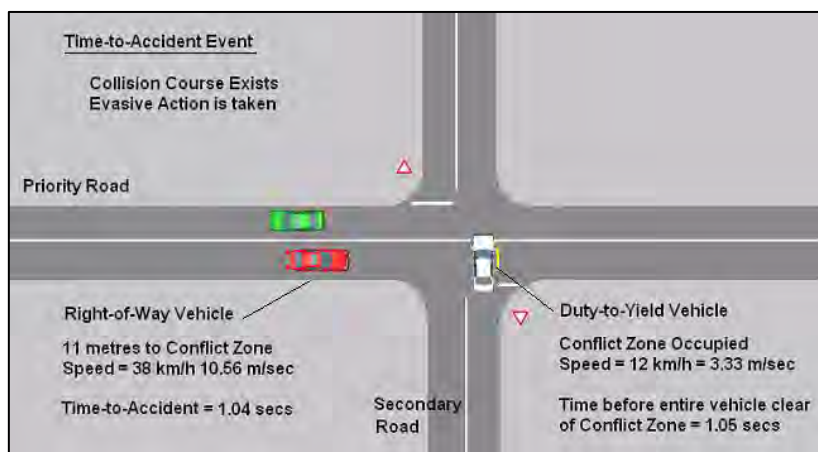


Figure 39: Example of a TTA event
Source: Archer, 2005a

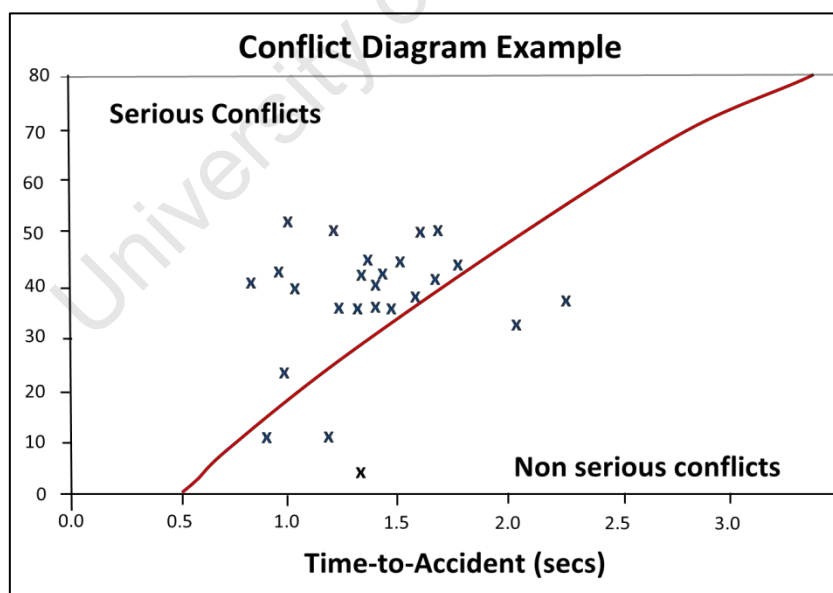


Figure 40: Definition of serious and non-serious conflict events in the Swedish TCT
Source: Archer, 2005a

Despite its extensive development, many national transport research institutes and researchers found reliability and validity questions surrounding the technique (see for example: Archer, 2005a; Chin and Quek, 1997; Cunto, 2008; Hauer and Garder, 1986), which have led to the doubt and scepticism about its potential use for safety assessment. Because of this, a number of different methodologies for the

conflict technique have been proposed by many researchers, however, in the light of the uncertainties identified, Chin and Quek (1997) suggest that it may be a futile and unnecessary exercise to establish a statistically significant relationship to justify the use of the conflict technique, particularly where it is used as a diagnostic and evaluative instrument rather than for crash prediction. This argument emphasises the need for proximal safety indicators, to be useful in their own right without the need for validation against measures of accident occurrence.

While this situation prevails, studies by researchers (see for example: Svensson and Hydén, 2006), have indicated that conflict studies can produce estimates of accident occurrence that are as good as, or better than, those based on accident data (and require a considerably shorter data-collection time-period).

This assertion is supported by a more recent study by Davis et al., (2011), which states that it should be possible to predict the expected number of crashes from a measure of conflict frequency, but that initial difficulties in establishing stable crash versus conflict relationships have led to an interest in grading the severity of conflicts, the hope being that severe conflicts would be more reflective of crashes. The literature contains descriptions of several different methods for grading the severity of non-crash events, which appear to rely, either implicitly or explicitly, on measures of intensity for evasive actions.

5.7.2 Other time based measures

A number of safety performance measures based on the projected time of a potential collision can be found in the literature. The most common of these are: Time-to-Collision (TTC), Time-to-Zebra (TTZ), Post-encroachment Time (PET), Encroachment Time (ET), Initially Attempted Post-encroachment Time (IATP) and Gap Time (GT). These concepts, along with TTA and headways, are investigated in more detail in Appendix C and are briefly reviewed and compared below.

Time-to-Collision

TTC is regarded as a more objectively determined measure of crash proximities when time and speed are determined through the use of video/photometrically determined measures rather than by human observers. Typically, the actual TTC-value used represents the minimum time recorded during the entire interactive process of the safety critical event, rather than the value recorded in the TCT (the time evasive action is first taken). TTC values can vary from infinity (when vehicles are not on a collision course) to minimum safe values (based on an arbitrary scale of danger for near misses) which range between 1 and 1.5 seconds for vehicle-vehicle and vehicle-bicycle near misses (see for example: Van der Horst, 1990 and Archer, 2001). The general TTC definition implies that the reaction time of the road-user is considered, which in some cases may be important with regard to the intention and purpose of safety study (Chin and Quek, 1997).

Obviously, the TTC measure implies the existence of a collision course, i.e., vehicles traveling in the same direction must have a speed differential and, for potential angled crashes, the projected position of conflicting vehicles must overlap at a given time interval.

Two examples showing a typical conflict scenario and the calculation of TTC are shown in Figure 41. Although the calculations are for a specific time interval, they would be made continually at regular time intervals during the course of a safety critical event for the purposes of determining a 'minimum' TTC value.

The severity of a particular TTC event is represented by the time value derived from measures of speed and distance. This is a particular issue of the TTC technique as several combinations of speed and distance can produce the same TTC measure, and yet it is reasonable to assume that situations

with a higher kinetic energy and linear momentum will result in a higher severity crash. The TTC concept may therefore not be a reliable comparative measure of conflict severity. To overcome this problem an additional severity structure, such as vehicle deceleration rate, can be usefully applied.

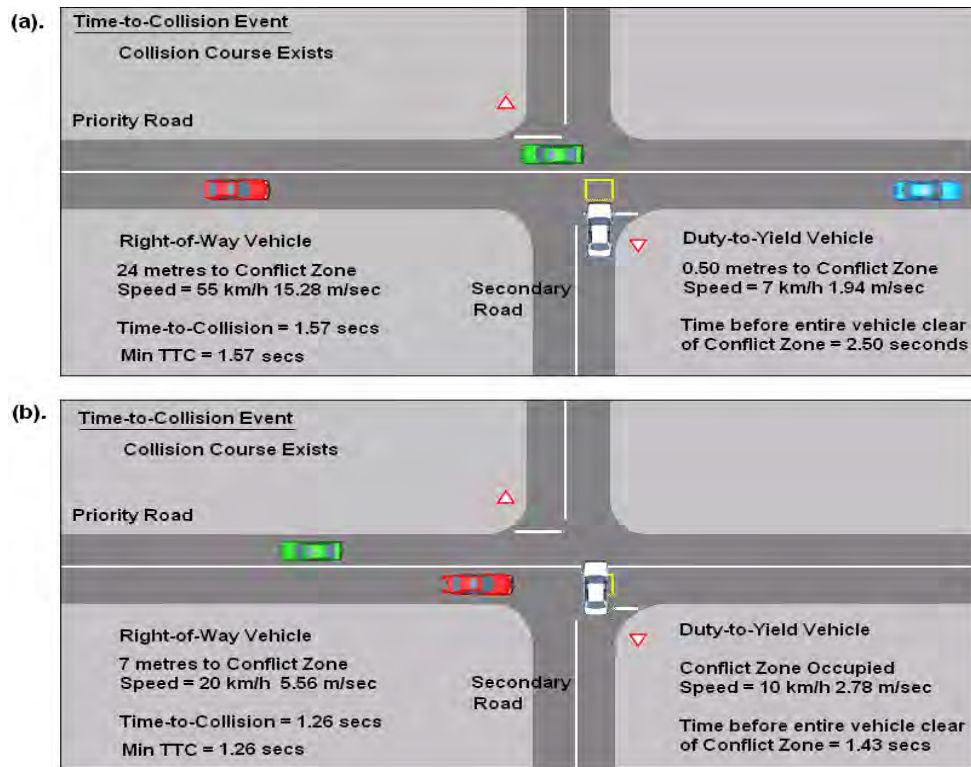


Figure 41: Examples of conflict situations and the calculation of TTC

Source: Archer, 2005a

Time-to-Zebra

The variation of TTC for the purposes of estimating traffic safety at pedestrian (zebra) crossings is referred to as Time-to-Zebra (TTZ). The TTZ value has been used to assess the frequency and severity of critical encounters between vehicles approaching a pedestrian crossing and pedestrians who cross from either the left or right side of the road.

In a study carried out in Sweden, only one out of every four drivers stopped or braked to allow pedestrians to cross, and pedestrians were in many cases forced to actively ‘take’ priority on the crossing (Archer, 2005a)²¹. As a comparison, a study of driver behaviour towards pedestrians at four un-signalised zebra crossings in Cape Town carried out using a ‘step-off’ test to determine whether vehicles responded to the presence of a pedestrian when the pedestrian stepped out onto the crossing found that only 60% of drivers yielded to allow the pedestrian to cross. The results also showed that the yielding occurred mainly at locations where speeds were lower, due to traffic calming or other influences (David, 2006).

Post-Encroachment Time

The concept of TTC requires a collision course. However, when road users just miss each other at high speeds without measurable path or speed changes, there is no collision course, yet there is a chance that a slight disturbance in their course may easily result in a collision. From an analysis of

²¹ These studies were conducted before the pedestrian-crossing reform in Sweden, which now insists that drivers stop to allow waiting pedestrians and cyclists to cross.

both collisions and conflicts collected by time lapse video, Allen et al., (1978) frequently found encounters of this type for left-turns at signalised intersections and concluded that the PET was a promising measure for defining a conflict situation. Figure 42 illustrates the definition of post encroachment time for an angled conflict.

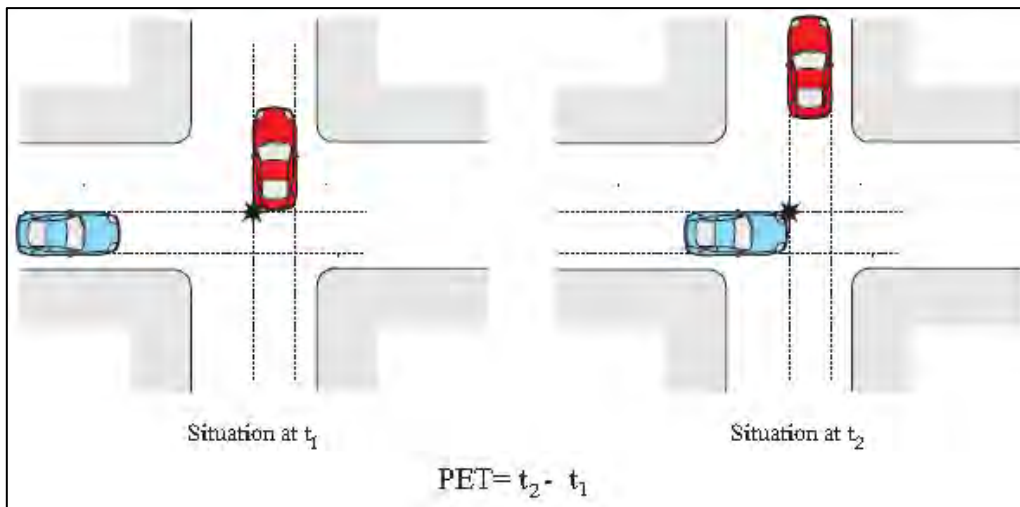


Figure 42: Example of a Post-Encroachment Time event
 Source: Cunto, 2008

Other Measures and Derivatives of Post-Encroachment Time

Other proposed measures defining and characterising a conflict are presented in a report by published by the US FHWA (Gettman and Head, 2003). These measures are primarily defined for left-turn conflict events and are defined in Figure 43 and Appendix C.

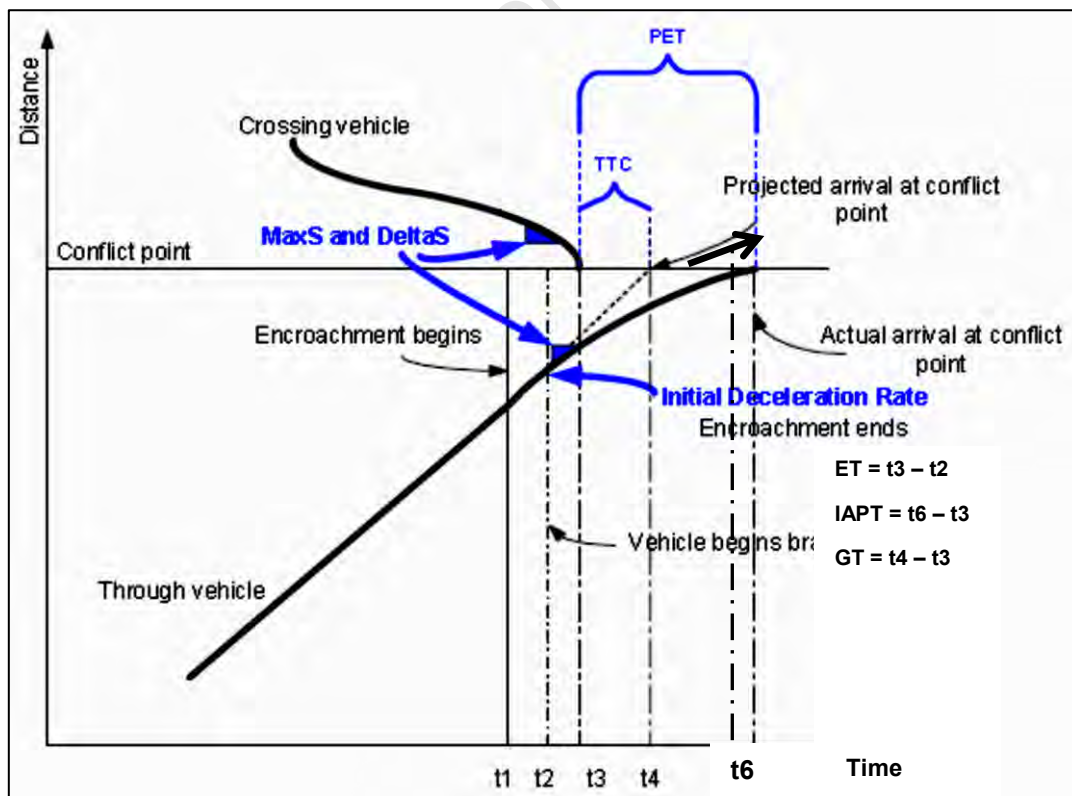


Figure 43: Surrogate measures on conflict point diagram
 Source: Adapted from FHWA, 2003

Summary/ analysis

The size of the conflict measures usually indicates the severity of the conflict event such that lower TTCs indicate higher probability of collision; lower PETs also indicates higher probability of collision; and higher DR indicates higher probability of collision.

Many of these conflict measures require trained field observers, instrumented vehicles or video analysis (see for example: Laureshyn et al., 2010). However, the question as to which measure is appropriate for which situation remains. For example: when is it more appropriate to use TTC rather than PET (Svensson and Carsten, 2007)?

To attempt to answer this question, an evaluation of the relative merits of the conflict measures defined in this section is attached in Appendix C. It is clear from this analysis that most of the measures have their advantages and disadvantages and have different resource requirements. However, given the requirement of trained observers and/or specialised video analysis as well as the likelihood of inter-observer differences in most measures and the need to address the issue of pedestrian safety, the approach taken in this research is to evaluate safety via the use of surrogate measures and measures that conform to the principles of TTC and deceleration through micro-simulation of road-user interaction.

5.8 Traffic simulation models for safety assessment

Traditionally, transport models were developed to support decision-making in the transport planning process which involved forecasting travel patterns at some time in the future for various temporal and spatial application areas. With the recent increases in both computing power and programming skills, a wide variety of models are now available to the transportation profession, ranging from strategic to operational levels of application within fuzzy boundaries and, depending on the assignment technique used, either static or dynamic (see Figure 44) . Their use in safety studies through many measures has increased in the recent past as outlined below.

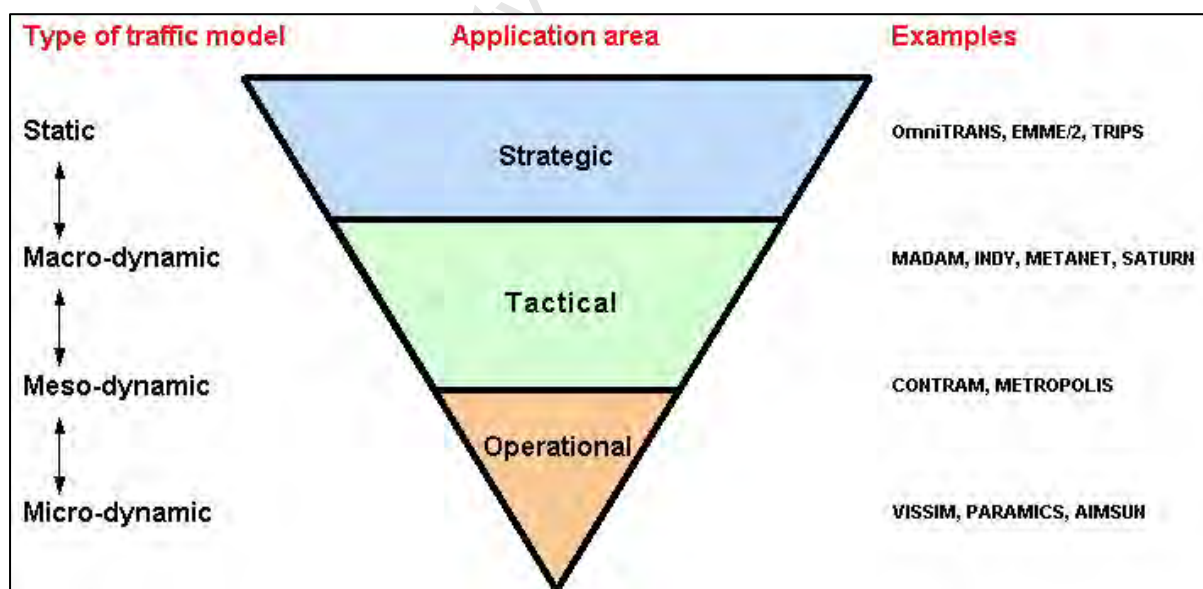


Figure 44: Traffic simulation models - overview of types, application areas and examples

Source: Morsink et al, 2008

Static traffic models describe the interaction between supply and demand of infrastructure and assume a constant supply and demand over time. Static traffic models are based on the classic four-step transport model: trip generation, distribution, modal split and assignment. They are generally used at

strategic level to carry out long-term studies of the effect of mobility measures. Static models can be used to assess the effect of measures on road safety by applying the relationship between exposure and risk. Risk is defined as a crash rate, i.e. the quotient of the number of fatalities, or severe injuries, and the amount of exposure. Exposure is expressed by the number of kilometres travelled.

Dynamic traffic models are typically time propagation models, which calculate the resulting traffic efficiency, reckoning with changes in supply and demand in time. *Macroscopic dynamic traffic models* are usually based on hydrodynamics theories. These models use time of the day as a continuous variable and describe traffic streams moving through a network. *Mesoscopic dynamic traffic models* are often based on gas-kinetics and use aggregate behaviour of individual vehicles and therefore traffic is represented by groups of traffic entities. Like static traffic models, both types of models can be used to assess the effect of measures on road safety by applying the relation between exposure and risk. However, the dynamic assignment offers more options, for example their use in Accident Prediction Models (APM) via the relationship between crashes and characteristics of traffic (e.g. density), traffic behaviour (e.g. speeding) or the infrastructure (e.g. intersection types). Macroscopic and mesoscopic models are situated between static and microscopic dynamic traffic models and are generally used at a tactical level to carry out mid-term studies.

Microscopic traffic simulation models simulate the space-time behaviour of individual road users and their interaction on a fraction of a second basis. The models use characteristics and behaviours of road users combined with infrastructure details, resulting in an overall simulation of the traffic stream within the modelled area. They are extensively used to analyse new and existing traffic facilities, including the performance of new designs before they are implemented. These tools are extremely valuable in analysing the relative performance of one design against another and in the ex-ante calculation of the effects of redistribution of traffic across networks.

In terms of measurement of safety, as the normal use of microscopic simulation models is for traffic efficiency, the models provide little guidance to analysts with regards to safety. However, because statistical models based on historical data are not always able to consider the interaction between crash causation factors which are influential in determining the overall level of safety at a particular traffic facility, commercial software vendors as well as researchers have become aware of the possibility of the use of microscopic traffic simulation models in safety analysis. Furthermore, current commercial software allows the possibility of tailoring models to road user situations with high levels of details that encompass most of the factors that have direct or indirect influence on safety.

Despite these possibilities, the main use of microscopic traffic simulation models is still for the investigation of and improvements in the efficiency of transport infrastructure. This is reasonable since capacity is the most widely used concept in traffic engineering and the most common objective of transport planning and traffic engineering related analytical models (Akçelik, 2008). More recently, there has been an interest in obtaining traffic system impact related to other objectives, such as environmental issues, and while some existing commercial micro-simulation tools have provided support for environmental issues (such as vehicle emissions to assess the impact of traffic on air-pollution), the issue of traffic safety is seemingly seen as a possible by-product.

Simulation models are also being extensively tested to verify the safety aspects of Intelligent Transport Systems (ITS) such as Advanced Driver Assistance Systems (ADAS), automated speed control systems, Intelligent Speed Assistant (ISA) and the like (Morsink et al., 2008).

That micro-simulation has the potential to provide a useful platform for many different types of evaluative and predictive safety analysis, and represents an alternative to more traditional measures

based on statistical modelling has been confirmed by many researchers (see for example: Cunto, 2008). Models can be also be developed and tested without implementation, and this is the main potential of simulation based methodologies as they can be used as a preliminary form of analysis in the early stages of research, development, and design. Assessment of comparative before-and-after type situations could also be made through simulation studies to establish the effects of alternative safety enhancements or measures in the road environment. In addition, recent developments in pedestrian simulation modelling now mean that the effects of pedestrian-vehicle interactions at various situations can be investigated. Simulation modelling should therefore provide a more holistic approach to the assessment of road-user safety. This potential is investigated in more detail in the following chapters.

University of Cape Town

6 The use of microscopic traffic simulation models in road safety assessment

This chapter provides a detailed review of micro-simulation, its requirements in terms of data, parameter setting, parameters related to road safety and calibration and validation methods. The review also details the recent and emerging field of simulation modelling: pedestrian modelling, which is of particular interest to this study given the number of pedestrian fatalities and the hypothesis formulated. It concludes with a section on the benefits and burdens of using micro-simulation for road safety and reasons why a particular tool was selected.

6.1 Background on modelling detail and possible benefits

The use of traffic simulation models for the study of traffic operations and traffic system impact is becoming commonplace among transportation planners and traffic engineers. Simulation software has become increasingly graphical, detailed and flexible. It is also better documented than it used to be, and easier and more intuitive to use due to rapid advances in programming skills and computing power.

Traffic simulation provides a number of clear advantages over more traditional traffic analysis tools in that it can provide comprehensive results for an entire study area. It allows real-time visualisation that is often valuable as a preliminary form of validation, and it can be tested in a virtual environment before implementation - which is especially appealing in situations where budgets are limited and where geometric and operational changes would be expensive and possibly troublesome.

Although the majority of traffic simulation tools have been developed specifically for traffic performance analysis (where the primary focus is related to capacity), there has been an interest in obtaining traffic system impact-related data for other objectives, such as traffic safety and environmental issues. Most commercial micro-simulation tools provide support for environmental issues (such as emissions), but traffic safety continues to be largely neglected. This lack of safety evaluation measures was identified as a significant deficit in a review of 58 micro-simulation models undertaken several years ago as part of the SMARTTEST²² project funded by the EU (Algers et al., 1997). Later reviews and comparisons have found little progress in this area (see: Bloomberg et al., 2003; Brockfeld et al., 2004; Cunto, 2008; W. Young and Archer, 2010).

Given the scope of the traffic safety problem in terms of fatalities and injuries and their related socio-economic values at the national and international level, this lack of investment and allocation of resources in developing simulation methods, tools and techniques for valid and reliable safety assessment is surprising.

In theory, micro-simulation has the potential to provide a useful platform for many different types of evaluative and predictive safety analysis, and represents an alternative to more traditional measures based on statistical modelling. The main potential of simulation-based methodologies is likely to be preliminary forms of analyses in the early stages of research, development and design as well as in the assessment of comparative before-and-after type scenario studies to establish the effects of safety

²² The SMARTTEST project was directed toward modelling and simulation of dynamic traffic management problems caused by incidents, heavy traffic, accidents, road works and events. The specific deliverable referred to is one which reviewed existing micro-simulation models to identify gaps.

enhancements or safety influencing measures in the roadway environment at specific locations, and in relation to specific road-user groups.

On the downside, a significantly higher level of modelling detail is required for safety assessment than for other traffic system objectives (Archer, 2005b). This is particularly evident as behavioural sub-models describe the interactive processes and provide the simulation output such as: ‘car-following’, ‘gap-acceptance’ and ‘lane-changing’. For safety analysis in particular, the accurate representation of interactive behaviour between road-user entities (e.g. gaps accepted, headways between vehicles) and road-user interaction with the environment (e.g. vehicle and pedestrian speeds, sight distance, etc.) is of critical importance. It is also important to ensure that values of road-user behaviour and vehicle performance are appropriate to the local conditions. These higher levels of modelling fidelity require the collection of more detailed empirical data and demand greater stringency in the processes of model calibration and validation. This makes simulation modelling aimed at safety assessment more complex and resource-demanding than is generally the case in traffic performance and capacity analysis. The questions that must then be addressed are these: are other methods of assessing safety less resource-demanding? Can they be used to produce results of sufficient validity and reliability? Or do micro-simulation models have sufficient benefits to warrant these onerous data requirements?

Statistical models based on historical data are not always able to consider the interaction between crash causation factors influential in determining of the overall level of safety at a particular traffic facility. The use of micro-simulation allows the possibility of ‘tailoring’ a model to meet the specific criteria of an existing real-world traffic situation and to incorporate those factors that have been identified as having a direct or indirect influence on traffic safety (Archer, 2005a).

This includes factors related to:

- differences in vehicle characteristics such as length, weight, engine-power, and acceleration/deceleration;
- differences in behaviours of drivers and pedestrians as well as categories thereof;
- the accurate representation of the base model geometry including control devices, lane markings etc.;
- the interaction between vehicles and other classes of road-users including pedestrians and cyclists; and,
- a good representation of traffic flows, turning movements (origin-destination matrices) and traffic compositions, over time, and specific to link roads (Archer, 2005a).

This list is not exhaustive, although it highlights the level of detail required in micro-simulation modelling. It also indicates the potential types of analyses available for safety estimation at specific traffic facilities. Other useful aspects are the possibility of performing sensitivity analyses based on standard roadway designs where the safety influence of various traffic parameters (such as changes in averages speeds, speed variation or flow-rates) can be estimated. Simulation models can also generate all types of data simultaneously (safety, traffic performance and capacity). This allows the analyst to get a more complete and comprehensive picture of the many different operational effects related to a particular study. Furthermore, as already noted, modelling allows the preliminary testing of the effects of various safety influencing measures in a safe off-line environment.

6.2 Pedestrian simulation modelling

Pedestrians are probably the most vulnerable user group within a road environment and, in many cases, form the largest single road user group. Unlike the rules that govern vehicular traffic within a road environment, there are few formal procedures or rules that govern pedestrian movement, resulting in complex and sometimes chaotic movement. Pedestrians are not restricted to lanes or specific routes; they are restricted only by the physical boundaries around them such as the width of doorways or presence of walkways. The modelling of pedestrian movements, therefore, presents some specific problems not encountered in other forms of transport modelling (Harney, 2002). In open spaces, pedestrian flows conflict from a number of directions. Unidirectional flow requires less perceptual energy from the pedestrian, relative to bi- or multi-directional flows, it is also associated with lower collision probabilities. Opposing flows may use the same 'lanes', and cross traffic can present itself at any time in open spaces. Pedestrians also have a tendency to walk in groups or clusters.

6.2.1 Features of pedestrian movements

The decisions made by, and interactions between, pedestrians are extremely flexible and intelligent processes. To accurately model pedestrian behaviour, the physical features of pedestrian movements such as walking speeds, acceleration, headway, overtaking and queuing must be reproduced. The walking capabilities of pedestrians vary widely. As a percentage of mean speed, pedestrians have a much wider range of desired speeds when compared to drivers (Blue and Adler, 2001). Several studies have been conducted to describe the characteristics of the walking speed of pedestrians. They reason that walking speed depends on age, sex, physical ability, social position (in groups), trip purpose, weather, amount of baggage, gradient of walkway, mixture of flow directions, and the density of pedestrians. Walking speed has also been shown to vary between cities (Harney, 2002).

Acceleration is another area in which pedestrian behaviour varies greatly from that of vehicles. Pedestrians can accelerate very quickly from standstill and can change speed quickly when gaps arrive, manoeuvring through flows more frequently and casually than vehicles can. A range of accelerations must therefore be accounted for in a representative model.

Headway - the time separation between individuals - between pedestrians also varies considerably in comparison to vehicular flows. Due to the multi-directional behaviour of pedestrians, both headway distributions and resulting queuing can be extremely complex.

At the operational level, pedestrian behaviour involves decisions that affect pedestrian walking characteristics such as choosing to walk fast, or slowly, or to stop and wait, and when to cross a street. The decisions at the operational level are affected by the choices made at the tactical and the strategic levels. The strategic decision regarding whether to walk or not can be dependent on the tactical level, for example, the choice of speed and the level of risk-taking in crossing streets, whether signalised or not. These issues are important for the design of urban areas and the traffic facilities within them. This was recognized over 40 years ago by Buchanan et al. (1963), in the classic report '*Traffic in Towns*', in which they define the 'environmental capacity' of a street to be largely represented by the difficulty with which a pedestrian can cross it and the delay that they may face, based on the volume of traffic, the width of the street, and the level of pedestrian activity (Ishaque and Noland, 2008).

Despite these seemingly random and unpredictable features, Helbing et al., (2001) in a study of pedestrian movements state that: '*Although pedestrians have individual preferences, aims, and destinations, the dynamics of pedestrian crowds is surprisingly predictable. Pedestrians can move*

freely only at small pedestrian densities. Otherwise their motion is affected by repulsive interactions with other pedestrians, giving rise to self-organization phenomena. Examples of the resulting patterns of motion are separate lanes of uniform walking direction in crowds of oppositely moving pedestrians or oscillations of the passing direction at bottlenecks' (see Figure 45). This study formed an integral part of a pedestrian 'Social Force' model commonly in use in many simulation models.



Figure 45: Photo of bi-directional pedestrian flow.

Source: Helbing et al., 2001

In a similar study, Usher and Strawderman (2010) found that when travelling in large groups, pedestrians tend to space themselves from each other and obstacles. Pedestrians take into account their familiarity with the surrounding pedestrians, uncertainty of the other's actions and prioritisation of trajectories, when maintaining their distance from other pedestrians.

Densely packed pedestrians travelling in opposite directions - such as in a public transport facility - is how pedestrians automatically form lanes. The number of lanes formed depends on the density of pedestrian traffic and the width of the walkway. The formation of lanes is a result of self-organised pedestrian behaviour. Pedestrians prefer to walk behind another pedestrian rather than making their own path. By joining a travel lane, a pedestrian is able to minimise interactions that require avoidance manoeuvres. This leads to more efficient travel for pedestrians (see for example Helbing et al., 2001 and Usher and Strawderman, 2010). A digital representation of the formation of lanes is depicted in Figure 46.

Usher and Strawderman's (2010) investigations also showed that when pedestrians meet at an intersection, a phenomenon known as striping occurs (see Figure 47). The emergence of stripes allows pedestrians to move through an intersection without the need to stop. Similar to lane formation, striping at intersections maximises travel efficiency by limiting obstructions and increasing average speed.

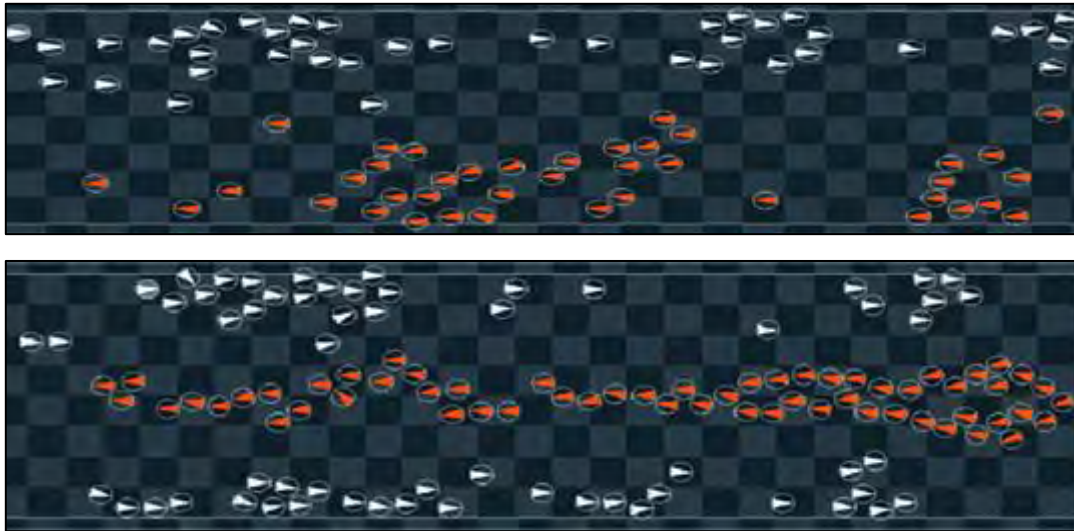


Figure 46: Digital representation of lane formation

Source: Usher and Strawderman, 2010

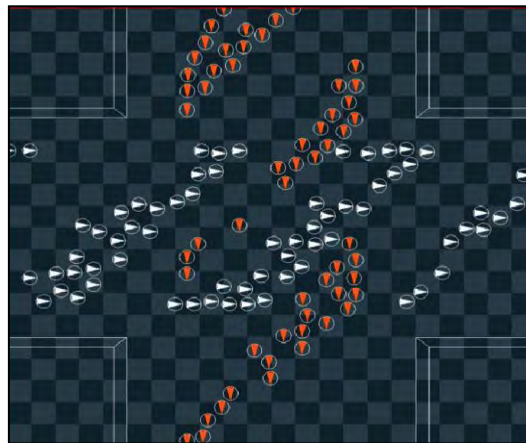


Figure 47: Digital representation of striping

Source: Usher and Strawderman, 2010

6.2.2 Methods used to model pedestrians

The literature shows that a number of methods and types of models have been developed in various disciplines to model pedestrian movements in various settings, ranging from crowd dynamics to buildings and transport scenarios. As with vehicular traffic, pedestrian models fall into the macroscopic, mesoscopic or microscopic groups.

The recent increases in computing power, programming and analytical skills have led to an increase in the range and availability of microscopic pedestrian models. Most models utilise cellular automata, GIS, social force, gas kinetics or agent-based coding techniques.

In a pertinent study in this regard, Papadimitriou et al., (2009) carried out an exhaustive review of pedestrian route choice and crossing behaviour models. In this study, they suggest that the majority of existing models are stochastic and more macroscopic than required, and that they seldom incorporate the interactions between pedestrians and traffic. With regard to existing models on pedestrians crossing behaviour they state that, ‘.although their approach is usually detailed, deterministic and traffic-oriented, they are mainly devoted to a local level behaviour and focus on only one type of all the potential determinants’. With regard to the simulation framework, they say that most researchers

agree (see for example: Dijkstra et al., 2001) that multi-agent simulation is an appropriate technique for pedestrian modelling because of the microscopic and dynamic modelling it offers, the fact that pedestrians can be given a variety of vision, cognition and learning capabilities, the systems can accept detailed rules and that they are in accordance with discrete choice models.

Another critical aspect in relation to simulating pedestrian movement is the definition of how pedestrians interact with vehicles on shared surfaces. Gap acceptance is the normal method of judging safe road crossing - pedestrians will only attempt to cross a road when they are presented with a gap that is at, or greater than, their crossing criterion. From a modelling perspective this can be presented in terms of a critical gap (CG) and can be represented as follows (Yang et al., 2006):

$$CG = \frac{L}{S} + F \quad (11)$$

Where L is the crosswalk length, S is the pedestrian's average walking speed and F is a safety factor that reflects pedestrian aggressiveness. Pedestrians will compare the vehicle gaps and the CG. A gap that is smaller than the CG will be rejected and gaps larger than the CG will be accepted and crossing will occur. In areas where pedestrian-phase traffic lights are not present, this would be the model used. Even in the case when pedestrian phases at traffic lights are available, pedestrians tend to cross when an opportunity presents itself in order to reduce their travel time. This is commonly termed pedestrian compliance and is investigated further in Chapters 7 and 8.

6.3 Micro-simulation programs

Many commercial and academically developed micro-simulation programs currently exist. Commercial products provide regular support and functional improvements as a result of on-going research and development work that is necessary to meet clients' needs, market forces and the ever evolving computing industry. Typical of these types of simulation packages are PARAMICS, VISSIM, AIMSUN and CORSIM. Each one has its own peculiarities and strengths and is usually under constant development, with additional functions and features provided with each new version.

Academically developed and maintained software tends to be used in research environments and often lacks comprehensive support and maintenance as well as regular upgrades. It also tends to be more specific in nature and is generally only used in specialised areas.

Commercial packages have limited functionality, however, in relation to the modelling of road user behaviour (i.e. drivers, pedestrians and cyclists), overtaking on single lane carriageways, the representative modelling of car-following and gap-acceptance behaviour, the modelling of heterogeneous traffic and, more generally, the evaluation of safety and environmental impacts (Archer, 2005; Alcelik and Besley, 2001)

6.4 Reported studies/ state of the art

The first use of simulation models in safety studies is variously attributed to Cooper and Ferguson in 1976 and Darzentias et al. in 1980 (see for example: Cunto, 2008 and Guido et al., 2011). Both studies were carried out using a number of assumption - for example, vehicle types and performances were assumed to be the same. The studies concluded that the conflict rate at three-legged intersections was independent of average vehicle speeds but that conflict severity increased with speed and its standard deviation (in Cunto, 2008).

More recently, Archer and Kosonen (2000) presented an early attempt to investigate the potential use of micro-simulation as a tool for safety assessment through the SINDI project (SINDI is an acronym

for Safety Indicators). Their goals were to evaluate the potential of different safety counter-measures that fall under the umbrella of ITS and possibly develop and adapt the model to safety assessments.. Their research was carried out using a specially adapted version of HUTSIM, a microscopic simulator developed by the Helsinki University of Technology. Although the authors did not conclude the study with any detailed evaluations, they were confident that the project would be useful for such studies.

Archer (2005) focused on the analysis of different proximal safety indicators (TA, TTC and PET) at three T-junctions in the urban and suburban environment in Sweden using commercially available micro-simulation software, VISSIM. He compared the findings of simulation runs to observation techniques using the Swedish TCT. The severity of safety critical events was measured using a 'Required Braking Rate' concept, as shown in Table 6.

The two critical issues in developing the simulation model for his study were the development and calibration of the main priority vehicle time-gaps and the gap acceptance behaviour. The latter was found to be too simplistic in the software²³ and was modified using a probabilistic gap acceptance function.

Apart from the various limitations of the software, a key difference between the field studies observed conflicts in the TCT and the simulation model was that the simulation model required the existence of a collision course whereas the TCT requires road user behaviour suggesting a collision course.

Table 6: Deceleration-to -safety braking levels

Conflict Level	Deceleration-to-safety	Description
No Conflict	Braking rate $\leq 0\text{m/s}^2$	Evasive action not necessary
No Conflict	Braking rate 0 to -1m/s^2	Adaptation necessary
1	Braking rate -1 to -2m/s^2	Reaction necessary
2	Braking rate -2 to -3m/s^2	Considerable reaction necessary
3	Braking rate -3 to -4m/s^2	Heavy reaction necessary
4	Braking rate -4 to -5m/s^2	Emergency reaction necessary

Source: Adapted from Archer, 2005a

In summary Archer's (2005a) findings were: the simulated number of serious conflicts were largely and consistently underestimated with regard to both frequency and required braking rate severity levels in each of the time periods simulated. However, when totalled for all three time periods, the TTC and PET measures showed a high level of consistency with observed data and the numbers of simulated conflicts were sufficient to identify a similar ordering among time periods between observed and simulated results.

Archer (2005a) goes on to suggest modifications to his study, for example additional TTC and PET event data be collected (six hours of data were collected for the study), and that future modelling environments should allow the definition of more flexible vehicle input functions. He also suggested that car-following models should incorporate a suitable level of variation that is not entirely dependent on desired or actual speed levels. He concluded that this type of modelling has considerable and important implications for transport safety work; it has many advantages over traditional diagnostic and analytical tools and that it presents a cost effective and ethically sound, proactive approach to traffic safety.

²³ The author's tests were carried out in 2004/5. It is known that the software has been modified since this date and therefore the gap-acceptance algorithm has probably also been modified and may now be more realistic.

Cunto (2008) investigated potentially unsafe vehicle interactions for different vehicle movements based on three types of traffic behaviour protocols - car-following, lane change and gap acceptance using a microscopic traffic simulation tool (VISSIM). The microscopic model for safety assessment applies a safety performance measure based on pairwise comparisons of spacing and speed differential between adjacent vehicles and individual braking power in real-time, the measure is called a Crash Potential Index (CPI). A *'heuristic calibration/validation procedure'* using factorial analysis is also presented to select best model input parameters for safety performance measurement by using high resolution vehicle tracking data. The ability of the proposed safety performance measure to reflect real-life observed high-risk vehicular interactions was explored in three intuitive tests using observed crash data (temporal variations in CPI/vehicle five minutes before a crash event, a comparison between simulated and recorded traffic attributes and a link between observed crash rates with simulated safety performance for the same periods of time). The results of these tests supported his hypothesis that crashes occur when the CPI/vehicle is higher than normal at the same location.

His final test concerned the usefulness of the model that was used to investigate the safety implications of two different geometric and operational traffic strategies (an intersection in an arterial and sections of freeway). The results of this investigation indicated that the average CPI/vehicle obtained from simulations compared well with observed values from both the intersection and freeway vehicle tracking data.

Bonsall et al. (2005) studied the modelling of safety-related driver behaviour and the impact of simulation model parameter values on the outcomes of various studies. Their paper identifies the key parameters of traffic simulation models and notes that: *'several of them have been derived from theory or informed guesswork rather than observation of real behaviour and that, even where they are based on observations, these may have been conducted in circumstances quite different to those which now apply'*. They undertook tests with the micro-simulation model DRACULA to demonstrate the sensitivity of model predictions to the value of some of the key parameters. They concluded that, in general, it is better to use values that are realistic-but-unsafe than values that are safe-but-unrealistic, although the use of realistic-but-unsafe parameter values could result in the adoption of unsafe designs. They posit that this problem can be overcome by paying attention to the safety aspects of designs.

Morsink et al. (2008) used micro-simulation models to study the road safety impact of Advanced Driver Assistance Systems (ADAS). They reviewed related literature from which they identified driver behaviour sub-models and road safety indicators as the key components. They concluded that micro-simulation adds to other research methods and that it is best used in combination with these methods as part of a wider impact assessment framework for ADAS. For the short term they recommend the use of models in a qualitative way, i.e. showing relevant overall differences between scenarios or conditions, and for the longer term, they recommend further development of models, especially indicators.

In order to remove the vagaries of observer differences in traffic conflict studies, and motivated by the need to assess and manage the safety of traffic facilities more effectively and without years of statistically significant data, Gettman and Head, (2003) undertook a study for the US FHWA that investigated the application of micro-simulation models in safety studies of intersections. The study evaluated the ability of commercially available simulation models to output meaningful measures of safety based on the *'occurrence of conflicts during the simulations'* they also assessed whether the outputs would provide a relative difference in conflicts and severity between distinct infrastructure types for the same level of traffic demand (thus indicating relative levels of safety).

The simulation packages CORSIM, SIMTRAFFIC, VISSIM, HUTSIM, PARAMICS, TEXAS, AIMSUN, WATSIM, and INTEGRATION were each evaluated in terms of five major groups of attributes: general features, behavioural modelling of driver/vehicle interactions, ability to extract detailed data from the simulation, ability to calibrate and select parameters of models and cost to modify source or outputs to support safety performance measures. Among the models tested, none were found to be clearly superior, and most provided the features required for safety studies at a reasonable level of fidelity.

In a follow-on project, Gettman et al. (2008), developed a software tool for deriving surrogate safety measures for traffic facilities from data output by traffic simulation models. This software is referred to as SSAM—an acronym for the Surrogate Safety Assessment Model. The surrogate measures developed in this project are based on the identification, classification, and evaluation of traffic conflicts that occur in the simulation model. By comparing one simulated design case with another, this software allows an analyst to make statistical judgments about the relative safety of the two designs. An open-standard vehicle trajectory data format was designed, and support for this format was added as an output option by four simulation model vendors/developers—PTV (VISSIM), TSS (AIMSUN), Quadstone (PARAMICS), and Rioux Engineering (TEXAS).

Gettman et al. (2008) performed 11 theoretical validation tests to compare the surrogate safety assessment results of pairs of simulated design alternatives. In addition, a field validation exercise was completed to compare the output from SSAM with real-world crash records. The processed conflict results were then compared with the crash records in a number of different statistical validation tests. Lastly, a sensitivity analysis was performed to identify differences between the SSAM-related outputs of each simulation model vendor's system on the same traffic facility designs. Although, once again, none of the models tested was deemed to be superior than the other, a number of issues are highlighted in the report, specifically: the need to improve driver behaviour modelling in the simulation models; the incidences of 'trade-offs' between surrogate measures in their validation exercises (which has led the authors to propose a development of composite 'safety index'); the tendency of the analyses towards less dangerous events; and the need for more conflict classification types.

A final point to note in relation to SSAM is that the focus of their exercise was purely on vehicular interaction and conflicts. Although FHWA's initial report in 2003 acknowledged the fact that pedestrian movement within the road space influences collision rates, their consideration in the software and analysis is missing.

Astarita et al. (2011) developed a micro-simulation model TRITONE to overcome the limitations that many commercial traffic micro-simulation packages presented by not being open source; users were not able to modify simulation procedures and evaluate safety performances. However, the main difference evident from their paper is the possibility of a user-defined car following sub-model from a choice of four. Traffic data is imported into a database via video recordings and, similar to Cunto's (2008) study, safety performance is considered via the measures of Deceleration Rate to Avoid Collision (DRAC) and Maximum Available Deceleration Rate (MADR). The use of the model is demonstrated for a two-lane rural highway in Italy. The authors conclude by recommending that more complex simulation algorithms are needed in models in order to account for a wider range of behavioural attributes related to speed and distance misjudgements, inexperience and motivational factors.

In another study on freeways in Australia, Bevrani and Chung (2011) used the simulation program AIMSUN to test its ability for traffic safety (again vehicular only). They found that their results underestimated almost all of the safety indicators tested compared to observed data. They concluded that *'the level of resolution and realism of current general purpose models needs to be improved.'* They suggested that improvements to current models is required for them to be of greater use for safety studies, especially the Car Following sub-model which, in general, they felt needed to better emulate driver behaviour and its variations.

In contrast to the study above, Yang and Ozbay (2011), developed a stochastic and gradient-based calibration approach to be able to identify optimal input parameters as calibration based solely on safety criteria can be in conflict with other operational performance criteria. Their results show that the fine-tuning of parameters can greatly improve the performance of simulation models to describe traffic conflict risk, as well as the operational measures observed from field data.

Pirdavani et al. (2010) introduced a micro-level behavioural approach for estimating the crash potential at un-signalised intersections for different conditions using the proximal safety indicator of PET. Their results demonstrate the sensitivity of PET to changes in the speed limits on roads and show that PET can be used to carry out safety evaluations of uncontrolled intersections.

Although many studies have dealt with the behaviour and movement of pedestrians at intersections and/or crossing locations, they have done so using gap acceptance models, levels-of-service, discrete choice models and the like. Only a few studies have attempted to simulate road safety issues involving vehicle-pedestrian interaction, possibly because of the complexities involved in accurately modelling pedestrians. Doniec et al., (2008), used the simulation tool ARCHISIM to model pedestrian movements at intersections and roundabouts, while dealing with several issues involving multi-agent simulation.

Yang et al. (2006) proposed a micro-simulation model of pedestrians' crossing behaviour, compliance and gap acceptance that includes the effect of the presence of police officers, other pedestrians and vehicles. It represents the behaviour of two types of pedestrians (law-obeying ones and opportunistic ones, with the possibility of shifting from one group to the other (under specific conditions) when facing a red light at a junction. The model was calibrated on the basis of questionnaire responses and video recordings of pedestrians in China, and was validated on the basis of further video recordings. However, the effects of the various crossing behaviour determinants were not statistically quantified.

Ishaque and Noland (2007), studied the effects of signal cycle timings on delay and travel time costs for both pedestrians and vehicles to examine the cost trade-offs between them using the VISSIM simulation tool. Although the study is not specifically aimed at a safety analysis, it suggests that signal timing policy is solely based on vehicular traffic efficiency and that this could be the cause of some non-compliant pedestrian crossing behaviour. Although safety aspects have not been considered in their analysis, they argue that one way of improving pedestrian safety is to consider pedestrians as a unit of traffic in the implementation of traffic control measures and in the design of traffic management systems by incorporating this fact into practice.

From these reviews it can be seen that microscopic traffic simulation models have the potential to account for and to measure important factors that influence crash occurrences including different behavioural aspects of drivers and individual pair-wise vehicular interactions. However, it is evident that to date, there have been few attempts to include the more vulnerable road users in any of these studies, or to link simulation modelling to the more straightforward safety surrogates of speed and

volume by testing the interaction between road users on safety-related infrastructure measures like traffic calming devices. Studies such as these should provide a platform for the development of more holistic safety assessments that apply a mechanistic, rather than observational, microscopic approaches to evaluate the relative safety of infrastructure.

6.5 Safety related parameters and modelling principles

In general, driver behaviour is determined in traffic simulation models via sub-models representing car-following, gap-acceptance, and lane-changing behaviour, as well as behaviour related to traffic regulation compliance. Recent changes to many simulation models specifically designed for mixed traffic scenarios, mean that similar sub-models exist to simulate the behaviour of pedestrians as well as their interaction with vehicles. These sub-models are, in turn, dependent upon parameters that encapsulate the relevant aspects of road user behaviours through variable values, their structures, and the relationships between them. The values and their inter-relationships are central to the concept of safety-related simulation modelling and therefore fundamental to the work in this thesis.

A general description of the main safety related behavioural sub-models commonly used in micro-simulation and the values typically adopted for parameters defining them are described in the following sections and summarised in Table 7.

In preparing this table, due cognisance was taken of a widely quoted paper by Bonsall et al. (2005), where the underlying assumptions made by many micro-simulation software programs are investigated with regard to road-user behaviour and the effect that parameters have on traffic safety. In this paper, they state that *'most of the parameters used in micro-simulation models have implications for safety - even a parameter as seemingly neutral as the simulation interval will have an impact on safety if, as is commonly the case, it effectively defines the drivers reaction time'*.

6.5.1 Car-following

Car-following models are of particular interest to traffic safety as they represent the longitudinal interaction among vehicles in a single stream of traffic. The speed of the following vehicle is assumed to respond to stimulus from the vehicle or vehicles in front. The stimulus is usually represented in terms of distance and speed differences. Close following is a common factor in rear-end collisions and determines the distribution of gaps in traffic streams.

Some authors reserve the term 'car-following' exclusively for the preceding/following situation while others extend it to cover anything related to the longitudinal progress of vehicles (thus including the determination of free-flow speeds, acceleration and deceleration profiles and response to traffic signals). In a simulation model developed for safety assessment, such distinctions or variety of forms for car-following models are not important, the concern is that model parameters are based on observed values where possible and that definable parameters are quantified to enable a match to local conditions. Taking the broadest definition of the car-following model, the main parameters used in the models are defined as follows.

6.5.1.1 Desired speed or speed limits

Desired speeds of drivers are generally input parameters and are often directly made equal to the free-flow speeds on the road. They will vary according to the character of the road. For example, a dual-carriageway road may lead to higher free-flow speeds than residential streets will. In city-centre streets, pedestrians, intersections and volumes will force down the free-flow speeds, as would excessive curvature or gradient. Speed limits are used as a proxy for free-flow speeds.

6.5.1.2 *Desired or target headway*

Car-following algorithms generally use a specified minimum or target headway that a following vehicle wishes to keep. This is usually represented as a time gap for ease of specification. When the following and the lead vehicle driver are at the same speed, the time headway represents the time available to the driver of the following vehicle to reach the same level of deceleration as the lead vehicle in case it brakes. This available time is independent of speed. Typical values for various models are between 1 and 2 seconds time headway (see Table 7).

Some models, for example, PARAMICS and CORSIM, recognise various categories of driver 'aggressiveness' and 'awareness' according to driving style (the more aggressive, the smaller the gap between vehicles, or more rapid acceleration/deceleration). In PARAMICS, this characteristic is specified by an overall mean target headway measured in seconds. This value will not necessarily be equal to the mean measured headway - the relationship between target and actual headways depends on traffic flow levels, driver behaviour and several other factors. The proportion of drivers in each 'aggressiveness' category can be based on empirical evidence and can be adjusted as part of the model calibration process to reproduce aggregate values of measurements such as average speeds or flows (see Section 6.5.2.1).

6.5.1.3 *Driver reaction time*

Driver reaction time is a key dimension in both car-following and lane-changing models. It represents the driver's ability to react to situations, such as changes in preceding vehicle speeds or the presence of pedestrians and make particular decisions. Typical values range from 0.8 to 3.0 seconds for individual drivers.

6.5.1.4 *Normal and maximum acceleration/deceleration*

The application of normal and maximum acceleration or deceleration varies according to the situation present during the driving task. Values are specified at the start of a simulation and are applied accordingly. Clearly, they vary between vehicle type and can be modified to suit site specific characteristics in models. Typical values from the literature are shown in Table 7 and are investigated in more detail in section 7.5.5.

6.5.2 **Gap-acceptance**

Gap-acceptance behaviour of road-users represents the process by which they find an acceptable gap in a traffic stream when they want to cross or merge. Gaps are fundamental in representing conflicts between high and low priority flows, in determining how a vehicle or cycle from a low priority flow will cross or merge into a higher priority flow and, how a pedestrian crosses the road. Gap acceptance models are also used to deal with aspects such as overtaking which involves use of the opposing carriageway (how much of a gap in the opposing flow is required), lane-changing (how much of a gap in the traffic using the intended lane is required), and uncontrolled pedestrian movements (how much of a gap in the traffic flow a pedestrian will require before attempting to cross a carriageway).

Gaps are usually represented in time units. The key parameters for gap-acceptance models are as follows.

Table 7: Safety related parameters commonly included in traffic simulation models

Sub-model (s)	Parameter	Type	Notes	Typical values
Car-following	Desired speed	Behavioural and policy	Generally link-specific, should reflect the speed limit, the road layout and frontage and the amount of pedestrian activity	Legal speed limit; Speed of vehicles that have headways >6s
Car-following	Desired headway	Behavioural	May be expressed in units of time or distance	1.5-2.5s; 2.12s 5.96s for truck; 6.5m
Car-following	Reaction time (s)	Physiological	May not be explicitly represented (may be inherent in the simulation interval)	0.57-3.0s
Car-following	Rate of acceleration (m/s^2)	Behavioural (constrained by vehicle performance)	May distinguish between normal rate of acceleration and maximum rate of acceleration, may differ depending on vehicle type	1.5-3.6 (max); 0.9-1.5 (normal) 1.2-1.6 (buses)
Car-following	Rate of deceleration (m/s^2)	Behavioural (constrained by vehicle performance)	May distinguish between normal deceleration and emergency braking, may differ by vehicle type	1.5-2.4 (emergency) 0.9-1.5 (normal) 3.0 (theoretical)
Car-following	Critical gap (s)	Behavioural	From the back of one vehicle in the target stream to the front of the following vehicle in that stream	3.5-8.5
Car-following	Stimulus required to induce use of the reduced gap	Behavioural	Time spent waiting for acceptable gap or number of rejected gaps	Various
Gap acceptance	Minimum gap (s)	Behavioural		1.0
Gap acceptance	Willingness to create gaps to assist other vehicles to merge, cross or change lanes	Behavioural	May be expressed as a percentage of the priority traffic stream who stop accelerating or even start decelerating once they "see" a vehicle attempting to merge, cross or enter the lane	20% if the other vehicle is a car, 70% if the other vehicle is a bus
Lane changing	Rules for mandatory lane change	Behavioural and political	May simply reflect traffic regulations but may vary depending on enforcement policy	Various
Lane changing	How far ahead the driver anticipates the need to change lanes	Behavioural and policy	The behavioural element may be constrained by sight lines, etc.	1 to 2 links or 500m
Lane changing	Minimum acceptable gap when changing lanes	Behavioural	As in gap-acceptance model	As gap acceptance model
Lane changing	Variation in the gap depending on the urgency of the desire to change lanes	Behavioural	May depend on size of time advantage or distance remaining before mandatory change must be completed	50-100m 5-10s
Lane changing	Willingness to create gaps to assist other vehicles to change lanes	Behavioural	May be expressed as a percentage of the traffic in the target lane who stop accelerating/start decelerating once they "see" a vehicle attempting to enter the lane	20% if the other vehicle is a car. 70% if the other vehicle is a bus
Varies/ pedestrian	Level of compliance of drivers and pedestrians	Behavioural and policy	May vary for different types of regulation. Should vary depending on enforcement policy	50-100%
Car following/ pedestrian	Distribution of aggressiveness	Behavioural	The proportion of drivers of several pre-set categories	n/a.
Pedestrian	Base walking speed	Behavioural	Base or 'crowd' speed, varies between areas and regions	Average: 1.2m/s
Pedestrian	Walking speed deviation	Behavioural	Deviation from base speed for individuals or groups or for event type situations	n/a
Pedestrian	Scan area	Behavioural	Area that is scanned by agents for wayfinding, interest points and for crossing	n/a

Source: Adapted from Bonsall et al., 2005

6.5.2.1 *Critical gap*

Micro-simulation models typically use the concept of a critical gap value which is usually defined as a gap that a driver or pedestrian will accept in the traffic stream to contemplate his intended manoeuvre as long as the gap is longer than the critical gap. The use of a fixed value will clearly have implications for capacity and may cause underestimations. As with the car-following behaviour, it is unlikely that such deterministic behaviour is representative of actual behaviour. It is therefore modelled in DRACULA, and some other models, as a random variable drawn from an assumed probability density distribution of critical gaps (Bonsall et al., 2005).

6.5.2.2 *Gap-reduction, minimum gap and 'gap-creation'*

Given the individual differences in the qualitative estimation of safe gaps, models could use a fixed value for each driver, or allow critical gaps to be situation-dependent in order to reflect the phenomenon of impatient drivers. This would allow some drivers to accept a shorter gap and others slightly longer gaps with the majority closely distributed around the central 'critical' gap. However, the critical gap cannot decrease infinitely, hence a minimum gap needs to be set as a lower boundary. Additionally VISSIM, for example, allows for 'considerate' driving styles where gaps are created in traffic streams to allow other drivers to merge.

6.5.3 **Lane-changing models**

Lane-changing models in most micro-simulation packages are currently limited to multi-lane roads (Archer, 2005b). They consider the individual driver's desire and ability to change lanes. A desire to change lanes will reflect the advantage to be gained (from an increase in speed or an avoidance of delay) or the need to do so (in order to comply with a traffic regulation, to avoid an incident in the current lane, or to prepare for a turning movement). The intention to make a lane-change may be triggered when the time advantage to be gained by changing lanes exceeds the current value. Some models may allow drivers to anticipate the need for a change of lane, in which case a parameter will be required to determine how far ahead the drivers anticipate. The ability to change lanes will be a function of the lane space available and the relative speeds and locations of surrounding vehicles and is generally modelled in a way that is analogous to a gap-acceptance model. The parameters controlling this function include the minimum acceptable gap in the target lane, together with parameters which allow for variation in the gap (Bonsall et al., 2005).

Modelling lane-changing behaviour is a complex decision-making analysis process, due to questions involving discretionary and mandatory lane changes, the effects of gaps, the anticipation of gaps, the urgency of the manoeuvre, tendencies to keep to certain lanes, compliance levels and so on. The modelling of urban networks and isolated intersections therefore generally lacks this potentially unsafe form of behaviour. Similarly, problems related to the process of parking and parked vehicles on urban link roads are rarely modelled.

It appears that there is no universally accepted structure for this process; each model or package has a unique list of lane-changing reasons and a unique structure for the decision-making process. Once a lane-changing intention is triggered, a gap-acceptance model is used to find the gaps in the target lane that are acceptable to the driver wishing to change lanes. The parameters considered here are front gap and rear gap (lag) in the traffic stream of the target lane, and the critical gap acceptable to the driver. The parameters in the gap-acceptance models for lane-changing situations are similar to those for gap-acceptance described above (Bonsall et al., 2005).

6.5.4 Adherence to regulations

Adherence to regulations is rarely introduced into models except via assumed levels of compliance which may differ for various types of regulation and should, ideally be treated as variables reflecting different levels of enforcement.

For red-light violations, some simulation models have built-in probability functions, such as a 'reaction-to-amber' function, that can be used to define stop or go behaviour when faced with the onset of amber while in a potential dilemma zone situation. This type of probability function is usually based on empirical measures of vehicle speed and distance in relation to the signalled stop line (Archer, 2005b).

6.5.5 Pedestrian parameters

As with vehicular parameters, most of the parameters used to simulate pedestrians and their movement through the network have implications on safety especially when there is an interaction with vehicles, particularly, when road space is defined as being 'shared'. In PARAMICS, pedestrians are simulated through a sub-model which allows the specification of parameters which affect movement through walking speeds, behaviour and manoeuvres. As many of these parameters cannot be empirically measured, they require user assessment for local conditions and a rigorous calibration procedure to ensure that values are optimised and simulations reflect real-world observations. A detailed analysis of these parameters using PARAMICS is presented for two local case studies in Chapter 8.

6.5.6 Other variables which affect safety

Besides the behavioural sub-models that can be applied to different road-users, there are many other important variables used in simulation models that have an influence on safety. Many of these are obvious given that they have been recognised as safety influencing factors in the literature (see Chapter 5).

6.5.6.1 Speed and speed variation

Speed and its variance are of huge significance to safety and its modelling. Desired speed is essentially an individual (behavioural) attribute that is often assigned randomly to drivers from an observed or hypothesised distribution based on the related road speed limit. Some micro-simulation modelling environments (such as PARAMICS) allow the user to define a distribution of desired speeds (via link speeds for example), occasionally in relation to particular stretches of the road or network areas, or in relation to different road-users (via acceleration profiles).

Essentially, desired speed represents the speed at which drivers will travel if they are not restricted by other road-users, restrictive objects in the roadway, or various forms of traffic regulation. The distributions of desired speed used in simulation models are ideally based on empirical measurements that reflect speed in free-flow conditions.

Simulation models can measure the effects of desired speeds/target headways at particular points which can be compared to observed field values. For simulation models aimed at studying safety, attention to detail with regard to different measures of speed is a particularly critical issue (according to the theory presented, an increase in average speed shows a tendency to increase the severity of crashes and an increase in speed variation may cause an increase in the number of safety critical events).

6.5.6.2 Traffic flows

The relationship between traffic flow and its influence on safety has been described in Section 5.5.2. It is generally assumed that elevated traffic volume increases the risk for crash involvement by increasing levels of exposure, and by placing higher demands on road-user interactions. At intersections in particular, greater volumes of traffic on the primary road make the process of gap-acceptance more difficult. However, it is also true that greater traffic demand and higher flow rates reduce average speed thereby resulting in less severe crashes, where and when they actually do occur. This is also suggested by the statistics in and around the City of Cape Town (CoCT, 2005), which show higher numbers of police reported crashes (and therefore elevated crash risk levels for drivers) during the morning and afternoon peak hours when the traffic flows are at their highest.

A further issue of relevance is that traffic demands, compositions and turning proportions are accurate and are made to vary in accordance with time to capture an appropriate level of detail.

6.5.6.3 Simulation time resolution

In any discrete time-based computer simulation, the time step must be less than the time for some significant action to occur, preferably, considerably less. A suitable simulation time resolution is therefore one that can capture the interaction between vehicles and also to allow for the dynamic feedback loops to inform drivers of possible delays in their chosen routes.

6.5.6.4 Vehicle performance characteristics

Simulation models generally allow the specification of a number of different vehicle types, classes and performance characteristics. Amongst others, these include: maximum acceleration and deceleration, power and physical dimensions. These characteristics have an influence on safety, and their accurate specification in terms of representative variation between vehicles is vital to achieve realistic simulations.

6.5.7 Implications of choice of parameter values on safety

The previous sections have highlighted some of the key safety-related parameters in simulation models and have illustrated the effect that choice of parameter values can have on system performance from a safety perspective. The values of parameters should be as realistic as possible in order to meet calibration and validation tests. However, as can be seen from the calibration exercise, the process of paring down parameters to key ones with optimal values is complex, and can lead to errors in some parts of the system despite achieving calibration targets.

Errors in parameters reflecting fundamentals of human physiology or of the performance of vehicles or system components can have serious implications for the design of system components such as sight lines or inter-greens. For example, an over-optimistic assumption about driver reaction time or vehicle braking performance will lead to overestimation of the operational performance (defined in terms of flows and journey times) and of the inherent safety of the system. Pessimistic assumptions will lead to similar underestimations.

Overestimation of operational performance may lead to the adoption of unsafe or inefficient designs; underestimation of performance may lead to over-specification of the design; and, as a consequence of this, perhaps to fewer projects being built. From this, it seems reasonable to conclude that the analyst should err on the side of underestimating the capabilities of drivers, their vehicles and other system components.

For parameters reflecting enforcement or behaviour the situation is much more complex because the consequences of using the wrong parameter value will depend on the way that the model is being used. This complexity results from the fact that a given error in the parameter value will affect the predictions of operational performance in the opposite direction. For example, if the assumed adherence to speed limits is too low the model will over-estimate the operational performance of the system whereas if the assumed adherence to speed limits is too high the model will under-estimate the operational performance of the system.

In a study of safety-related driving behaviour, Bonsall et al. (2005) conclude that there is a general tendency to use 'unrealistically safe' parameter values, which result in an underestimation of system performance but provides an overestimate of its safety - the use of unsafe but realistic parameter values will have the opposite effect. They continue to state that a fundamental contributor to the problems above is the concentration on indicators of operational performance and the failure to consider indicators of safety, but that this is difficult to avoid as models do not produce any indicators of safety. However, as crashes are rare and unpredictable events, their prediction is only practically useful if they are extracted from thousands of days' worth of computing and in the form of probability rather than from singular events. This would require an enormous amount of computing in a relatively short time - which is not possible at the moment. Bonsall and colleagues therefore advise the consideration of proximal safety indicators such as TTC or 'near miss' scenarios, derived from the number of occurrences of emergency braking, very low headways or very short gaps.

6.6 Model calibration and validation

6.6.1 Overview

The aim of all transport simulation models is to create a representation of the road network, in which drivers (and possibly, pedestrians) move with a single-minded goal of reaching their destination as efficiently as possible, whilst obeying the rules of the road (as set by the model) and interacting safely with each other in the network.

Building a transport model begins with the scope of the study and its area followed by a number of key requirements. Amongst others these are:

- The geometric layout of the traffic site including the correct width of lanes, traffic islands etc., and the precise positioning of stop and yield lines;
- The accurate representation of traffic signal control strategies including vehicle actuated signalling and co-ordinated signalling;
- The representation of traffic flows, turning movements and traffic compositions over time and specific to link roads either by origin-destination matrices or observed counts;
- Speeds specific to link roads, turning manoeuvres, and speed influencing objects (e.g. speed signs, speed humps etc.);
- Vehicle composition and differences in vehicle characteristics between and within specific vehicle classes and types (e.g. length, weight, engine-power, braking and acceleration ability, power-to-weight ratios, etc.);
- Pedestrian composition and characteristics

In addition, some characteristics that help define the working model prior to calibration need to be collected or defined. Simulation models aimed at a level of analysis broader than traffic capacity or efficiency require a higher level of modelling fidelity and the collection of suitably detailed empirical data, as well as greater stringency in the overall process. For example, parameters related to road user

behaviour and detailed vehicle characteristics, which would be required for safety assessments, are difficult to collect from the field; consequently, the analyst needs to assess these values.

In simulation models, calibration is defined as the process of adjusting the parameters used in the model to ensure that it accurately reflects input data. The subsequent process of validation is to run an independent check on the calibrated model. Two sets of observed data are therefore required during the model development process. One is used to calibrate the model by adjusting the parameters to ensure that the output matches observed data, and the second is used to verify that the aspects of the performance of the calibrated model are in agreement to the set of observed data (Sykes, 2010). Micro-simulation models that have not been properly calibrated can produce unrealistic or misleading results. For example, tests of six different software packages found differences of 13% in simulated freeway speeds for existing conditions and 69% for future forecast traffic (Bloomberg et al., 2003).

Calibration of models is also necessary because no single model can contain all the necessary variables that affect real-world traffic conditions or replicate local conditions everywhere. Every model must be adapted to local conditions (Dowling et al., 2004).

All micro-simulation models contain many adjustable parameters. The relevant adjustments vary for each software package. If a model fails to achieve calibration targets, it is essential to verify that the right parameters are modified to correct the situation. However, the transportation profession has not yet established any formally accepted or consistent guidelines for the calibration of these models.

Calibration is performed after the base model has been developed and checked for errors. However, prior to this, it is usual to conduct multiple runs with the base model and its default values of adjustable, un-assessed parameters, as it is possible that this model may provide an acceptable result. Multiple runs have to be carried out to obtain results that would provide a representative output for comparison with observed data. The number of runs is statistically determined from estimating a standard deviation and selecting an appropriate confidence level, usually between 90-95% (Dowling et al., 2004). The acceptability of the base model can then be determined by either a histogram plot of single parameters or X-Y bivariate plots, again using appropriate confidence limits. Usually the base model with default parameters does not provide an acceptable match with field observations and the simplified procedure illustrated in Figure 48 needs to be followed.

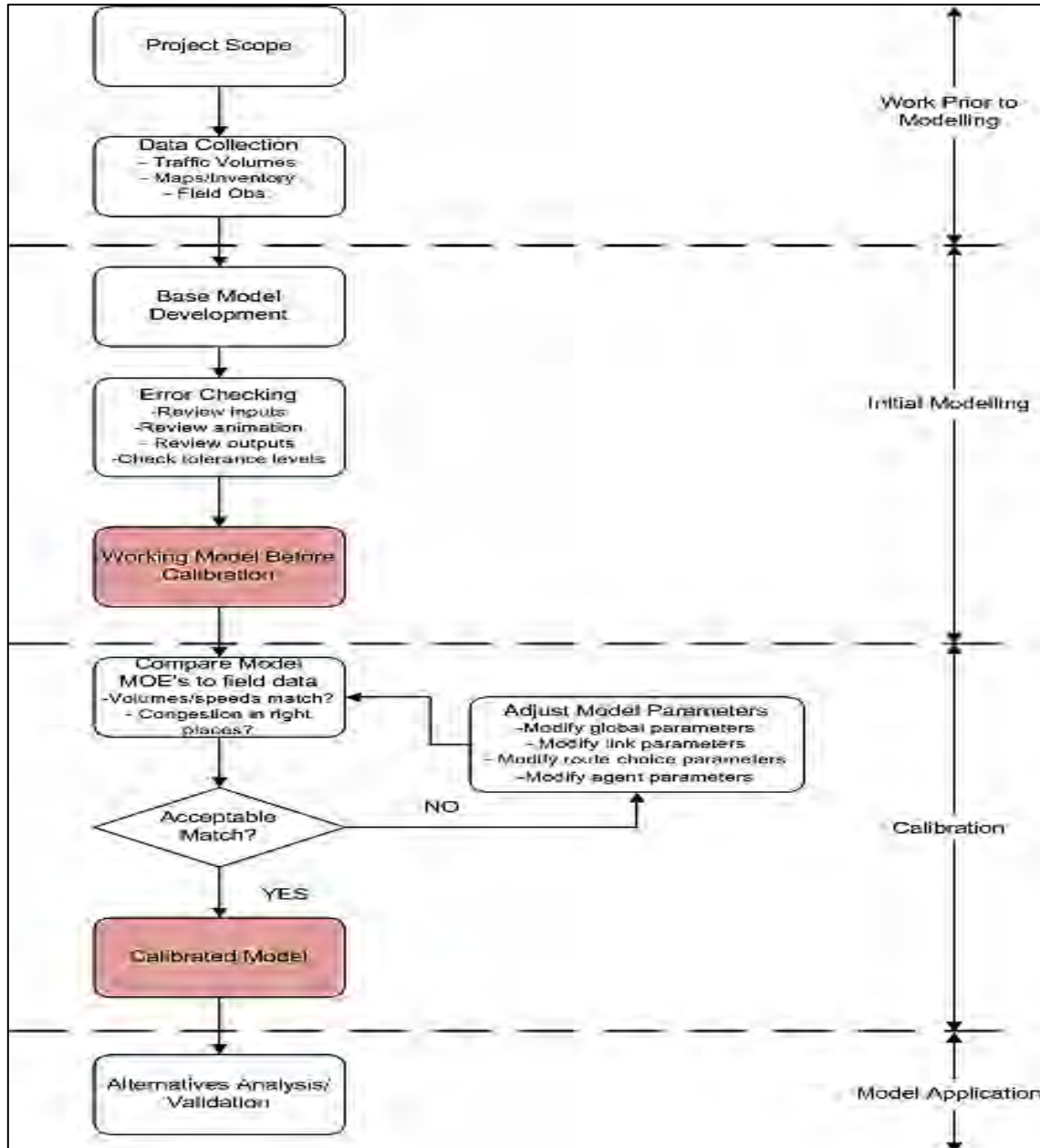


Figure 48: Model calibration - simplified procedure

Source: Adapted from MDOT, 2008

The establishment of the possibility of the acceptability of the default model parameters involves two steps: multiple runs of the model with the default set and subsequent comparison to observed data. Multiple runs are required as simulation models give slightly different output values for repeated runs as seed number ensures that vehicle types and numbers are randomly generated from zones (which should be the case for most simulations). The number of simulation runs required can be calculated via a statistical process based on standard deviations and confidence limits (FHWA, 2004). The final equation for this process is represented as:

$$C = 2 * t_{(1-\alpha/2), N-1} \frac{s}{\sqrt{N}} \quad (12)$$

Where, $C = 1 - \text{Confidence Level}$. For example, for a 95% confidence level, C equals 0.05. $t_{(1-\alpha/2), N-1}$ is a t-statistic value for the probability of a two-sided error summing to alpha with N-1

degrees of freedom. S is the standard deviation and N is the number of repetitions required. Frequently used sets to obtain the minimum number of repetitions needed for a desired confidence interval (ratio of confidence level to standard deviation) are presented in Table 8: Minimum number of simulations required for desired confidence .

Table 8: Minimum number of simulations required for desired confidence interval

Desired Range (C/S)	Desired Confidence	Minimum Repetitions
0.5	99%	130
0.5	95%	83
0.5	90%	64
1.0	99%	36
1.0	95%	23
1.0	90%	18
1.5	99%	18
1.5	95%	12
1.5	90%	9
2.0	99%	12
2.0	95%	8
2.0	90%	6

Source: FHWA, 2004

The validity of a default set of parameters can also be assessed by graphical methods rather than the statistical method shown above (Park and Won, 2006). A histogram analysis and X-Y plot analysis can be used to check the validity of the calibration result by using single and multiple measures. The example in Figure 49 indicates an unacceptable case (the observed travel times are shown in red and simulated frequencies are in blue), where the first two observed times fit inside the distribution but the other two do not.

Figure 50 illustrates a comparison of observed and simulated data for two performance measures. The ranges of field-collected data for performance measures 1 and 2 are presented as the dark-shaded box. This range should overlap the X-Y plot of simulation outputs for its 90% confidence interval region of the total data point cluster (shown as a red-shaded box).

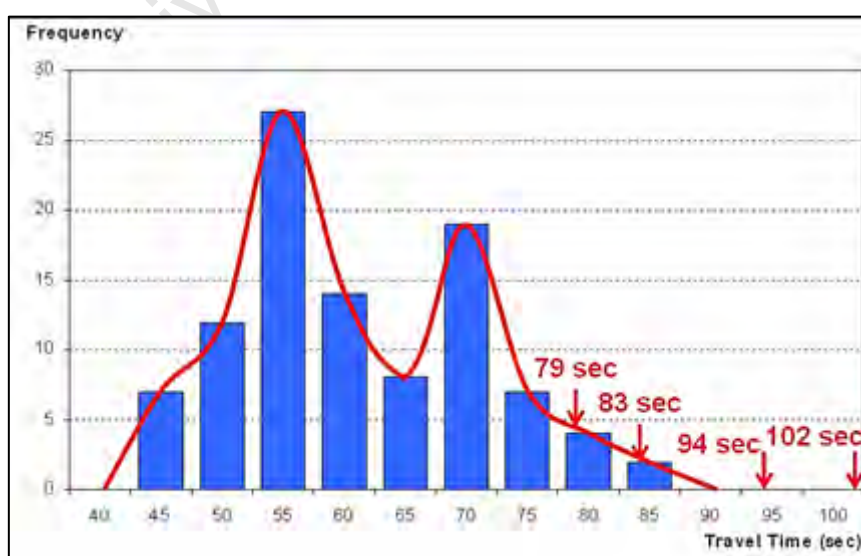


Figure 49: Example of an unacceptable case – Histogram

Source: Park and Won, 2006

If the 90% confidence interval region falls on the field-collected performance measures region, the model output can be considered to be feasible. However, if those two regions are not overlapping at all, it cannot be considered to be feasible and a calibration procedure needs to be conducted.

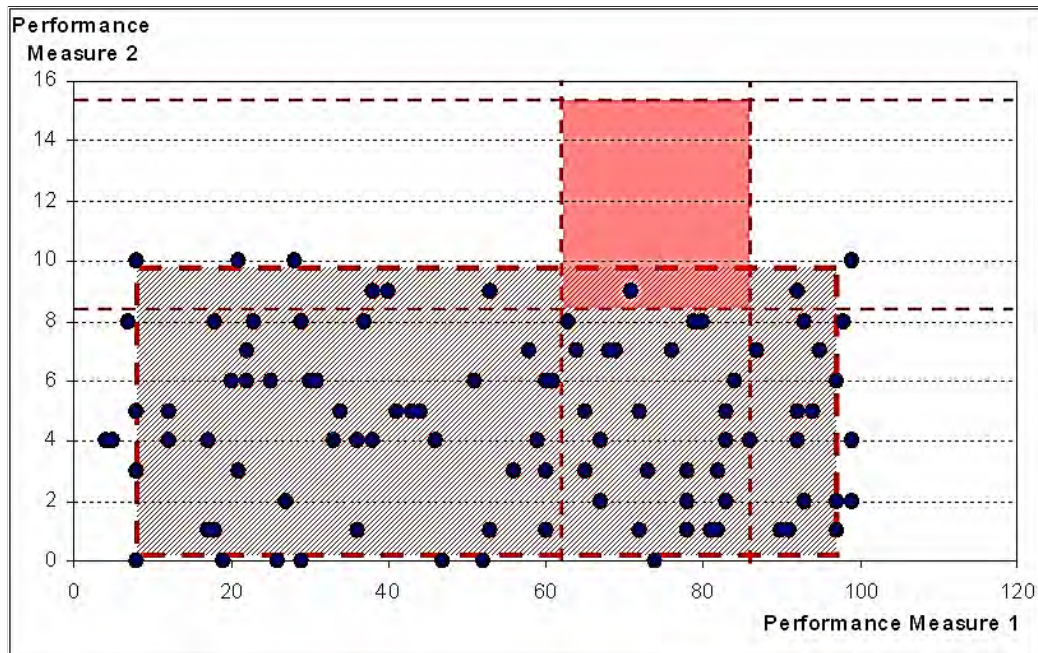


Figure 50: Example of an acceptable case: X-Y plot

Source: Park and Won, 2006

A calibration exercise needs to be undertaken in most cases as the default set of parameters rarely fit field observations. Usually, this is dealt with by adjusting key parameters which are defined in the following section. An iterative method whereby a range of values for key parameters is determined, checked and re-evaluated is the normal procedure from this point. However, the selection of key parameters is not at all straightforward because of their interdependence.

The main components of a simulation model that require calibration include: traffic control operations, traffic and pedestrian flow characteristics and pedestrian and driver behaviour.

6.6.2 Review of published calibration methods

The adjustment of the working model to achieve an acceptable result involves the review and adjustment of a number of parameters. The impact of adjusting one parameter is correlated to that of others on a network-wide basis. This is the case for almost any size and complexity of network - the analyst can easily get trapped in an endless process of fixing one problem only to discover that a new one pops up elsewhere. Calibration therefore needs to be a multi-faceted and iterative process. Additionally, although the aim of calibration is to match simulated outputs to observed data, there is a practical limit to the amount of time and effort that can be put into achieving a close fit – there comes a point of diminishing returns where the amount of effort yields only a small improvement in accuracy. For this reason, it is general practice to set calibration targets. Generally, for vehicles, calibration targets are limited to the consideration of delay, queue length, speeds, travel time and flow rates. A fairly typical example of acceptance criteria for freeways from the Wisconsin Department of Transport (McNally and Oh, 2002) is provided in Table 9.

Table 9: Model Calibration Criteria

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model versus Observed	
Individual Link Flows	
Within 15%, for 700vph < flow < 2700vph	>85% of cases
Within 100 vph, for flow < 700vph	>85% of cases
Within 400 vph, for flow > 2700vph	>85% of cases
Sum of all link flows	Within 5% of sum of all link counts
GEH ²⁴ statistic < 5 for individual link flows	>85% of cases
GEH statistic for sum of all link flows	GEH < 4 for all link counts
Travel Times, Model versus Observed	
Journey times network within 15%	> 85% of cases
Visual Audits	
Individual Link Speeds	
Acceptable speed-flow relationship	To analyst's satisfaction
Bottlenecks	
Acceptable Queuing	

Source: McNally and Oh, 2002

Despite the general use of targets for calibration and the fact that it is a multi-faceted approach, the literature cites several examples of studies focused on search algorithms for calibration based on a single criterion fitness function – normally either volume or travel time. A summary of selected studies is presented in Table 10.

Table 10: Summary of single criterion studies

Study	Type of Optimization	Model	Network	Measures of Performance	Results	Notes
Ma and Abdulhai (2002)	Genetic algorithm	PARAMICS	Arterial	Network flows	46.09%(GRE)	Global relative error
Hourdakis et al (2003)	Heuristic search	AIMSUM	Freeway	Volume	8.84%(RMSPE)	Root mean square percentage error
Park and Qi (2005)	Genetic algorithm	VISSIM	Freeway	Interchange travel time	12.60%(RMSP E)	Root mean square percentage error
Kim et al (2005)	Genetic algorithm	VISSIM	Freeway	Network travel time	1% (MAER)	Mean absolute error ratio
Cunto and Saccomanno (2008)	Genetic algorithm	VISSIM	Intersection	Crash Potential Index (CPI)	0.03%(RMSPE)	Root mean square percentage error
Cicu et al (2011)	Experimental	VISSIM	Roundabout	Capacity	Visual Inspection (graphically)	Authors did not estimate errors
Vaiana and Gallelli (2011)	Experimental	VISSIM	Roundabout	Speed	5%(MAER)	Mean absolute error ratio

Source: Duong et al., 2011

²⁴ The GEH statistic is computed as follows: $GEH = \sqrt{\frac{(V-E)^2}{(E-V)/2}}$ where E is the model estimated volume and V is the count.

A practical way of approaching the problem of calibrating parameters using the single criterion approach suggested by Dowling et al., (2004) is to break the calibration down into a series of logical sequential steps.

Model parameters can be divided into categories and each category needs to be dealt with separately. The available calibration parameters should be divided into those which are known or which the modeller is fairly certain about and does not wish to adjust, and those which he is uncertain about and is willing to adjust.

‘Adjustable’ parameters can be subdivided into those that affect capacity and those that affect route choice. Capacity is calibrated first followed by route choice. Each set of adjustable parameters can be further subdivided into those that affect simulation on a global basis and those that have a more localised effect. The following three-step strategy is generally followed for calibration by many practitioners (Dowling et al., 2004):

1. Capacity calibration – an initial global calibration is performed to identify values which enable the model to best produce observed traffic flows. This is followed by link-specific fine tuning;
2. Route choice calibration - assuming the model incorporates parallel streets, a second calibration process on global route choice parameters followed by link-specific fine tuning will be required;
3. System performance calibration - finally the overall model estimates of the system performance (travel times and queues) are compared to observed values and fine-tuned to match.

Each step is then calibrated using the per cent mean square error using a single set of model parameter values with different random number seeds.

The literature also provides several studies, which suggest that as the single criteria approach which ensures the accuracy in one attribute (e.g. travel time or speed) does not ensure accuracy for another attribute (e.g. acceleration profile or headway). This has led to the development of several multi-criteria approaches to resolving the calibration issue as shown in Table 11: Multi-criteria parameter calibration studies. The usual method followed is to fix one set of parameters for the calibration of a second set and so on. Such procedures do not include feedback loops to capture interactions between the parameters of interest (Toledo et al., 2004). One such method firstly matched observed traffic flows by calibrating global vehicle characteristics. Next it calibrates local link specific speed limits, to match observed speeds. Another method uses quasi-Newton algorithm for the various sub-problems and so on (Hourdakis et al., 2003). This lack of a definitive method of calibration and the variety and number of simulation models has led to the development of several multi-criteria approaches to resolving the calibration issue. A summary of some of the more recent developments in the resolution of the calibration issue is shown in Table 11.

Table 11: Multi-criteria parameter calibration studies

Study	Type of Optimization	Model	Network	Measures of Performance	Results	Note
Toledo et. al. (2004)	Iterative Averaging	MITSimLab	Freeway	Speed & Density	4.6 % (MAE for speed)	Only speed data shown; does not apply multi-criteria framework
Balakrishna et. al. (2007)	Simultaneous Perturbation Stochastic Approximation (SPSA)	MITSimLab	Freeway	Volume (counts)	22 to 65% (RMSPE)	Introduces a multi-criteria framework but does not apply it.
Ma et. al. (2007)	SPSA	PARAMICS	Freeway	Link Capacity & critical occupancy	0.70% (Sum of GEH)	Two-criteria calibration
Ciuffo et. al. (2008)	OptQuest/Multi start Heuristic (OQMS)	AIMSUM	Freeway	Network travel time	11 % (RMSPE speed); 17% (RMSPE Volume)	Mean absolute error ratio
Duong et. al. (2010)	Genetic algorithm	VISSIM	Freeway	Volume & Speed	1.9% (RMSPE Speed); 10.5% (RMSPE Volume)	Introduces the concept of Pareto optimality (non-dominance) to the traffic calibration problem
Huang and Sun (2009)	NSGA II	VISSIM	Freeway	Volume & Speed	1.0 (Volume Fitness) and 0.97 (Speed Fitness)	Applies the NSGA II without looking at the resultant non-dominant set

Source: Doung et al., 2011

As simulation runs can be viewed through the animations output, they can be used as a last step of the calibration process to make sure that the animation gives a visual confirmation of anticipated queues and acceptable distribution, and that there are no unrealistic road-user movements.

6.7 Benefits, burdens and validity of micro-simulation as a tool for safety indicators

In general, a significantly higher level of modelling detail is required for safety assessment than for other traffic system objectives. This is particularly evident for pedestrian and behavioural sub-models that describe the interactive processes and provide the simulation output. For safety analysis, it is of critical importance to ensure the accurate representation of interactive behaviour between road-user entities and their interaction with the environment. It is also important to ensure that the values of road-user behaviour and vehicle performance are appropriate to the local conditions. These higher levels of modelling fidelity require the collection of more detailed empirical data and demand greater stringency in the processes of model calibration and validation.

Also, as noted, and confirmed in studies carried out (such as the one by FHWA, 2004), micro-simulation models for safety studies rely on the assessment of surrogate or proximal safety measures. The validity of appropriate safety indicators requires a statistically reliable causal relation with injury crashes. The three hypotheses for the utility of simulated safety measures presented by FHWA: i) discriminating between the safety of two design alternatives in a simulation; ii) correlation of the surrogate safety measure with real world traffic conflict studies; and iii) correlation of surrogate safety measure reductions with predicted reductions in traffic conflicts, provide a robust test for model validity and, therefore, these criteria need to be met. This is an additional burden to normal calibration criteria that would be required to fulfil the outcomes of traffic efficiency analyses.

Other important points of interest are the accuracy that is used for modelling vehicle mobility, the interaction between vehicles and pedestrians, and pedestrian behaviour. The derived safety indicators are based on the details of road-user movements resulting from simulations, and simulations can produce oddities like unrealistic movements or manoeuvres; these must be prevented or accounted for to ensure accuracy of the analysis. Specifically, the accuracy of lateral movements, the level of reality of road-user movements on intersections non-compliant behaviour have been seen to be issues in some models and therefore need to be visually checked.

The benefits of simulations for safety assessments are likely to result from the fact that simulations can be carried out in an off-line environment, without the incursion of cost and once appropriately calibrated can be used to test several different options in a comparative manner which is unlikely to be the case without the use of some form of modelled outcomes of safety indicators. Further benefits can accrue for pro-active investigations of infrastructure or design encompassing safety simulation. Simulation also has the advantage of removing any human element of the analysis of the outcome such as is found in TTC or TTA for example.

6.8 Choice of simulation model

Although micro-simulation software has been around for quite some time (and possibly because they are constantly evolving) there are relatively few studies which compare all available transport related software. The most comprehensive of these was the SMARTTEST project commissioned by the European Commission in 1997 (SMARTTEST, 1997). This report compared over 30 different software tools using various tests to examine capabilities only. More recent but limited studies focussed upon particular aspects that were being investigated. For example: Bloomberg et al (2003) – on a comparison to the Highway Capacity Manual; Yang and Ozbay (2011) - on safety analysis; and Papdimitriou et al (2009) - on pedestrian modelling. The conclusion in relation to software choice from all of these studies is that there all packages have benefits and dis-benefits and none is clearly superior. Yang and Ozbay selected PARAMICS for their safety analysis because of the ability to customise it. Because of this aspect, its agent-based modelling system for pedestrians, which allows a variation of behavioural parameters to suit real-life local conditions for all road users and visualisation of vehicle-pedestrian interaction on the road network (including collisions), PARAMICS was used for the investigation that follows.

7 Case Study I - Modelling the effect of road-based traffic safety measures: Traffic Calming

7.1 Scope and objectives

The studies in this chapter and in Chapter 8 examine the ability of micro-simulation models to perform '*safety simulations*'. The simulation studies are an attempt to put many of the recognised theoretical issues into perspective through practical application. The main aim is to develop a functional and representative approach to safety, where the dynamic and complex interactive behaviour of modelled entities (i.e. road-users, vehicles and the traffic environment) reproduce risk profiles which correspond to those found in real-world (local) situations through the use of surrogate and proximal safety measures. This type of simulation requires the use of detailed empirical data and as few un-validated parameters as possible regarding road-user behaviour.

For road-based traffic calming in particular, the aim is to determine whether the simulations can produce results that differentiate potential speed and traffic flow changes for different types of infrastructure interventions (which can be equated to a measure of relative safety). If successful, the further conditional objective of this analysis would be to understand the safety effect likely as a result of the application of a particular traffic calming measure or strategy.

7.2 Background to the reasons for simulating traffic calming measures

The strong relationship between speed and crash potential, as well as crash severity, is well established (see chapter 5): lower speeds provide the opportunity for more reaction time for all road users as well as reducing the likelihood of serious pedestrian injury, especially at speeds below 50km/h. The conclusion drawn from this in many countries, is that speeds in urban areas where vehicles and pedestrians are likely to interact should be at, or preferably, below, this threshold. This seems to be the guiding principle of urban road safety in strategies such as Sweden's 'Vision Zero', the Dutch 'Sustainable Safety' and 'woonerf' systems, 'Civilised Streets' in the UK (for further details, see for example: WHO, 2009 and Appendix D). The consequential effects of such speed reducing strategies are usually beneficial in that they facilitate more cycling as well as walking, and lead to better air quality as vehicles tend to seek out routes which allow higher speeds.

It is general practice to set speed limits at the 85th percentile operating speed (i.e. the speed which around 15% of vehicles exceed). In South Africa, a study of speeds of vehicles of all types carried out by the RTMC (2005), found that around 30% of drivers exceeded the 120km/h freeway speed limit with quite a few drivers travelling in excess of 140km/h, particularly over the weekend, indicating that general levels of compliance to speed limits in South Africa are particularly low. Non-compliance of speed limits also tends to be exacerbated by other attitudinal, behavioural and road environmental factors. An example of the road environmental factor is shown in a study by the FHWA in the US (Stuster et al., 1998) which reports that drivers who had travelled at 70 mph (102 km/h) for more than three minutes tended to drive 5 to 15 mph (8-24 km/h) faster in a 30 mph (48km/h) zone than drivers who had not previously driven at the faster speed.

Road-based traffic calming is fundamentally concerned with reducing the adverse impact of motor vehicles in urban areas; it usually involves reducing vehicular speeds and providing safer crossing points or more space for pedestrians and cyclists thereby improving the 'liveability' of the local environment. With increasing congestion, transport policies are attempting to shift transportation towards walking and cycling and to make environments more attractive for walking in terms of safety, efficiency and convenience, especially in more densely populated areas, where pedestrian vehicular interactions can have a significant impact on each other.

Traffic calming measures, consist of engineering and other measures (perceptual or psychological), that can be implemented to achieve a change in driver behaviour and through them, a reduction in the adverse impact of motorised transport in urban areas. Such measures have been successfully implemented in cities across the world for decades in response to safety-related neighbourhood traffic concerns.

The potential range of calming measures in current use is fairly extensive. Types used vary depending on the application area and desired effect. Application areas can vary from minor changes to local streets to area-wide strategies - the latter being preferable because of the ability to assess and control the nature and effects diversionary traffic.

In Cape Town as levels of urbanisation (and thus congestion on the major routes) increase, motorists seek out alternative routes through residential areas which negatively impacts the liveable quality of these areas. Mainly in an attempt to address these issues, traffic calming policies adopted by various authorities²⁵ previously responsible for the overall municipal area of Cape Town were disparate and uncoordinated and have resulted in a non-uniform approach to traffic calming across the city (City of Cape Town, 2008). Because of this there has been a lack of commonality in the use of traffic calming to address safety issues.

The change to a 'uni-city' model of governance, and a revised Traffic Calming Policy, which now approaches traffic calming from a more 'liveable' rather than a vehicle-centric perspective (see: City of Cape Town, 2011), should ensure a more integrated approach to need and provision levels. Despite this, the policy document stops short of proposing guidance on typology and strategies in terms of impact. Given this omission, the variety of solutions available and the difficulty in assessing their relative level of effectiveness without implementation, the development of a method to study a broad range of traffic calming measures, in different settings prior to implementation is necessary in order to assist the decision-making process and incur the least amount of cost, time delays and risk of inappropriate interventions.

The use of micro-simulation modelling, which can provide a more scientific basis of assessment of the relative safety of potential measures, is proposed as an appropriate way to undertake such an investigation. The method has the added benefits of applicability and uniformity of analysis. Not only does it allow specific traffic facilities to be modelled dynamically in great detail, in a safe off-line environment, it can represent a large number of factors that have a direct or indirect influence on traffic safety and performance that can be varied in a model, including: flow rates, turning movements, average speeds and speed variance, signalling, various aspects of road-user behaviour, and aspects related to site geometry and design.

However, the usefulness of this methodology (in terms of safety assessment) relies on its ability to capture the overall level of turbulence for different transportation scenarios as a function of a number of geometric and traffic attributes. As an added benefit over the literature, the analysis should be able to provide meaningful insights about changes in overall safety for different engineering countermeasures, and for example, what would the safety benefits (or dis-benefits) be of speed humps compared to chicanes at the same location? Are the results sensitive to changes in spacing, volume and different modes of transport, and what is the optimal spacing for safety? And, by extension (with the use of the safety surrogates of speed and volume), what would the relative reductions in fatalities be for each measure modelled? These questions are investigated in the following sections.

²⁵ Until 2000 the City of Cape Town was divided into six municipal authorities.

7.3 Traffic calming techniques

Traffic calming techniques can be categorised into two groups of measures based on the intended impact. **Volume control measures** are primarily used to address cut-through traffic problems by blocking certain movements, thereby diverting traffic to streets better able to handle it. **Speed control measures** are primarily used to address speeding problems by changing vertical alignment, horizontal alignment, or narrowing the roadway in some fashion. The distinction between the two effects is not as clear as the labels suggest, since speed control measures frequently cause traffic to divert to alternative routes, and volume control measures also slow down traffic flows. Studies also indicate that a combination of measures (any category) have the most beneficial effect (www.trafficcalming.org).

An overview of the most common measures in current use and their applicability in terms of road type and anticipated impacts are provided in Table 12 and 13 respectively.

Table 12: Types of traffic calming measures

Speed control measures				Volume measures
Vertical deflection	Horizontal deflection	Horizontal narrowing	Others	Divertive/ restrictive
<ul style="list-style-type: none"> • Speed hump • Speed table • Raised crosswalk • Raised intersection • Textured pavements • Speed cushion • Rumble strips 	<ul style="list-style-type: none"> • Traffic circle • Roundabout • Chicanes • Realigned intersection • Tight radii 	<ul style="list-style-type: none"> • Neckdowns • Centre island narrowing • Chokers • ‘Road diets’ • Bike lanes 	<ul style="list-style-type: none"> • Speed Limits • Speed alerts, enforcement • Road markings • Warning Signs • Textured paving • Landscaping • Perceptual design 	<ul style="list-style-type: none"> • Full closure • Half closure • Diagonal diverters • Lateral shift • Median barriers • Neo-traditional design

Source: Adapted from www.trafficcalming.org and www.vtpi.org

Table 13: Traffic calming measures, strategies, application areas and impacts

Type	Description	Application Area		Impacts	
		Arterial	Local	Volumes	Speeds
Speed limits	Reduced speed limits.	✓	✓	Yes	Yes
Speed alerts, enforcement	Radar-clocked traffic speeds displayed to drivers. Speed limit cameras, enforcement.	✓	✓	No	Yes
Warning signs and gateways	Signs and gateways indicating changing road conditions.	✓	✓	No	Yes
Speed hump	Curved raised paving usually 7-10cm high.	-	✓	Possible	Yes
Speed table	Ramped surface above roadway, 7-10 cm high, 3-6 m long.	-	✓	Possible	Yes
Raised crosswalk	Ramped surface above roadway, 7-10 cm high, 3-6 m long.	✓	✓	Possible	Yes
Raised intersection	Ramped surface above roadway, covering the entire intersection, usually in a different texture.	With caution	✓	Possible	Yes
Textured pavements	Special pavement textures (cobble, bricks etc.) and markings to designate special areas	✓	✓	Possible	Yes
Speed cushion	Two or more speed humps with gaps between to allow emergency vehicles to pass through without slowing down	With caution	✓	Possible	Yes
Rumble strips	Painted or low raised paving that make noise when driven over.	✓	✓	No	Yes
Traffic (mini) circle	Small raised circles at intersections	-	✓	Possible	Yes
Roundabout	Medium to large raised circles at intersections	✓	-	Unlikely	Yes
Chicanes	Kerb bulges or planters (usually 2 or more) on alternate sides, forcing motorists to slow down	-	✓	Yes	Yes
Realigned intersection	Realigned intersections are changes in alignment that convert T-intersections with straight approaches into curving streets that meet at right-angles.	✓	✓	Possible	Yes
Tight radii	Reducing the radius of roads to force lower speeds	✓	✓	Possible	Yes
Neckdowns	Kerb extensions at intersections that reduce the roadway width from kerb to kerb usually at intersections.	✓	✓	Possible	Yes
Chokers	Kerb extensions, planters, or centreline traffic islands that narrow traffic lanes to control traffic and reduce pedestrian crossing distances. Also called “pinch points.”	✓	✓	Possible	Yes
‘Road diets’	Reduction in road width or lanes to slow vehicles down.	✓	✓	Yes	Yes
Bike lanes	Marked lanes for bikes	✓	✓	Possible	Possible
Perceptual design	Patterns painted into road surfaces and other perceptual design features that encourage drivers to reduce their speeds.	✓	✓	Possible	Yes
Full closure	Restrict entry/exit to/from neighbourhood. Limit traffic flow at intersections.	-	✓	Yes	Yes
Half closure	Restrict entry/exit to/from neighbourhood. Limit traffic flow at intersections.	✓	✓	Yes	Yes
Diagonal diverters	Barriers placed diagonally across an intersection, blocking through movements and creating two separate, L-shaped streets	✓	✓	Yes	Yes
Lateral shift	Lane centreline that curves or shifts	✓	✓	No	Yes
Median barriers	Raised island in the road centre (median) narrows lanes and provides pedestrian with a safe place to stop.	✓	-	Yes	Yes
Neo-traditional design	Streets with narrower lanes, shorter blocks, T-intersections, and other design features to control traffic speed and volumes.	✓	✓	Yes	Yes
‘Woonerf’	Streets with mixed vehicle and pedestrian traffic, where motorists are required to drive at very low speeds.		✓	Yes	Yes

Source: Adapted from www.trafficcalming.org and www.vtpi.org

7.4 The effects of traffic calming strategies

The literature on traffic calming contains many examples of the effects of strategies on speed, volume as well as crashes and environmental impacts in various cities. A selection of these studies is presented below.

A study of before and after effects of a range of measures in various US cities by the Institute of Transportation Engineers (Ewing, 1999), found that some applications were effective in reducing speeds or volumes, and that others were not. Impacts were '*highly case-specific, depending on the geometrics and spacing of the measures, availability of alternative routes, treatment of other streets in area-wide application and many other factors*'. The range of impacts found for various measures and strategies are presented in Table 14 along with the findings from other studies.

Studies on volume effects indicate an elasticity of vehicle travel demand with respect to travel time of -0.5 in the short run and -1.0 in the long run, suggesting that a 20% reduction in vehicle speeds would reduce total vehicle travel by 10% in the short term and up to 20% in the longer term (www.vtpi.org).

Studies on the safety effects of speed are many and varied. Among these, a review of 20mph (32km/h) zones in the UK by the Transport and Road Research Laboratory (TRL) in 1996, found that the average all-crash frequency fell by 60%, and that child pedestrian crash rates were reduced by 70% (FHWA, 1999). Gårder (2004) found that crashes involving pedestrians were lower in two-lane streets with a middle island than on wider streets due to lower vehicle speeds. Ishaque and Noland (2008) reported that pedestrian compliance rates decreased when the width of the carriageway is smaller or in the presence of central refuge islands.

Of significance to this study, is a study by Harvey (1990), which indicated that between 1980 and 1990, pedestrian fatalities in West Germany fell by over 60%. This was largely attributed to lower vehicle speeds in urban areas, primarily as a consequence of heavy investment in traffic calming. Harvey (1990) also found that an overall reduction of 57% in fatalities personal injury accidents of 41% was achieved in the Berlin Moabit scheme, with a reduction and a 45% reduction in serious injuries and a reduction of 43% in casualties compared to untreated areas .from a review of 600 traffic calming schemes in Denmark.

Various studies regarding the safety effects of replacing a four-arm intersection by a single-lane roundabout have been carried out in the Netherlands (see for example: Van Minnen, 1990; 1995; 1998; and Dijkstra, 2005 in SWOV, 2010b). Dijkstra (2005) concluded that replacing a four-way intersection by a roundabout resulted in a reduction of about 75% of the total number of severe casualties. Among cyclists, moped riders, and light-moped riders a reduction of about 60% was found. These percentages could be an overestimation of the safety effect because, usually, the most dangerous intersections are the first to be considered for road safety measures ('diminishing safety returns'). Elvik (2003) studied 30 before-and-after cases to evaluate the effects on road safety of converting intersections to roundabouts from various countries. He made statistical corrections (to account for bias etc.) and found that roundabouts are associated with a 30% to 50% reduction in the number of injury accidents and that fatal accidents are reduced by 50% to 70%.

A study by the University of Cape Town aimed at understanding driver behaviour at un-signalised pedestrian crossing facilities in Cape Town, found that the proportion of drivers who yielded to a pedestrian stepping onto the crossing was significantly higher at sites which incorporated some kind of traffic calming device (around 80% yield rates) than at sites which did not (around 35% yield rate). All sites were still located in areas with a considerable amount of pedestrian traffic (David, 2006).

Similarly, a study of the European Road E12 through the community centre of Storuman, Sweden, was undertaken following its reconstruction in 2000 to investigate improvements in safety for pedestrians and bicyclists, primarily for children, the elderly and the disabled and to reduce the barrier effect of the E12 thoroughfare. The combined effect of reconstructions and change of code governing drivers²⁶ showed that at the intersection where the roundabout was constructed, yield behaviour towards pedestrians changed. The difference was even greater with respect to yielding to child cyclists - from 6% before to 84% after - even though the code change only related to pedestrians. Crash data analysis suggests a minor increase in fall injuries after reconstructions and change of code. Measures of speed, behavioural studies, questionnaires, face-to-face interviews and crash data analysis suggest that safety has increased not only along the E12 but also along adjacent roads (Leden et al., 2006).

The above relates to physical traffic calming measures which, as shown, can generate substantial reductions in vehicle speeds and accidents. However, on the downside, they can be unpopular with drivers, they can result in driving styles that lead to a high degree of acceleration and deceleration, increase vehicular emissions, and they generate increased noise, they can also be costly and an unwelcome visual intrusion and, if driven on inappropriately can damage vehicles. With this in mind, in the UK, the TRL (Kennedy et al., 2005) developed and tested alternative traffic calming techniques that make greater use of psychological (non-physical) measures, but which were intended to still have significant speed-reducing capabilities.

The study reviewed psychological theories that provided insight into how specific road design measures might reduce driving speeds. Ideas for traffic calming based on these principles were illustrated using photomontage and evaluated by means of focus groups, a questionnaire survey, using the TRL Driving Simulator, and finally in on-road trials. The studies compared the focus group's perception of their own driving speed, the speed of others and their thoughts on a 'safe speed' in the case of the photomontage and questionnaires. The driving simulator was used to assess the more promising measures from these experiments. Overall, the results indicated that 'psychological' measures do induce speed reductions. The largest reductions were reported for a combination of measures rather than individual measures. The simulator trial showed that continuous or repeated measures were required to sustain speed reductions; that coloured surfaces on their own had little impact; and uncertainty appeared to reduce speeds.

As a corroboration of all of these findings, the FHWA state that: *'Perhaps the most compelling effect of traffic calming is in the area of safety'* (Ewing, 1999).

To summarise, the literature indicates that traffic calming measures designed to reduce speeds have been successful to varying degrees. They have been successful in reducing crashes and crash severity by reducing speed and conflicting movements and by focusing driver attention. Volume control measures have also been successful in achieving their objective. The degree of success is likely to be context and type specific. An aggregated representation of the findings for physical measures is presented in Table 14.

²⁶ In May 2000, the code governing the conduct of drivers at marked crosswalks in Sweden became stricter to improve safety and mobility for pedestrians

Table 14: Summary of findings of effects for various traffic calming strategies/measures

Strategy Type	Sample Measure	Speed* (km/h)		Volume	Crashes**
		Average after calming	Percentage Change	Percentage Change	Percentage Change
Vertical deflections	Speed humps	45-27	-22 to -48	-15 to -25	-13 to -65
	Speed tables	48-27	-9 to -48	-10 to -15	-40 to -65
	Raised intersections/ crosswalk	54-20	-1 to -50	-10 to -15	N/A
Horizontal deflections	Traffic circles/ roundabouts	50-30	-11 to -48	0 to -5	-10 to -90
	Lateral shifts	35-22	-40 to -45	N/A	N/A
	Diagonal diverters		+5 to -10	0 to -60	N/A
	Chicanes	35-22	-40 to -45	-10 to -20	-75 to -82
Road narrowings	Road 'diet'	55-22	-4 to -45	-10 to -20	-25 to -65
	Central islands	55-40	-10 to -15	-20 to -30	N/A
	Half closure	50-30	-10 to -30	-20 to -65	N/A
	Choker/bulb-out	50-30	-10 to -20	-5 to -25	N/A

* 85th or 50th percentile speeds. ** Injury only crashes (i.e. excludes property damage)

Source: Adapted from Ewing, 1999; Elvik, 2003; <http://www.its.leeds.ac.uk/projects>; (SWOV, 2010b); FHWA, 1999; www.trafficcalming.org; www.vtpi.org)

7.5 Simulation study sites

To test the capability of micro-simulation models with regard to capturing the possible impact of various traffic calming strategies, the PARAMICS suite of micro-simulation models was used to model a network of roads near the centre of the City of Cape Town (see highlighted area in Figure 51). The link used to test the impact of traffic calming interventions was approximately 1.5km long, and 7.3m wide and the network formed part of a model encompassing the outer edges of the City, which allowed the possibility of diversion routes being used by vehicles to avoid any increases in their generalised cost of travel. This provision allowed both volume and speed effects to be measured for each intervention considered from the simulation outputs.

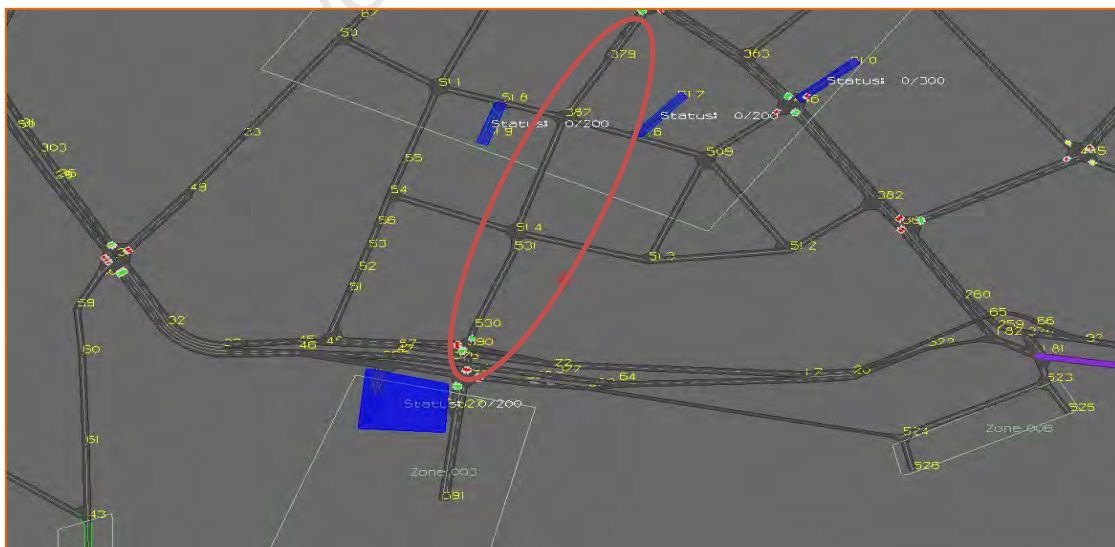


Figure 51: Screenshot of model network

7.5.1 Link and junction data

The base model was built and populated using local geometric, traffic control and street furniture details. In addition the following data was captured on the selected test network:

- Traffic flow rates during the mid-day peak (between 12 p.m. and 3 p.m.);
- Measures of travel time and ‘spot’ speeds ;
- Vehicle time-gap data;
- Pedestrian flow rates, walking speeds and a broad categorisation of types;
- Signal timings and phasing on intersections within the model confines;
- Locations of public transport stops and bus details;
- Location and capacities of car parks, again within the model confines; and,
- Empirical data from several traffic calmed sites around Cape Town (see Table 15 and Figure 52).



Figure 52: Sample photos of selected traffic calming measures

Table 15: Characteristics of existing traffic calming sites used to gather empirical data

Traffic calming measure	Site	Characteristics
Traffic circle	Central Avenue Kildare Lane	Raised textured islands 5-8m in diameter around which traffic circulates by restricting through movements
Speed hump	Ring Road	Parabolic shaped humps 7-10cm high and 7cm high thermoplastic humps both extending transversely across the width of the road
	Kildare Lane	Parabolic shaped humps 7-10cm high extending transversely across the width of the road
	Central Drive	Parabolic shaped humps 10cm high painted tarmac, extending across road
Raised crosswalk	Ring Road	Flat-topped raised crosswalk 10cm high in textured paving or painted tarmac across the road
	Port Road	Flat-topped raised crosswalk 7-10cm high in coloured texture paving and zebra crossing markings.
Raised intersection	Kloof Road	Flat topped raised intersection, 15cm high across the full extent of the intersection
	Victory Avenue	Flat topped raised intersection in tarmac, 7-10cm high across the full T-junction
Textured Paving	Port Road	Red brick paved area marking entrance to area of high pedestrian activity across length of dual carriageway.

7.5.2 Traffic flows and composition

Traffic flow volumes were calculated using City of Cape Town's macroscopic O/D matrices for zones for the overall city network. The composition of flows was based on the City's overall modal share split specified in its Integrated Transport Plan (City of Cape Town, 2009). Bus schedules were obtained from the local provider's (Golden Arrow) web site (www.gabs.co.za).

7.5.3 Driver behaviour, traffic speed and travel time measurements

To compare the changes in driving behaviour with and without traffic calming measures, both before and after driving data are required. Driver behaviour is often characterised using the average vehicle speed, typical acceleration and deceleration values, travel time, and delay (or stopping time). The general methodology used to measure and/or estimate driving behaviour (apart from simulation) is to collect in-field average speed and/or spot speed measurements.

These methods, however, cannot accurately capture or reflect driving behaviour resulting from various traffic calming measures. To overcome these shortcomings, a portable in-vehicle GPS device and a cell-phone application were used in this study. Data were collected on a neutral weekday in the evening peak to match the O/D traffic data. Both units collect travel time, speed and location data at one second intervals. At least 10 valid trips were made on the study link for each direction and on each of the existing traffic calmed sections detailed in Table 15.

Both methods provide a continuous measurement of speed which can be averaged for comparison with simulation runs. Data were collected for the length of the calmed road section or at least 50m from the start of each device depending on which was most appropriate. In addition, spot speed data were also collected using a hand-held speed gun for traffic travelling in both directions at the mid-point of the study link and the traffic calmed sections.

Figure 53(a-d) provides examples of the type of empirical data collected: (a-c) indicate an average of the speeds over time for each direction for each measure, collected at a set distance upstream and

downstream of the calming measure using an in-car vehicle tracking and video device that uses GPS to locate the vehicle and record its speed (see Figure 54). A series of 10 runs for each measure were conducted and averaged. The vehicle speed data were validated by similar cell-phone applications. The data collected for all measures clearly indicates the relative effect on speed of each measure, including the effect of a ‘Stop’ enforcement at the Kloof Street intersection. Additional spot speed measurements were undertaken at two speed hump locations and at the Kloof Street the raised intersection at the point of all devices over a period of 30 minutes (Figure 53(d)) to ensure that speeds used for model calibration purposes were a true reflection of the average speeds and not just from one sample. These show that, in the majority of cases, vehicular speeds were consistent with those obtained from the in-car recorders but that there was some variation, mainly higher, providing an indication of the variations in driving styles. This data also confirmed that, in general, speed humps have the greatest effect on vehicle speeds despite the fact that the devices were not exactly the same in each case.

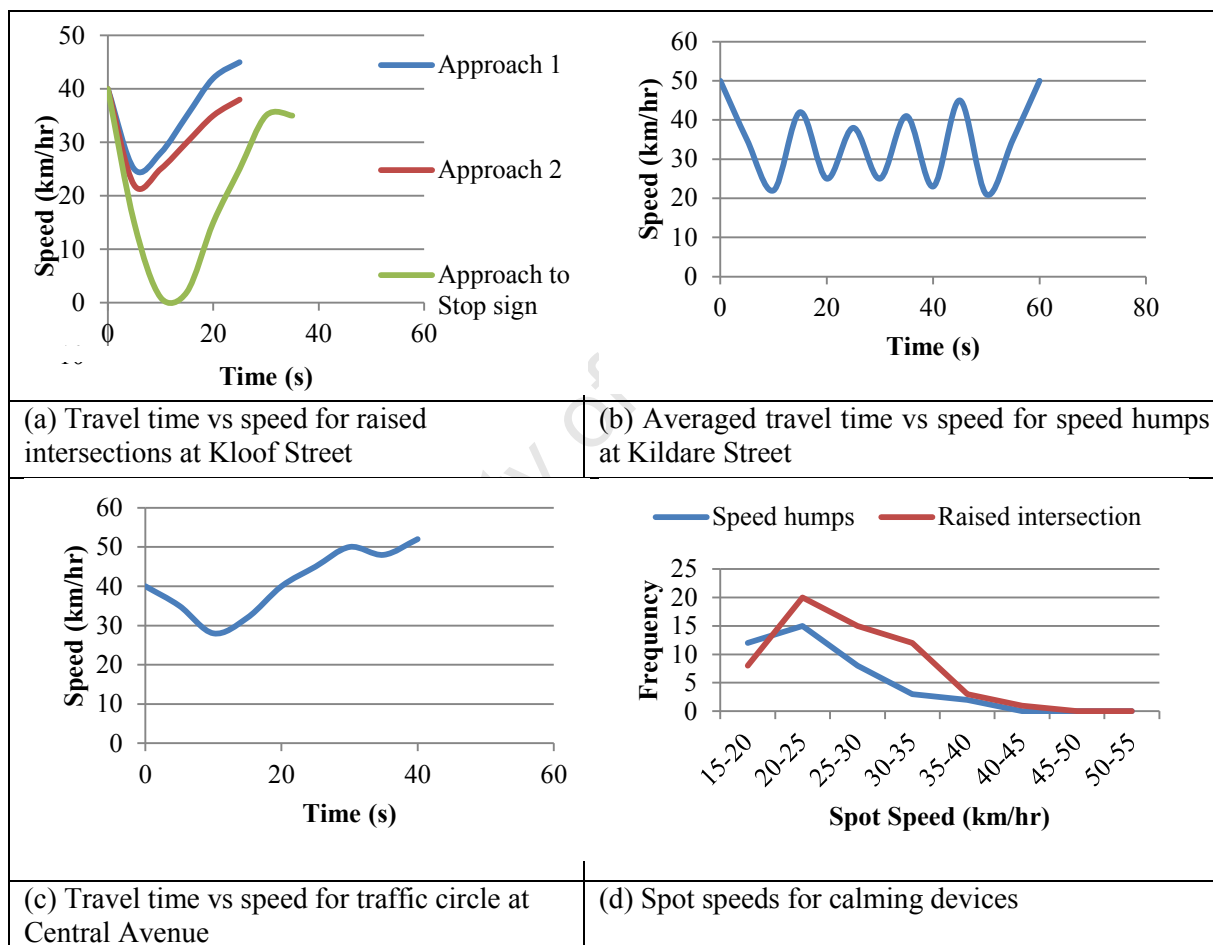


Figure 53(a-d): Examples of empirical data collected



Figure 54: Example of speed and travel time data collection using in-car tracking system

Speed characteristics from the driving cycles and spot speed measurements for each location used in the modelling exercises, are summarised in Table 16. The average cycle speed of 49km/h for the test case study link is much greater than the speeds recorded for the calmed sections of roads with the exception of the textured paving section and traffic circle where speeds were found to be similar. Speed humps have the highest speed standard deviation and the lowest average speed, indicating that they have the greatest effect on speed and also generate the largest range of speed differentials.

Table 16: Summary of traffic calming drive cycles (midday peak, averaged)

Cycle/ Measure	Average speed (km/h)	Standard deviation (km/h)	Maximum speed(km/h)
No calming	49	-	58
Traffic circle	45	8.3	50
Speed hump	25	10.2	32
Raised intersection*	28	7.7	36
Textured paving	45	-	58

* Average of measurement on free flow arms of intersection

7.5.4 Car-following data

The distribution of time-gaps or headways is an important indicator of road user aggression levels and has a significant influence on vehicle and pedestrian gap acceptance. The time-gap also provides an indication of the number of vehicles that are in a car-following mode and the number that are following too closely.

In this study, the measure of headway rather than time-gap (i.e. bumper-to-bumper) has been used as tests show that it is a parameter that has a major impact on the calibration process. However, for the mid-day peak hour, data collected show that headway values tended to be around the 10-11 second mark for both the study link and as averaged from observations at two sites containing speed humps (Figure 55). Observed values for raised crosswalks and the raised intersection in the main direction of flow (i.e. not at the stop section) were also similar.

The simulated value of headway for vehicles in PARAMICS is determined by a parameter termed the Mean Target Headway (MTH). As suggested, this parameter is used by the algorithm to provide a

target for vehicles - it is not an absolute value to be achieved by each vehicle. In free flow conditions, it is not a critical value in the calibration process and therefore, the default value provided by the software could be used for the analysis.

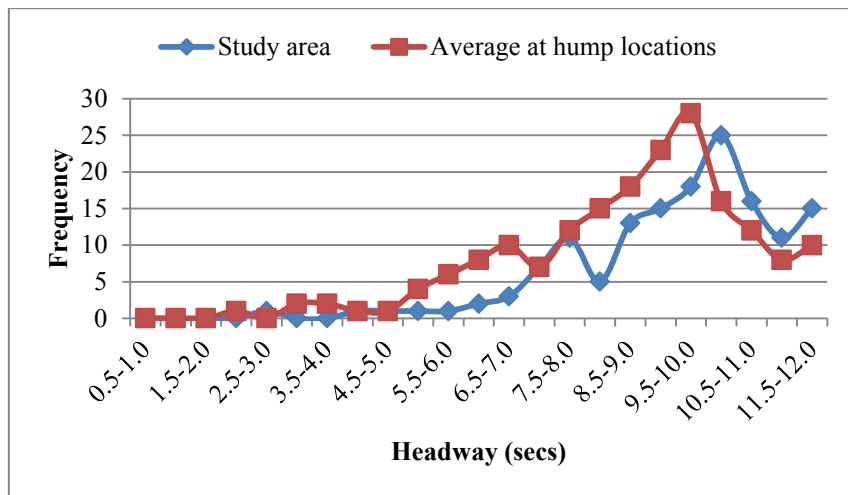


Figure 55: Observed headway values, mid-day peak hour values

7.5.5 Vehicle acceleration/deceleration

Vehicle acceleration and deceleration rates are important issues in this study - not only the average rates of deceleration and acceleration when stopping, slowing down to yield, or pulling away, but also deceleration behaviour in safety critical situations. The validity of the safety indicators is also dependent on the accurate representation of both the drivers' reaction times and the simulation of available deceleration rates.

Acceleration and deceleration values in PARAMICS are specified as maximum rates and are used by algorithms to simulate vehicle speeds. Default values are shown in Table 17, depending on vehicle type. In addition, the algorithms take account of each vehicle type's net horsepower and age specified, and adjusts by both to simulate more realistic speeds (Quadstone 2012). As an alternative, an option to simulate vehicle speeds with user-defined acceleration/deceleration profiles for any vehicle type is provided.

Table 17: Examples of vehicle acceleration and deceleration rates

Reference	Acceleration Rate	Deceleration Rate	Notes
PARAMICS (Quadstone, 2012)	1.1 to 2.5m/s/s	3.2 to 4.5m/s/s	Default values, depends on vehicle type
NHTSA (www.nhtsa.dot.gov/cars/testing/brakes)	n/a	23.8ft/s/s (7.25m/s/s)	Average value for all vehicles
Cunto (2008)	n/a	8.45m/s/s for vehicles; 5.01m/s/s for trucks	Average value for 'Deceleration Rate to Avoid Collision'
Ahn and Rakha (2009)	5km/h/s (1.4m/s/s)	9km/h/s (2.5m/s/s)	For traffic calming device areas with vehicle speeds ranging between 20 and 44km/h

In comparison to these values, data from a range of sources is shown in Table 17. Some of these values are a more accurate representation of current vehicle capabilities under general traffic conditions and from these, it was deduced that default model values for acceleration for standard vehicles were acceptable, but the maximum deceleration value was modified to 8.5m/s/s for standard vehicles and to 6m/s/s for heavy goods vehicles, coaches and buses. The average vehicle age was also adjusted to be 10 years old, to reflect the average age of the local fleet, as the algorithm used by the software accounts for age in simulating speed values.

7.5.6 Pedestrian data

Agent-based simulations require rich and accurate datasets to facilitate realistic representations and to provide adequate detail for interventions. For pedestrians, information requirements at selected locations include characteristics such as travel time/dwell time, gap acceptance, walking speed, speed fluxing, obstacle angle step (angular movements performed by a pedestrian to avoid an obstacle), stopping sight distances and blocking compliance. Many of these values can be empirical, but some require local assessment and analysis as the default values do affect modelled outcomes.

At any location where streams of vehicular traffic and pedestrians interact, there will, without doubt, be an impact on travel speeds and times of both road users. In this case, however, as the study was undertaken during the mid-day peak, the numbers of pedestrians crossing were low and because of this, their impact on vehicular travel times/speeds was negligible. The effects of traffic calming interventions could therefore be evaluated solely from a consideration of the change in vehicular speeds and volumes.

The influence of traffic calming measures on vehicular speed is well known (see section 7.4), and the importance of speed in terms of pedestrian safety in the urban road environment is unquestionable. This aspect is, therefore, considered in more detail in the following chapter at situations where there are known issues with vehicle-pedestrian interaction.

7.5.7 Calibration of models

As expected, initial simulation runs using measurable parameter values, assessed values and default values where it was not possible to measure parameters showed that a calibration procedure in line with the techniques outlined in Chapter 6 was required for the base case. Multiple simulations were run to achieve a 95% confidence level in the output in accordance with Table 8 and equation 12. The simulated output flow was compared to empirical data for traffic flow and found to be a reasonable representation (GEH statistic <5, see Table 9).

In addition, headway and speed profiles output for the base case before the consideration of traffic calming measures also compared favourably to empirical values (averages were within 5%, see Figure 56). Correspondingly, the travel times simulated were also within the 95% confidence limit range of observed values.

To ensure that simulated runs for the traffic calming applications would be representative of the effects observed locally, models of the applications were developed using appropriate observed data. In most instances, this was the average of the measurements obtained for each measure from the range of measures considered in Table 15. As the scenarios developed from this data are essentially test cases, the only and critical calibration that could be carried out was to ensure that speed profiles output were representative of those obtained from field observations. These are shown and discussed in the following sections.

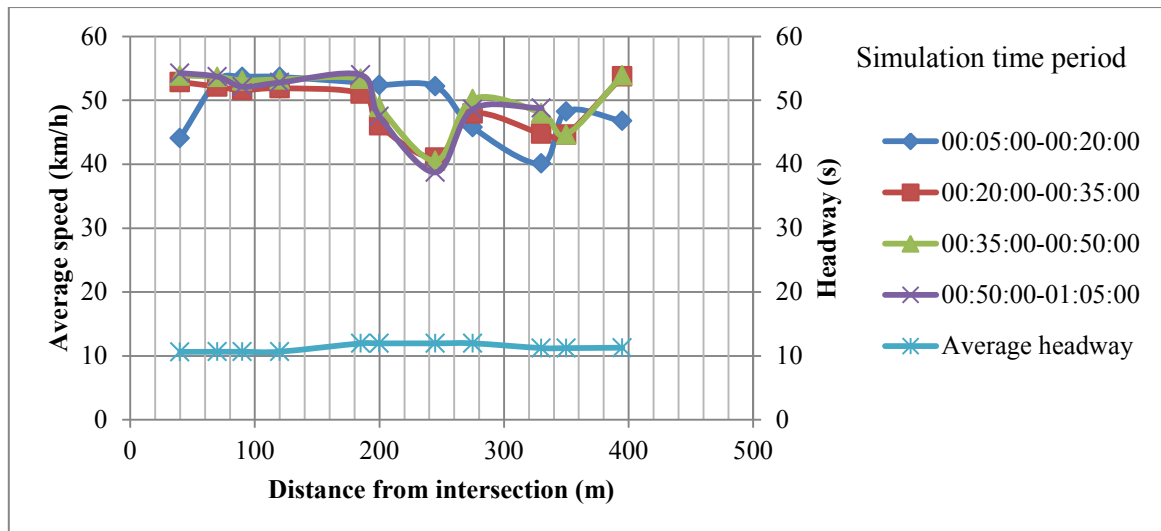


Figure 56: Simulation output of average speed and headway values for the base case

7.6 Simulation model issues

As micro-simulation models are generally aimed at modelling and assessing network performance and optimisation, the modelling of traffic calming measures is seldom straightforward in most simulation packages. At the time of testing, the software PARAMICS and VISSIM, were not designed to incorporate short and sudden changes in either vertical or horizontal alignments (which are the prevalent features of most calming measures). For instance, the minimum node spacing allowable (to form a link or road) in PARAMICS is 5m, which is clearly greater than the width of speed humps in normal use. In addition, the algorithms which simulate vehicle speeds do not specifically cater for changes due to vertical deflections as would be the case for humps, raised crosswalks or other applications which rely on a height differential. However, as is generally the case with most computer models, they are representations of reality and user defined modifications or manipulations can provide similar effects which, with adequate calibration should be close to reality.

Despite the ability to simulate in this manner, the modelling of measures such as: rumble strips, speed warning devices and modified pavement textures, was not possible. Furthermore, the modelling of bicycles, street lighting, landscaping, the proximity of adjacent buildings and different weather patterns - all of which have an effect on vehicle speeds in reality- either did not affect simulated outcomes or was not possible. These influences were therefore ignored for all options.

7.7 Model Outputs

Simulation outputs include all details relevant for traffic efficiency such as vehicular speeds, volumes, queues, hot-spots and so on for all classes of vehicles specified and, for this model, it can also include relevant details on pedestrians. From these outputs, environmental issues due to noise, air pollution and fuel usage can be deduced. Relevant outputs for the study of safety which include dynamic speed profiles, flows, and headways are considered in more detail below. The outputs are considered for a one-hour simulation period, allowing for a five minute 'warm-up' period for the network to settle into normal operational characteristics after an initial feedback period.

Details of modelled measures are as follows:

- Humps – spaced at approximately 75m intervals (intersections dependent), a link speed of 20 km/h at the measure and a 20km/h speed restriction over the hump;
- Two mini-roundabouts at the corresponding intersections (see Figure 51) each 12m in diameter and with a link speed of 40km/h;

- Two chicanes, one on each section of the link in consideration and software imposed speed limits based on the radius of the curve;
- Two raised intersections, again corresponding to the existing road layout, with a link speed of 20 km/h;
- Four sets of narrowings to allow for pedestrian crossings on each side of the two intersections with link speeds at the narrowings set at 40km/hr.;
- A road width of 5.5 metres to simulate a ‘road diet’ with a link speed of 40km/h.

Figure 57 to 62 provide details of the average speed profiles aggregated for all vehicles types over 15 minute simulation time periods for the traffic calming measures modelled. It is also possible to output similar data for disaggregated vehicle types and over different simulation time periods. Differences in the output values of speeds for some time periods are due to the influence of either levels of flow or vehicles turning at intersections along the road.

A comparison between these outputs and Figure 53 (a-d) shows that for all applications where the minimum speed and speed profile were measured, there is a good fit between the observed and output data and profile.

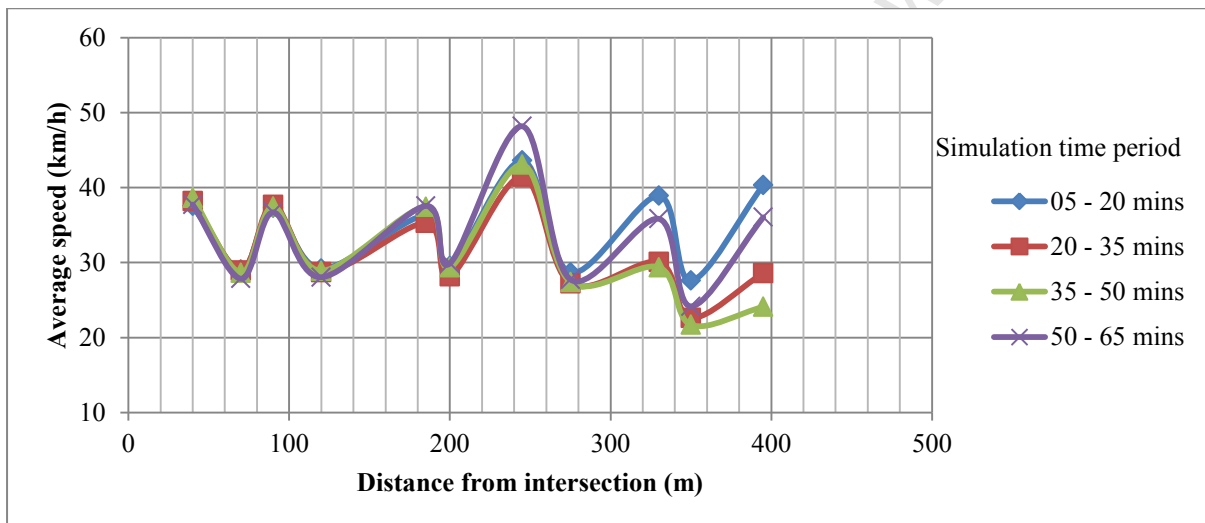


Figure 57: Simulation output of average speed values for speed humps

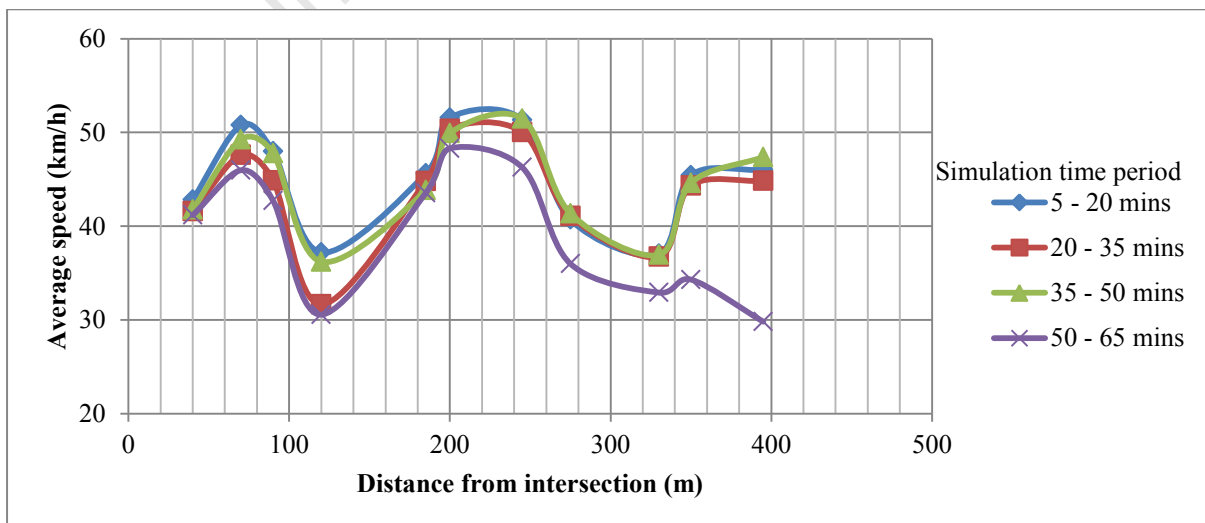


Figure 58: Simulation output of average speed values for mini-roundabouts

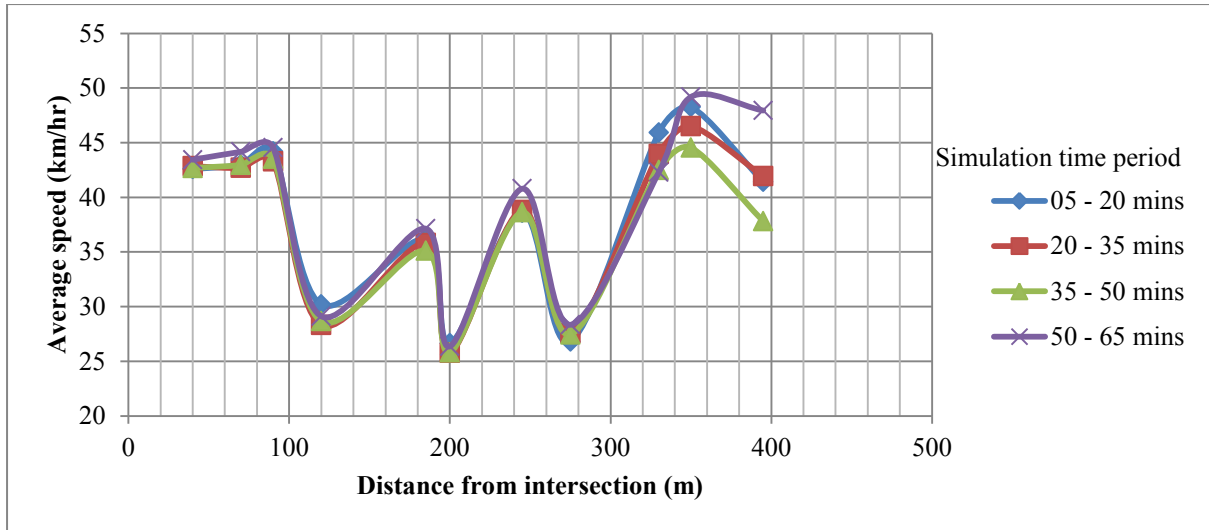


Figure 59: Simulation output of average speed values for chicanes

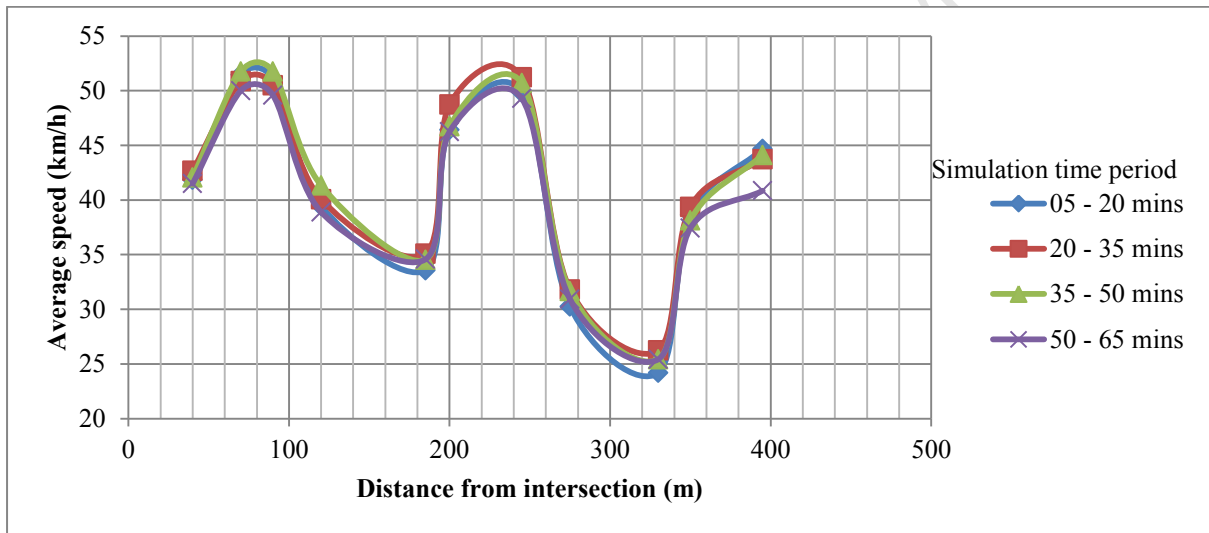


Figure 60: Simulation output of average speed values for raised intersections

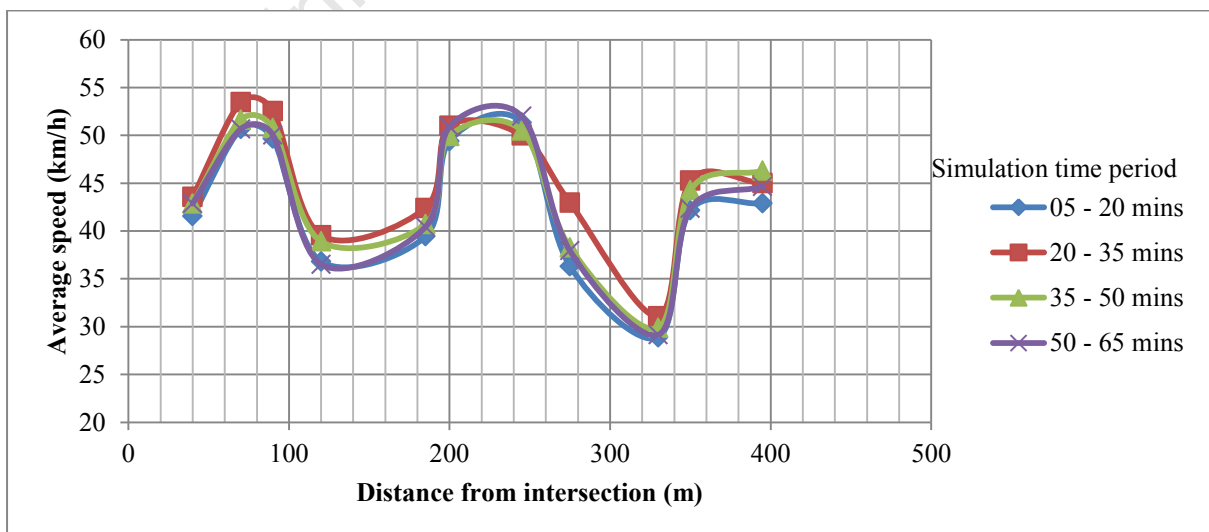


Figure 61: Simulation output of average speed values for narrowings

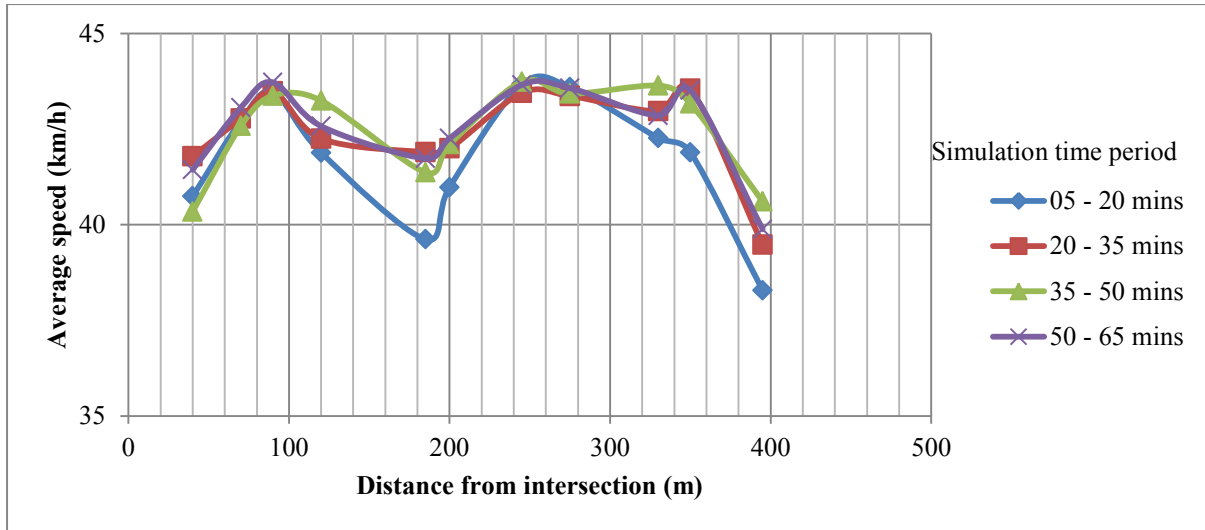


Figure 62: Simulation output of average speed values for road-diets

Table 18 provides a useful statistical comparison between all the traffic calming measures modelled and the base case. Mean speed values can clearly be seen to be less than the base case and vary between measures, but that the simulated mean speed value due to speed humps was predicted to be the lowest - which is reasonable because more humps were simulated than any other measure. The standard deviation value for the measures is an indication of the dispersion of simulated speeds around their mean value. It can also be assumed to represent the degree of safety of the measure because large variations in speed along a stretch of road can present difficulties for both drivers and pedestrians. Furthermore, the variation in speed from the mean can also be a proxy for the environmental impact of the measure, as it is an indicator of the level of acceleration and deceleration levels, which relate directly to emissions. From this analysis, it seems as though a traffic calming measure such as a road ‘diet’, which does not induce large variations in speed would be the best overall form of measure, if it could be implemented in a way which allowed a further, more even speed reduction.

Table 18: Statistical comparison of simulated traffic calming measures

Statistic	No-Calming	Speed Humps	Mini-roundabout	Chicanes	Raised Intersection	Narrowing	Road Diet
Arithmetic Mean Speed (km/h)	49.7	32.7	43.1	38.2	41.2	43.8	42.3
Maximum Speed (km/h)	54.3	48.2	51.6	49.2	51.7	53.5	43.7
Minimum Speed (km/h)	38.7	21.7	29.8	25.8	24.2	28.9	38.3
Standard Deviation	4.3	6.2	5.9	7.3	8.2	6.7	1.3

It is clear from the results that simulation outputs such as these can be used to optimise the design of potential new traffic calming applications – from the range of applications to achieve the desired outcome, to appropriate combination of applications and their spacing - and also to assess the relative effect of particular geometrical features of applications considered. The decision-making process using this type of analysis would be more scientifically grounded, and could encompass the effect of

and on, public transport options. Furthermore, as the gradient of the curves in these results, is an indication of the levels of acceleration and deceleration, the output can be used to determine noise and air pollution levels likely to result from each application and where, with appropriate calibration from the types of vehicles using the road, should these be sensitive issues in the area under consideration.

The application of traffic calming in pedestrianised areas is commonly undertaken throughout the world, not only in terms of textures but also to achieve a reduction in vehicular speeds. Again, it can be seen with output such as this (possibly with the additional consideration of traffic signals); it is relatively straightforward to calculate time available for pedestrians to cross/use shared surfaces and evaluate the impact of applications and changes thereto. This possibility (in terms of safety) is investigated in more detail in Chapter 8.

7.8 Study findings

In comparison to the base case, the simulated outputs for all traffic calming options considered indicate that there would be both speed and volume reductions, at the calming measure (Figure 63 and 64). In particular, they show that speed humps (at an average spacing of 75m), and a choker with a priority to one direction of flow, would have the largest speed reducing impact and, by proxy, would provide the safest infrastructure application. However, from experience, it is notable that measures with priorities in the direction of flow tend to have a disadvantage of stressing drivers to speed up on one of the directions. In this regard the modelling may not be capturing real world behaviour.

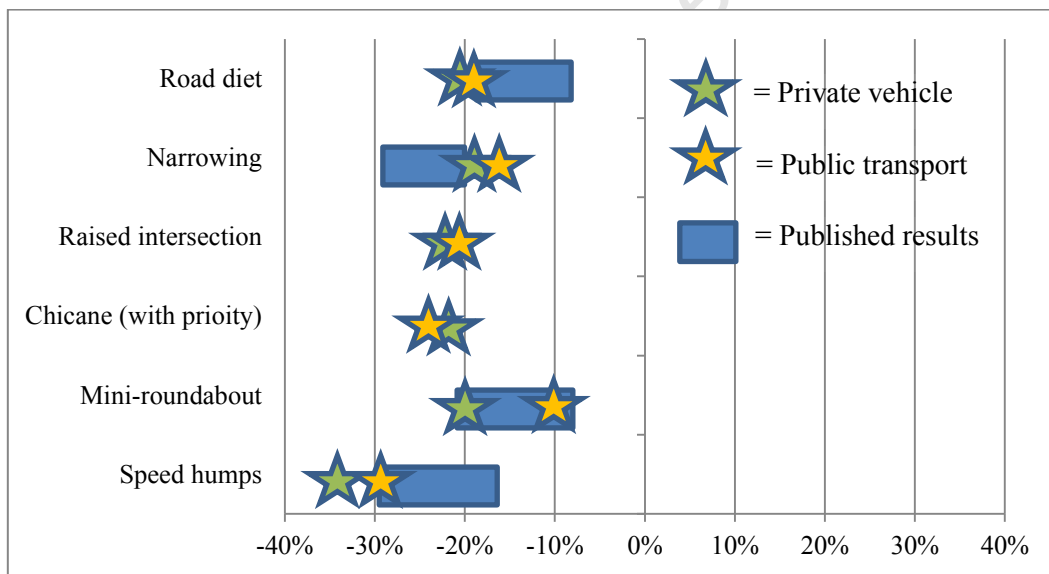


Figure 63: Simulated speed changes for traffic calming measures compared to published results.

The review of contemporary literature on common international road based traffic calming strategies and approaches undertaken, provided details of the relative speed and volume reductions achieved by similar measures already implemented (see Table 14). These findings provided a basis to compare the results of the simulated outputs for the same applications and thus a validation of the simulation method used. From the comparisons (see Figure 63) it can be seen that the simulated speed reductions, specifically in relation to the case of speed humps, were significantly different to published data. Some immediately apparent reasons for this difference are possible differences in the before and after speed limits, the point at which speeds were measured, the time of day of the assessments, the physical design of the measure(s), generalised driving behaviour and differences in law enforcement/driver compliance levels. Clearly, all of these aspects have an influence on the level of effectiveness of a particular measure and, given that the simulation of the speed humps was based

on local empirical evidence - the simulated result is seen as being acceptable and provides a realistic result for local conditions. The remainder of the simulated speed effects are reasonably comparable to published studies.

The simulated effects of traffic calming measures on traffic flow for the range of measures considered were consistent with published results (see Figure 64).

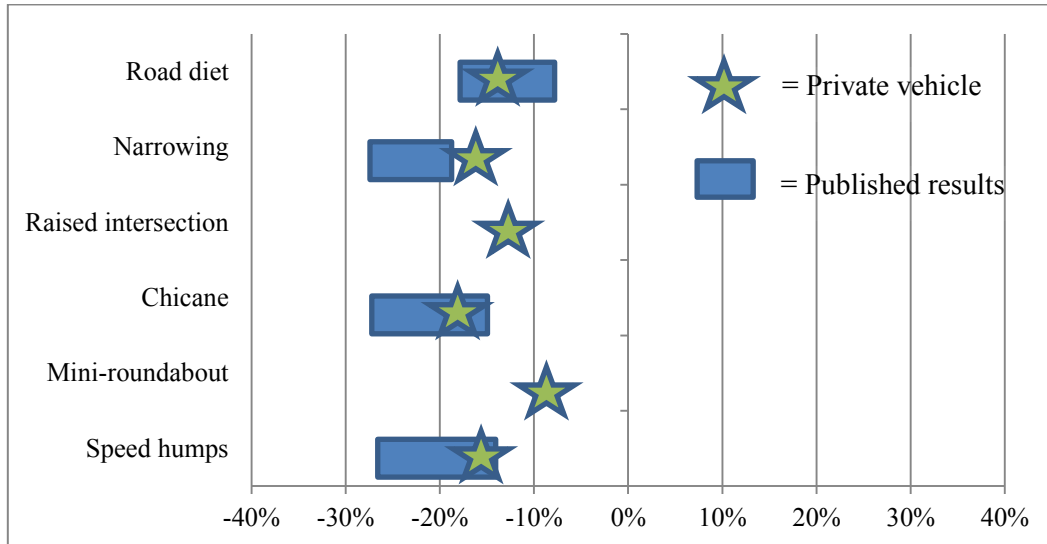


Figure 64: Simulation outputs for volume changes due to traffic calming measures

The main conclusion that is drawn from these findings is that the simulation method used can yield results for speed and traffic flow effects that vary depending on the type of traffic calming measure applied; it can therefore be used for a combination of measures and even area-wide strategies; and the level of impact that is output would be realistic. The method can therefore be used to provide a scientific basis for the evaluation of potential applications. The simulation software is also able to yield results for transport related environmental impacts, network wide volume effects as a result of the application of traffic calming measures, and allows the consideration of strategies such as the location of public transport stops and bus lanes. (The latter is considered further in Chapter 8).

7.9 The significance of model outputs

The simulation outputs confirms that the model can produce results that differentiate potential speed and traffic flow changes for different types of infrastructure interventions. The outputs also shows that the model is sensitive to different transport modes - indicating that this type of analysis could be used to evaluate the potential safety impacts different transport strategies such as public transport priorities or freight corridors.

Tests of the model in relation to changes in spacing of measures show that its output is also sensitive to changes in spacing; therefore the model is able to allow the evaluation of an optimal spacing for safety for specific locations without the need to implement.

The second objective of this analysis was to assess the level of impact that was likely from a particular intervention and, from this, the corresponding change in safety risk and crash severity (i.e., fatal, injury, no-injury). That the simulation outputs, specifically speed and volume, can be used as surrogates for safety risk and its reduction has already been confirmed by, amongst others, the WHO (2004). Generally, volume reductions provide adequate time and gaps to allow safer pedestrians crossings, cyclists to move in greater safety, and a general reduction in levels of exposure. Speed

reductions, on the other hand, are associated with a reduction in the risk of crash occurrence and its severity.

Methods which predict the level of risk reduction as a result of reductions in vehicular speeds and volumes are investigated below.

The US NHCRP (2008b) reported on the findings of a project aimed at developing Accident Modification Factors (AMFs) for traffic engineering and ITS improvements. AMF's were initially developed from using the effects of particular treatments on mean speeds, and from these, estimates of changes in crash frequency were derived. They are often used in program planning to make decisions concerning whether to implement a specific treatment and/or to quickly determine the costs and benefits of selected alternatives. They are also used in project development for non-safety as well as safety-specific projects and could be used by agencies in deciding on policies affecting general project design (e.g., context-sensitive design solutions and traffic calming). AMFs are also key components of the latest safety-estimation tools and procedures including those developed for the US Highway Safety Manual (NCHRP, 2008b).

The study by Nilsson (2004) hypothesised a 'power model' relating the ratio of before-treatment and after-treatment crash frequency to the ratio of before-treatment and after-treatment mean speed raised to some power, with the power changing for different crash severities (see Section 5.5). Elvik et al. (2009) further developed the power model using a large set of data extracted from published research reports (also detailed in section 5.5). The study by the NHCRP (2008b) re-analysed Elvik et al.'s data to determine if such a relationship exists and, if so, whether the power model or some alternative model form best describes the relationship between speed changes and crash frequency. The results of this study supported the existence of a relatively strong relationship between speed change and change in fatal and non-fatal injury crash frequency, and that the speed versus-crash relationship in Elvik's studies was similar to that in the U.S. studies. Quality of fit statistics indicated that both model forms were slightly more accurate than the power model.

The final AMF's published by NHCRP (2008b) for non-fatal and fatal injury crashes for reductions in mean travel speed (see Table E1 in Appendix E) do not provide factors for speed differentials greater than 5mph (8km/h), which means that a further evaluation was required to enable an estimate to be made of the effects from the outcomes of this simulation exercise. This was achieved by plotting predicted AMF's (for the 30mph case) and extrapolating values using reasonable fit curves (a polynomial curve for non-fatal injury crashes and an exponential curve for fatal injury crashes (to avoid a tendency towards a 100% reduction in crashes and to allow a more conservative estimate of AMF's)). The resulting curves were used in the evaluation that follows (see Figure 65).

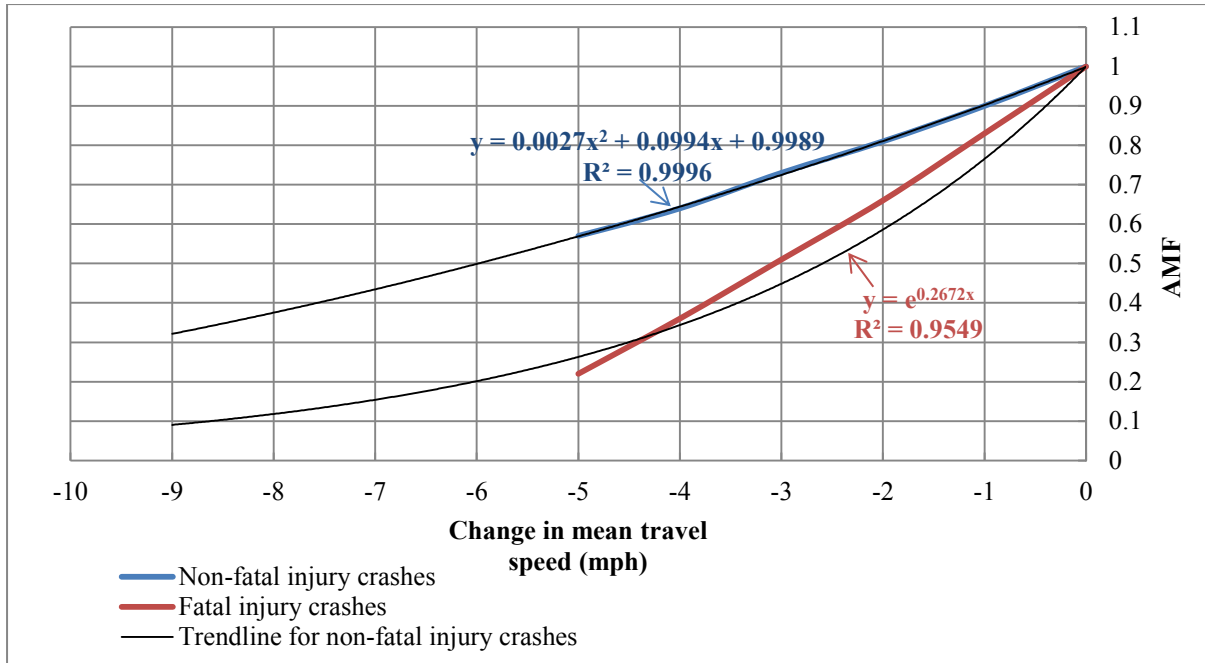


Figure 65: Plots of trend lines for non-fatal and fatal injury crash AMF predictions

Source: Modified using NHCRP, 2008b

A best estimate of the potential reduction in impact of the simulated speed changes as a result of the application of the traffic calming measures modelled onto the study link are shown in Table 19 for the three methods considered in this study. The estimated impacts were calculated using the mean simulated speed reduction for all traffic calming measures (from the observed average speed for the case study link, 45km/h) rather than the maximum as this seemed a more realistic approximation.

Table 19: Estimated safety benefits of speed reductions due to traffic calming applications

Measure	Author/ Technique	Simulated mean speed reduction	Crash type	Best Estimate of reduction in impact (95% confidence limits)
Speed hump/ traffic circle/chicane	Nilsson/ Power model	25%	Serious injury*	50% (27-66%)
			Fatal Injury	65% (60-75%)
	Elvik/ Revised power model	25%	Serious injury*	53% (28-76%)
			Fatal Injury	35% (23-45%)
	NCHRP/ AMF	25%	Non-fatal injury	56%
			Fatal Injury	83%
Choker	Nilsson/ Power model	15%	Serious injury*	32% (16-45%)
			Fatal Injury	44% (32-54%)
	Elvik/ Revised power model	15%	Serious injury*	22% (14-29%)
			Fatal Injury	34% (5-55%)
	NCHRP/AMF	15%	Non-fatal injury	38%
			Fatal Injury	65%
Road diet/tight radius	Nilsson/ Power model	10%	Serious injury*	22% (11-32%)
			Fatal Injury	32% (22-42%)
	Elvik/ Revised power model	10%	Serious injury*	15% (9-20%)
			Fatal Injury	24% (3-40%)
	NCHRP/AMF	10%	Non-fatal injury	27%
			Fatal Injury	47%

Note: *Estimates are for serious injury crashes only, i.e. exclude slight injury crashes.

As expected, the general trend of the estimated impacts confirms that the greater the speed reduction, the greater the reduction in safety risk. There are, however, considerable differences between the results from three methods considered – while the Nilsson and Elvik methods yield reasonably similar results for both injury types, the NHCRP method provides results for fatal injuries that are considerably higher. Despite these differences, all the methods used estimate that a relatively small change in speed should have a large and positive impact on crash risk over a long period at a given traffic volume and if all risk factors remain the same. Therefore, the simulated output can be used to estimate a range of potential impacts and through these, possible cost benefits of individual applications.

The evaluation of potential safety impacts as a result of changes in traffic volumes due to traffic calming is much more complex and case-specific. This is because: i) changes in volumes due to calming measures usually affect the entire network, not just the street in consideration; ii) changes in volume are affected by the availability of alternate routes; iii) the application of other measures in area-wide treatments may have as large an impact on volumes as the geometrics and spacing of calming measures applied to the street in question; and, iv) more significantly, volume impacts depend fundamentally on the split between local and through traffic, even though studies conducted (see for example: Ewing, 1999) confirm that traffic calming measures will not affect the amount of locally bound traffic unless they are so severe or restrictive that they ‘degenerate’ motor vehicle trips.

The location and nature of this area (i.e. it is not in a neighbourhood district or bounded by distributor roads), means that it is unlikely that there would be any through traffic. Therefore, the simulated reductions in traffic flow volumes can be considered as being wholly due to the application of each type of calming measure. Despite this deduction, it would be unrealistic to estimate numerical values for the safety benefits of volume reductions from a short term simulation. The net effect of volume reductions can be generalised as being positive, but it is not possible to rank the effectiveness of measures from volume reductions for such a short term result.

Over a longer term, the studies in section 5.5.2 indicate that reduced congestion and smoothed flow improve safety but this seems mainly to apply to roads of a higher category.

Equation 9 in Chapter 5 can be used to estimate the effect of exposure but it requires an accurate estimate of annual mileage which is difficult if not impossible to obtain from this method. Smeed’s law²⁷ could also apply – he proposed an empirical rule relating traffic fatalities to traffic congestion as measured by the proxy of motor vehicle registrations and country population. Thus, increasing traffic volume leads to an increase in fatalities per capita, but a decrease in fatalities per vehicle.

A possible method that could be used to estimate the safety impact of volume changes is documented in a study by Eenink et al. (2008) where the accident risk per kilometre of various European countries for rural and urban roads and for motorways basis is analysed (see Figure 66). From this graph, and assuming a crash profile which is similar to the ‘Netherlands urban’, a reduction of 10% in the AADT (which is predicted from the simulation output by extrapolation for each measure), would result in a reduction of between one and two crashes per kilometre of road in five years. This result, however, seems unlikely, as crash rates in Cape Town are much higher. For example, pedestrian incidents occurred on average 55 times per kilometre for an AADT of 14,000 on Lansdowne Road (see Chapter 3). Notwithstanding the fact that these incidents have occurred on a road which regularly features at the top of the list for the numbers of traffic incidents annually, the urban crash rate in South Africa is

²⁷ Smeed’s formula is expressed as $D=0.0003(np^2)^{1/3}$, where D is annual road deaths, n is the number of registered vehicles and p is the population (http://en.wikipedia.org/wiki/Smeed's_law).

likely to be far higher than in the Netherlands, which implies that the potential reduction in safety risk as a result of a 10% change in AADT is likely to be greater.

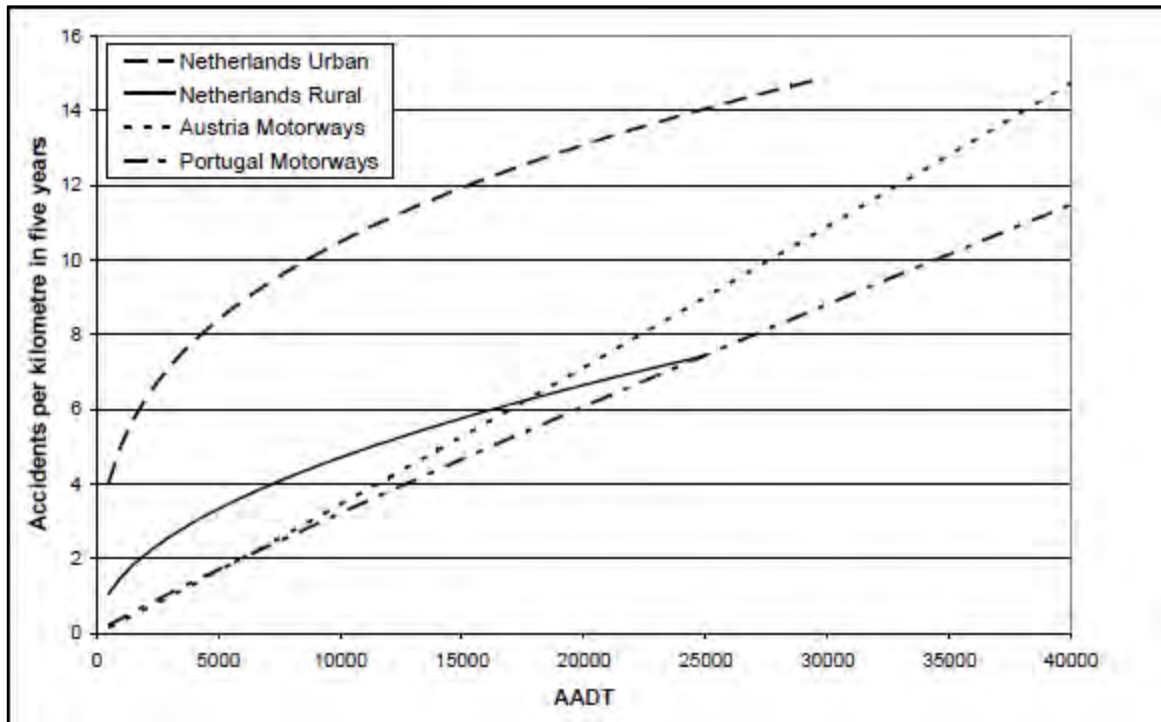


Figure 66: Reported crash rates per kilometre for different road types and AADT's in Europe
 Source: Eenink et al., 2008

In summary, it is significant that this study found that, through some innovative modelling and with careful calibration, micro-simulation can be used to simulate the effect of many traffic calming measures and combination of measures. The results of the simulations allow a distinction to be made between various applications in terms of relative speed and volume changes, and in comparison to the results of published findings, it can be concluded that these effects were simulated with a good degree of certainty. In terms of safety assessment, the simulations have the ability to capture the overall level of turbulence for different measures as a function of their geometric and traffic attributes and, through some post processing, the results, particularly speed reductions, can provide meaningful insights about the likely changes in overall safety. The study therefore confirms that this type of simulation has the potential to be a helpful tool at a decision making level and it provides the opportunity to explore impacts of different traffic calming measures or strategies in terms of safety, traffic and environmental impacts before implementation.

8 Case Study II - Pedestrian/vehicle interaction

8.1 Scope and objectives

The work in Chapter 7 confirms that micro-simulation models can successfully simulate the potential safety effects for a range of traffic calming measures using traffic speed and volumes as surrogates for safety. The work in this chapter adds to it by assessing the potential of simulation models to estimate the relative levels of safety for road infrastructure in two locations and provision levels and with different road user characteristics, within the Cape Town metropolitan area.

Both locations are known to have a history of pedestrian fatalities. Although it is not possible to replicate actual crashes by means of simulation, the aim of the study is to establish whether the simulation model can replicate the (un) safety of the infrastructure and to consider whether the output allows a distinction to be made between the two areas in terms of their relative levels of safety.

At the outset of this study, it was expected that this work, whether successful or not, would reveal many of the possibilities and limitations associated with micro-simulation modelling, and that it would serve to identify and recommend improvements specific to the modelling approach adopted and to the simulation tool used. It was also recognised at the outset that although cyclists can be simulated, albeit not very accurately, there are hardly any cyclists using either of these study areas during the peak hours under consideration and therefore cyclists were excluded from the study.

8.2 Study Areas

The two areas selected for this study were Lansdowne Road in the south-east part of Cape Town (Study Area A) and Coen Styler/Buitengracht Street (Study Area B) in the city centre (see Figure 67 and 68).



Figure 67: Study Area A-Lansdowne Road and vicinity
Source: Google Earth

Over the last 8-10 years, the City's reported crash statistics indicate that both areas have been the scene of many collisions, with a large proportion of pedestrian fatalities or injuries. In particular, Lansdowne Road regularly features in the annual list of worst-known locations for road traffic

fatalities (see Chapter 3). The majority of the fatalities were reported as having occurred during the peak periods, with the highest numbers being during winter.²⁸

The Lansdowne Road corridor is approximately 10km in length (total). It is a major urban arterial linking ‘low-cost’ residential areas (known as ‘townships’) to the Cape Town CBD and other employment areas/activity nodes. The adjacent land uses and direct (informal and unplanned) access to the corridor can be seen to create major traffic conflicts and flow issues.

On much of the northern side of the road the development is primarily residential with schools and other public facilities such as clinics and a library. Mixed land uses are found on the southern side including light industry, offices and warehousing. The width of the road reserve allows for future upgrading to a dual two lane carriageway over the majority of its length; this, along with many pieces of vacant land adjacent to the road, allow pedestrians to take short cuts across the area. Distinctive desire lines towards Lansdowne Road are visible from aerial photographs (see Figure 67).

Street lighting is present along parts of the corridor but its provision is haphazard. Maintenance of the roadway, street furniture and street lighting seems to be either haphazard or poor. Some lighting poles have been damaged (by what appear to be single vehicle crashes), and some lights do not function (light bulbs are missing or dangling for example). Illegal connections to street lighting are at times clearly visible.²⁹

Sidewalks have been provided on both sides for some parts of the road but in the main the provision is haphazard and sometimes unpaved – despite the location of six schools near to the corridor, most of which require scholars to cross the road.

The focus of this case study is on a stretch, approximately 600m in length which consists mainly of dual two-lane carriageways. A signalised intersection (Intersection 1) and a free-flow roundabout (Intersection 2) mark the start and end of the study area. There are no speed limit signs posted in the vicinity, the road is lit on both sides, and pedestrian footpaths are reasonably well provided at both intersections but haphazardly elsewhere. Some pedestrian desire lines across the site are clearly visible, but most of the foot traffic is in an east-west direction, alongside the road. During the morning peak, workers either access formal public transportation at stops located along both sides of the road, or via the randomly stopping, pre-dominant mode of informal public transport (otherwise termed ‘para-transit’). In the evening, similar numbers walk from public transport stops or nearby places of work, to their respective places of residence. From field observations, it is clear that there is a significant amount of jaywalking, mid-block crossing and occasional non-compliant crossings at the signalised intersection.

In contrast to Lansdowne Road, the Coen Styler/Buitengracht Street intersection provides access to two of the major areas of employment and interest in Cape Town – the CBD and the Victoria and Alfred Waterfront (V&A)³⁰ (Figure 68). The intersection is located on the fringes of the CBD and is flanked on the southern side by hotels and on the northern side by landscaped areas and a multi-storey

²⁸ The winter period in Cape Town usually runs from June to August and is characterised by periods of fairly heavy rainfall. December is a period of exceptional numbers of fatalities due to an annual migration of workers from dormitory townships surrounding most large conurbations to their ‘ancestral’ homes or places of birth.

²⁹ Illegal connections to electrical supplies such as those to street lighting are commonplace in many informal/unregistered ‘townships’ as a way of obtaining power (usually not paid for).

³⁰ The Victoria & Alfred Waterfront in the historic heart of Cape Town's working harbour is South Africa's most-visited destination, having the highest rate of foreign tourists of any attraction in the country (<http://www.sovereign-publications.com/waterfront.htm>).

car park. It consists of multi-lane approaches and exits and is heavily trafficked throughout the day because it provides access to and from the two main national routes in the Western Cape, the N1 and N2. The intersection is controlled by a four-stage signal system and all approaches and exits are subject to a 60km/h speed limit.



Figure 68: Study Area B – the Coen Styetler/Buitengracht Street Intersection
Source: Google Earth

The southern side of the intersection (Approach B) is a major crossing point for workers travelling on foot from the railway station (in the south-east) to the dockyards (to the north) and back; as well as for many tourists travelling to and from the V&A Waterfront. This level of pedestrian activity and vehicular traffic resulted in 206 serious pedestrian crashes and 27 fatalities in the period 2000–2008 (City of Cape Town, data received 2010). The vast majority of the fatalities occurred at the site of the main pedestrian desire lines - at the intersection and at some distance away from it - presumably because of the lack of appropriate crossing facilities, and despite a pedestrian signal phase at the intersection. The City's crash records indicate that most of these incidents occurred during the morning and evening peaks when pedestrian flows are at their highest.

8.3 Data collection, analysis and parameter setting

Along with the normal/key data required for model building and calibration, vehicle and pedestrian speeds, travel times and, where applicable, queue lengths were collected. Vehicle speeds and travel times were again collected from a combination of a GPS enabled smart phone application and the in-vehicle video based GPS vehicle tracking system. Pedestrian data were captured manually through field observations and by use of video recordings of the study areas from which walking speeds and compliance levels/ risk-taking behaviour data was extracted.

8.3.1 Traffic flow details

Vehicular and pedestrian flow information for Study Area A was collected during two mid-week days between 16:00 and 17:00 hours, a time-frame that corresponds to the reported period of high vehicle-pedestrian incidents. For Study Area B, vehicle and pedestrian flow details were also collected over

two mid-week days, but between 07:00 and 08:00 hours which corresponds to the morning peak period when there is a high amount of both pedestrian and vehicular traffic.

Being the peak commute period, the traffic composition was found to be relatively consistent throughout for both study areas, with sedan vehicles accounting for 75% of the volume, mini-buses for 10%, light goods vehicles for 12%, heavies for 1% and, buses and coaches for the remainder. Note that a distinct vehicle category is specified in the model for mini-buses as they are (currently) the pre-dominant mode of public transport, albeit semi-regulated. Drivers of these vehicles usually exhibit very different driving characteristics from the norm, such as frequent road-side stops (usually ad-hoc at non-designated areas³¹), and an aggressive, non-compliant (towards the law) driving behaviour. Much of this behaviour is because their livelihood depends upon transporting the maximum number of passengers (who normally travel during the peak periods), usually achieved by speeding and overloading.

It is difficult to accurately model the passage of these vehicles due to their random and unpredictable behaviour. Fortunately, the number of stops mini-bus taxis make during the peak commute hours are relatively few, as most passengers are commuting from origin pick-up points, where the mini-bus would usually be full (or overloaded) to the centre of the city or back (depending on the time of day). Therefore, it is mainly their driving behaviour that is of concern in this study and this can be simulated by assuming higher levels of aggression and risk taking behaviour for this mode.

8.3.2 Speed distribution and travel time data

Speed distributions for vehicles in a free-flow situation (i.e. with a time gap of more than three seconds between preceding and following vehicle) were derived at points 100 metres from each intersection using spot speed measurements from a hand-held speed gun (Figure 69). In addition, average speeds, as well as travel times, were derived from 10 runs using an in-car tracking system. These data were used to compare and calibrate simulated outputs for both study areas.

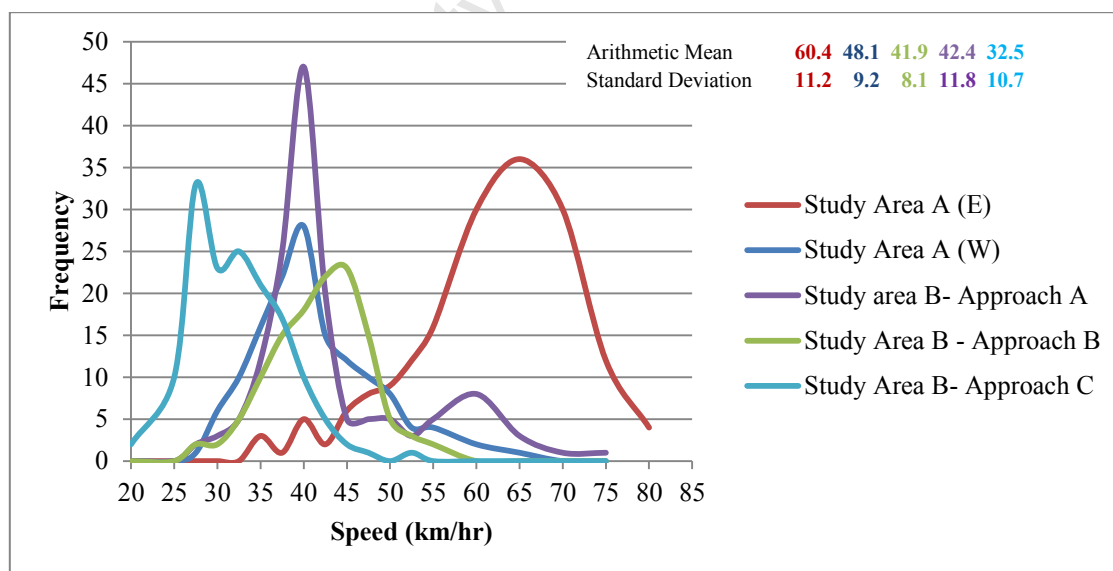


Figure 69: Free-flow spot speed distributions for case study roads

³¹ 'Mini-bus taxis' are mainly operated on a licensed basis (but due to high demand there are numerous unlicensed operators as well). Their permits allow operation either on specific routes or are on a radial basis. Despite the existence of these permits there are few designated stops and the overwhelming majority of operators pick-up and drop-off passengers at any location along their route in accordance with their customers' demands.

8.3.3 Headway data

As one of the aims of this study is the assessment of the relative safety of particular types of road infrastructure, it is critical that the distribution of headways between vehicles on the main approaches to each case study is accurately represented (prior to braking). If the number of shorter headways in the model is overrepresented when compared to the actual situation, the model will simulate a higher frequency of incidents. Conversely, if higher time gaps are overrepresented, then the model will reflect a reduced frequency of likely incidents. The target or minimum headway is also an important calibration parameter.

The eastbound peak hour headway distribution for Study Area A (Figure 70), indicates that approximately 70% of the vehicles were in car-following mode (i.e. driving with a gap of three seconds or less). Whereas for all three approaches in Study Area B there is a significant difference in profiles depending on the direction of travel and, that even at 100m from the signals, the data is affected by traffic volumes (Figure 71).

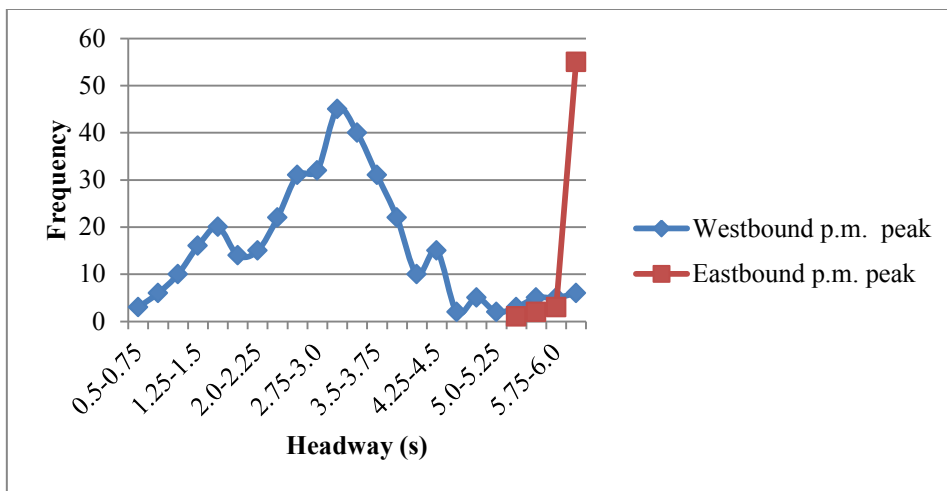


Figure 70: Distribution of observed headway data, Study Area A

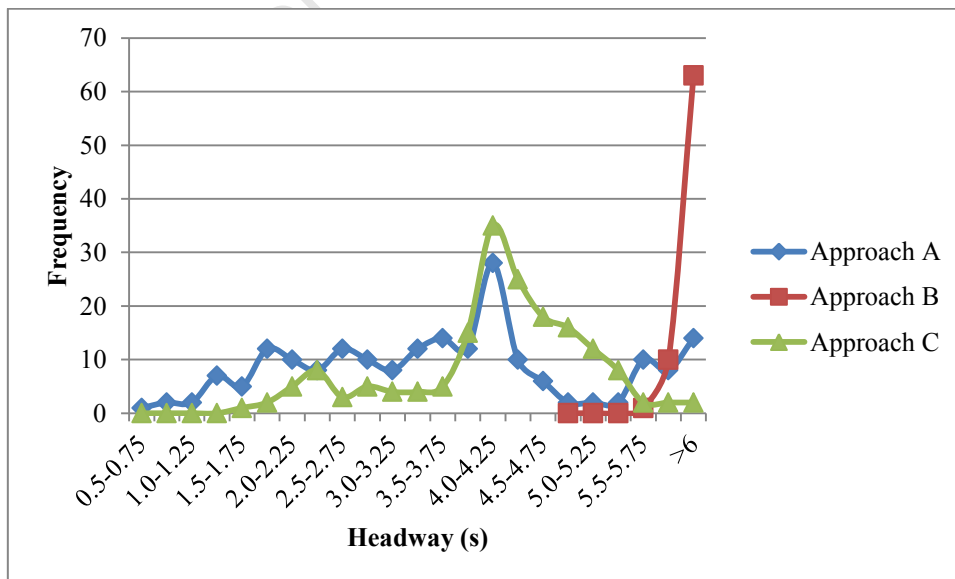


Figure 71: Distribution of observed headway data, Study Area B

8.3.4 Queue lengths

For realistic intersection performance modelling and calibration purposes, average and minimum queue lengths were measured on both study areas by counting the number of stopped vehicles (travelling at a speed of less than 5km/h) between the red and green phases (i.e. 2-3 seconds before the start of the green phase) at intersections that were signalised. Average lengths of queues at un-signalised intersections were based on observed lengths over the time period concerned.

8.3.5 Signal timings

Signal timings have a critical effect on road user speeds as well as on behaviour. Again, for realistic performance and to properly calibrate each model, the signal cycles and timings at each signalised intersection were recorded for the peak periods to accurately simulate these impacts. (Note that the majority of the signals in the study areas operate on a fixed plan during peak periods and are not affected by vehicle actuation loops).

8.3.6 Acceleration/deceleration data

As stated in Section 7.5.5, vehicle acceleration and deceleration rates are important issues in simulation modelling. Valid average rates of acceleration and deceleration when stopping, slowing down to yield, or pulling out from a secondary road, as well as deceleration behaviour in safety critical situations all provide accurate representation of the ensuing safety indicators.

8.3.7 Road-user behaviour

Apart from vehicular speed and headway, other important vehicular behavioural aspects for simulation models are: red-light violations by vehicle drivers (captured through non-compliance levels), driver behaviour towards pedestrians; and important pedestrian behavioural aspects are: risk taking behaviour at crossings (marked, un-marked, mid-block, at signalised and at un-signalised intersections), normal walking speeds and maximum speeds when crossing.

It is difficult to gather empirical evidence of some of these behaviour variables accurately during short survey periods, but anecdotal and general observation of several years of walking and driving in the city can be used to provide appropriate guidance. This guidance, supported by the following studies provided the input data requirements for the models.

Driver yield rates to pedestrians who are on, or are about to cross the road either at a marked crossing or mid-block, are low in Cape Town (see Section 7.4) indicating a generally arrogant driver attitude. This observation is confirmed by a comparative study of general behavioural differences between various cultures/countries by Hofstede (1991), which concludes that South Africans score high on a scale for masculinity and individualism, and average for uncertainty avoidance. Further, 'masculine' cultures are deemed to be less tolerant than 'feminine' ones and, Hofstede notes that high levels of masculinity and uncertainty avoidance are dominant indicators for 'aggressive' driving behaviour. In another study of 10 countries, Sukhai (2010) indicates that South Africa emerged as the country with the highest aggression levels.

In addition to these studies on levels of aggression, Trompenaars and Hampden-Turner, 1998 (in Vanderschuren, 2006) analysed eight cultural groups within South Africa. They concluded that behavioural differences between these groups are large and that differences in road-user behaviour are not only likely, but are probably larger than in many other nations. Despite the age of this report, its findings are still relevant.

In most traffic simulation software, aggressive driving can be set by parameters such as driver reaction times, headway distances, gap acceptance settings and by setting driver compliance levels. In

PARAMICS, global target headway times can be set from known averages. To fine-tune models, the user can adjust individual link reaction and headway times by a factor if required. Alternatively, it is possible to set behavioural factors for driver reaction times, target headways and perception time for particular vehicle types. In this case, headways have already been measured and driver reaction and perception times were set at 0.5 seconds below the default value to allow for the aggressive driving styles. To ensure that the behavioural differences of the mix of traffic was fully represented, different levels of these values were set for each vehicle type.

8.3.8 Pedestrian data

As described in Section 6.2, the modelling of pedestrian movements is complex and presents some specific problems not encountered in vehicular forms of transport models. To try to capture these complex characteristics, the physical features of pedestrian movements like walking speeds, acceleration, gap acceptance, as well as the seemingly random nature of pedestrian behaviours, must be adequately reproduced.

It is possible to measure walking speeds, relative numbers, the category of pedestrian (i.e. commuter, elderly, child and so on), and their relative compliance levels can be set from field observations. It is not possible, however, to measure other characteristics that help simulate a fuller range of pedestrian movements (such as scan areas and behavioural variables) – these require investigation or estimation in relation to their individual and collective impact on the simulation output. In the PARAMICS suite, the parameters identified in Table 20 represent other key values that need to be assessed.

To capture a representative range of pedestrian characteristics, measureable values were collected from field surveys consisting of origin/destination details and, average walking speeds at three distinct locations in the city. In addition, a questionnaire was undertaken at the same locations, designed to capture individual attitude to risk and whether this attitude was influenced by a particular characteristic (such as race, gender, education levels, age, job function etc.); this information was used to determine whether special categories of pedestrians needed to be modelled.

Table 20: Assessment of major pedestrian parameters in PARAMICS.

Parameter	Default value	Estimated acceptable range	Assessment
Obstacle angle step	15°	10- 180°	Requires sensitivity analysis
Maximum search angle	110°	45-270°	Requires sensitivity analysis
Primary scan area			Can be estimated using worst case
Secondary scan area	On	On/Off	Depends on compliance levels
Behaviour: Re-evaluation of compliance time	30s	5-300s	Requires sensitivity analysis
Speed Deviation	Toggle: off	Toggle on :0-5m/s	Can use field data
Compliance level	100%	0-100%	Can use field data
Speed Fluxing	Toggle: off	Toggle on: 0.25-0.5m/s	Works in conjunction with speed deviation. Set as 'off' and use speed deviation.

The parameters identified in Table 20 are defined as follows.

8.3.8.1 Obstacle angle step

The ‘*obstacle angle step*’ controls the degree of movement of a pedestrian when trying to avoid an obstacle, which could be a fence, barrier or even a vehicle. Its default value is set at 15 degrees (Quadstone, 2012). The value adopted in simulations affects pedestrian movement and whether they can become ‘stuck’.

8.3.8.2 Maximum search angle

The ‘*search area angle*’ is the maximum angle that a pedestrian will sweep in order to make a decision on a particular course (such as to cross a road) (Quadstone, 2012). A default value of 110 degrees is set by the software; this value also affects pedestrian movements and whether they can become ‘stuck’ (i.e. the algorithm does not allow the pedestrian to move forward because of this value) in the simulations.

8.3.8.3 Scan area

The method used by the software to replicate visual recognition of vehicles and pedestrians at potential crossing areas, as well as the gaps that pedestrians are willing to accept, is one that uses primary (vehicular) and secondary (pedestrian) scan areas. These are defined by the following factors.

A ‘*primary scan area*’ is used by vehicles to identify an agent (pedestrian) within a shared space area, in order to slow down accordingly. The area is made up of six points and the shape and size of the area is trapezoidal and is initially determined by the vehicle and adjusted by the following factors:

- *Additional start width (A)*: start width increase defined in %
- *Additional end width (B)*: end width increase defined in %
- *Additional width (C)*: width increase defined in metres/feet
- *Extension length buffer time (D)*: buffer time increase defined in seconds
- *Extension length (E)*: length increase defined in metres/feet, and
- *Vehicle wait for non-conflicting agents (F)*: if enabled a vehicle will wait for all agents within the primary scan area. If left unchecked a vehicle will only wait for agents which conflicts with their path and will ignore agents who do not conflict with their path

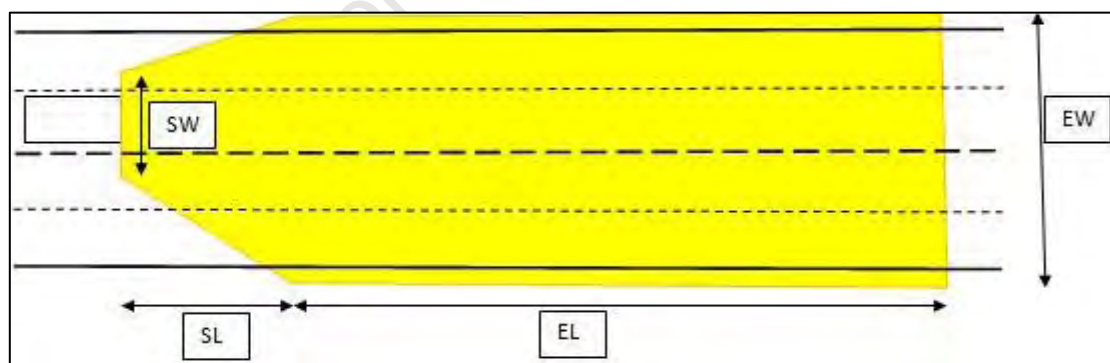


Figure 72: Diagrammatic representation of the Primary Scan Area as used in PARAMICS

Source: Quadstone PARAMICS, software active-help

Using the factors above the four main measurements: SW, EW, SL and EL are calculated as follows:

$$EW = (\text{Total Link Width} \times B) + C \quad (13)$$

$$SW = \text{Width of Vehicle} + ((EW - \text{Width of Vehicle}) \times A) + C \quad (14)$$

$$SL = vt + [v^2/2(d+0.1a)] \quad (15)$$

Where, v = speed of vehicle;

t = driver-perception reaction time (set by user per vehicle type)
 d = maximum deceleration of vehicle
 a = longitudinal gradient

$$EL = (\text{Vehicle Speed} \times D) + E \quad (16)$$

A secondary scan area or ‘agent detection area’ is used by agents to identify whether there is enough time to safely enter and complete their crossing (see Figure 73). The area is made up of four points and the shape and size of the area is determined by the parameters below (Quadstone, 2012):

- *Agent speed and distance collision detection (A)*: if left unchecked agents will not enter the crossing and will wait whenever they are inside the secondary scan area. If enabled, agents will carry out additional checks -based on vehicle distance and travel speed - to see if they are able to enter shared space and safely complete their crossing without conflict.
- *Additional width (B)*: width increase defined in metres
- *Nearside lane buffer (C)*: nearside lane buffer increase defined in seconds
- *Additional nearside lane length (D)*: nearside lane length increase defined in metres
- *Additional lane length (E)*: lane length increase defined in %
- *Additional gap finding buffer (F)*: gap finding buffer increase defined in seconds.

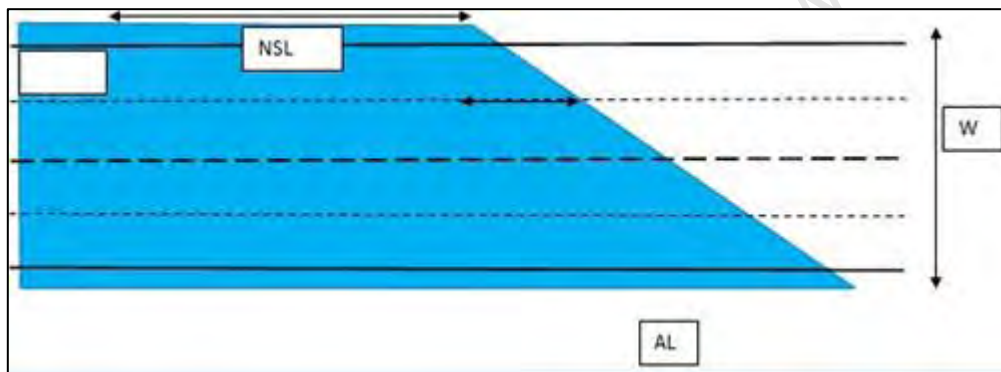


Figure 73: Diagrammatic representation of the Secondary Scan Area in PARAMICS

Source: Quadstone PARAMICS software active help (unpublished)

Using these factors the three main measurements are calculated as follows:

$$W = \text{Total Link Width} + A \quad (17)$$

$$\text{NSL} = \text{Vehicle Speed} \times B + C \quad (18)$$

$$\text{AL} = \text{NSL} \times D \quad (19)$$

8.3.8.4 Behaviour

Pedestrian compliance levels can be set using either a ‘blocking region’ or a separate, more global behaviour setting of compliance. ‘Blocking regions’ are used to forcefully control the flow of agents, usually at intersections. They are Boolean gates – either open (allowing agents to move forward) or closed, depending on the option specified by the user. The level of compliance in relation to this form of control is a user-defined value. In addition, the software allows an option for pedestrians to re-evaluate their compliance levels after a given amount of time³².

³² Agents are allowed an internal ‘patience’ value normally distributed around a mean value. Whenever an agent decides to be compliant (in situations when they have a choice) they will remain so until this patience threshold is exceeded, at which point they will re-test their compliance and decide if they will continue to wait or seek to cross if an opportunist gap becomes available (Quadstone, 2012).

The questionnaire supplemented by field observations in the three different locations indicated elevated levels of pedestrian risk acceptance in relation to road crossing. An average of 65% of questionnaire respondents were categorised as accepting a high risk level based on their attitude to crossing busy roads (in the relevant locations) with a 60km/h speed limit (n=297). This informed the parameter of blocking compliance (at signals, via '*blocking regions*'), and confirms that a large proportion of pedestrians jaywalk (which was observed during the survey and is known to be a common occurrence).

Speed fluxing is used to calculate the base pedestrian speeds and deviation thereto. The fluxing process is designed to create an average crowd speed based around a mean and associated distribution; fluxing allows the provision of representative results for crowd behaviour without the need for multiple sensitivity tests and averaging of results. Due to people's ability to stop, start, accelerate, decelerate, and completely change direction in a fraction of a second (unlike vehicles) crowd fluxing is used to dramatically reduce the time between network development and extraction of meaningful analyses. Users can alternatively define multiple agent types with specific speed distributions representing a particular demographic i.e. the elderly and the young, through the use of speed deviation should they wish to do so.

In the majority of cases there is limited need to define different agent types in detail as the software's internal crowd model continually fluxes the agents kinematic attributes to introduce typical random noise into the crowds performance and therefore into each individual agent.

The survey of walking speeds (measured along paths adjacent to the road and at appropriate crossing points) indicated that average walking speeds varied between 1.1 and 1.4m/s. Using these values, global model pedestrian walking speeds were set at an average of 1.2m/s with a 'fluxing' of 0.25m/s. The modelling of the possibility of extreme speeds in exceptional circumstances (such as when running across the road) was investigated via a sensitivity analysis of the '*base speed deviation*' as detailed in Table 21.

8.3.8.5 Parameter sensitivity analysis

Using Study Area B as a test case, Table 21 provides details of the relative sensitivity of vehicular travel times and flows for each approach, pedestrian walking speeds, overall mean travel time and overall numbers in the network (for the intersection) to modified values of adjustable pedestrian parameters (as identified in Table 21). Values for '*obstacle angle step*' and '*maximum search angle*' were individually modified. Values for the other parameters are set either at worst case levels or at surveyed values. There is some interdependence between these variables and because of this as well as the number of available adjustments, the analysis was undertaken using default or worst case values, as appropriate.

Table 21: Sensitivity analysis of non-measurable pedestrian parameters in PARAMICS

Parameter	Parameter set		Effect	
	Default Values (1)	Modified Values (2)	Vehicles	Agents
Obstacle Angle Step	15°	30°	Approach A /exit – flow: + 9%, TT: +3% Approach B/ exit – flow: -18%. TT: -3% Approach C/ exit – flow: -1%, TT: -15%	Mean average speed: +1% Mean average travel time: -4% Total number in network: -1%
Maximum Search Angle	110°	180°	Approach A /exit – flow: + 7%, TT: -10% Approach B/ exit – flow: +10%. TT: -7% Approach C/ exit – flow: +4%, TT: -7%	Mean average speed: +1% Mean average travel time: -3% Total number in network: -1%
Primary Scan Area				
Additional start width	0			
Additional end width	100			
Additional width	0	33	Approach A /exit – flow: + 18%, TT: -10%	Mean average speed: -9%
Extension length buffer time:	1.0		Approach B/ exit – flow: +7%. TT: -18%	Mean average travel time: -5%
Extension length:	0		Approach C/ exit – flow: +3%, TT: -10%	Total number in network: +2%
Vehicle wait for non-conflicting agents	Off			
Secondary Scan Area (Agent detection area)				
Agent speed and distance collision	On	Off	Approach A /exit – flow: + 0%, TT: -25% Approach B/ exit – flow: +15%. TT: -25% Approach C/ exit – flow: -1%, TT: -21%	Mean average speed: -10% Mean average travel time: -9% Total number in network: -1%
Behaviour: :				
Compliance level	100%	50%	Approach A /exit – flow: -12%, TT: +19% Approach B/ exit – flow: -9%. TT: +6% Approach C/ exit – flow: +2%, TT: -6%	Mean average speed: +12% Mean average travel time: -7% Total number in network: -12%
Mean re-evaluate compliance time	30s	10s	Approach A /exit – flow: -11%, TT: +17% Approach B/ exit – flow: -8%. TT: +2% Approach C/ exit – flow: -11%, TT: +8%	Mean speed: +7% Mean average travel time: -4% Total number in network: -5%
Base Speed Deviation	On	Off	Approach A /exit – flow: + 13%, TT: -16% Approach B/ exit – flow: +14%. TT: -17% Approach C/ exit – flow: +9%, TT: -4%	Mean average speed: +33% Mean average travel time: -42% Total number in network: -24%
Compliance level	100%	70%	Approach A /exit – flow: +19%, TT: -28% Approach B/ exit – flow: +20%. TT: -20% Approach C/ exit – flow: +11%, TT: -18%	Mean average speed: +30% Mean average travel time: -39% Total number in network: -21%
Speed Fluxing	Off	On	Approach A /exit – flow: + 15%, TT: -5% Approach B/ exit – flow: +16%. TT: -15% Approach C/ exit – flow: +1%, TT: -4%	Mean average speed: +5% Mean average travel time: -9% Total number in network: -3%

From this analysis, the obstacle angle step value used in the simulation was the default value as larger values increased the coarseness of agents' path evaluation and introduced unnecessary delay into the system.

The maximum search area angle set at 180 degrees provided a better simulation for urban contexts where 'jaywalking' is prevalent and where vehicles are more likely to be encountered from more than one approach at intersections. However, there is an impact on vehicle flows but this was mainly due to the coding of the road as a shared and 'aggressive' surface which reflects the reality of the situation.

The modification of the 'primary scan area' value, in this case to allow for right turners (and thus the worst-case value), seems to improve the overall performance of both vehicles and pedestrians. It is not entirely clear why this should be the case – one possibility is that both vehicles and pedestrians are more aware and therefore vehicles moderate their speed and pedestrians avoid conflicting situations in greater numbers.

As would be expected, blocking compliance values set at observed values (i.e. below default values) using a 'blocking region' influences both vehicular and pedestrian travel times and flows. In theory, the value to be used needs to be as observed; however, it was clear from the simulations that using this value lead to unrealistic crossing behaviour but values closer to 100% compliance produced better results. Similarly, the re-evaluation of compliance levels to values lower than the default triggered abnormal and unrealistic crossing behaviour and the value was therefore left at the default value in the analyses.

Both base speed deviation and speed fluxing values affect vehicular travel times and volumes and, as suggested by the software's help files, local conditions are better matched by setting a speed deviation value appropriate for disaggregated agents based on observational surveys.

In addition to these parameters, it is possible to categorise the shared road surface in terms of 'courtesy', 'priority' or 'aggressive' types. In both case study areas, normal practice where no jaywalking occurs and there is close to a 100% compliance level, the specification of the shared surface would be 'courtesy'. However, field observations (and the known general nature of pedestrian behaviour in South Africa) indicate that 'jaywalking' is prevalent in both study areas and therefore a different shared surface specification is required.

Figure 74 illustrates a hypothetical but typical pedestrian crossing situation in Cape Town (both at mid-block and at intersections), where pedestrian A would cross when a large enough gap (Gap A) presents itself. Pedestrian B has already begun to cross using a smaller gap (Gap B). Pedestrian C is waiting mid-block for a suitable gap and pedestrian D has not reached the road yet. This situation implies that 'shared aggressive' spaces (i.e. where vehicles and pedestrians effectively compete for road space within defined gap acceptance rules to reach their destination or goal) need to be specified where vehicles and pedestrians interact, along with a compliance rate at intersections that is appropriate to local conditions.

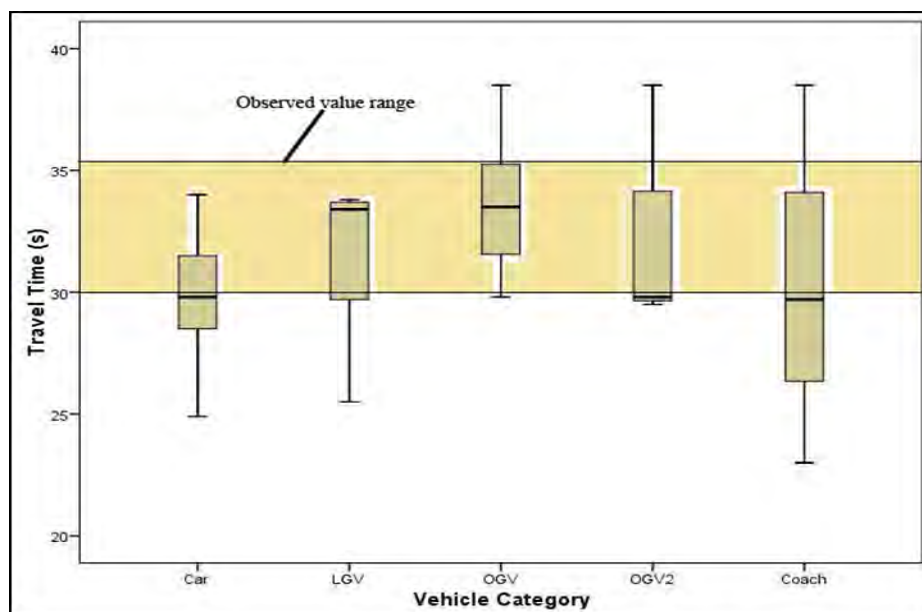


Figure 75: Comparison of simulated travel time and field values for Study Area A

Given the sheer number of potential parameters that can be adjusted as well as their combinations, a practical approach was used where available parameters were divided into two categories: parameters about which there was reasonable certainty, and therefore no reason to adjust; and parameters which were less certain and required evaluation. Observed data served as values for the majority of the adjustable parameters, leaving those that required evaluation to a minimum; these values were mainly related to road-user behaviour (such as compliance and reaction times), which are difficult to collect from the field. The latter was then sub-divided into a set that impacts capacity and a set that impacts route choice.

From an acceptable range of values for parameters for vehicles and pedestrians requiring specification, key parameters were determined by plotting output values for performance measure in histogram or X-Y format as per the calibration process detailed in section 6.6.

For vehicles, the key parameters were found to be Mean Target Headway (defined in time units as the gap between a leading and following vehicle and is related to driver aggression levels), Mean Driver Reaction Time (also measured in time units and defines driver awareness levels) and the assignment matrix type. Whereas, for pedestrians, blocking compliance levels (i.e. levels of jaywalking), the primary scan area and the base speed deviation values were found to be the most significant parameters.

Setting these values at appropriate assessed levels provided modelled outputs for both study areas for traffic flows, travel times and average speeds as well as average walking speeds. These were within a band of observed values or within a small error and, for flows provided GEH values of less than five for all approach volumes (see Table 22).

Traffic flow rates, travel times and speeds were validated against a second set of observed data for a different time period, to ensure that the correct road user characteristics were being simulated by the adjusted set of parameters.

Table 22: Case studies: Observed and simulated values for vehicle/pedestrian characteristics

Study Area	Vehicles							Pedestrians	
	Flows (vph)			Mean Travel Time (s)		Average Speed (km/h)		Average Free Flow Speed (m/s)	
	Observed	Simulated	GEH	Observed	Simulated	Observed	Simulated	Observed	Simulated
A (Lansdowne Road)									
Eastbound	923	936	4.5	35	33-36	60.3	62.5		
Westbound	1702	1692	5.0	56	47-79	41.0	39.6		
East- west								0.8-2.2	0.8 -2.9
West- east								0.9-2.8	0.8 -2.9
B (Coen Styler)									
Approach A	5860	5821	4.4	75	51-92	42.4*	28-63		
Approach B	312	324	2.5	35	29-41	41.9*	32-52		
Approach C	2502	2464	4.2	85	60-108	30*	22-37		
East- west								0.9-2.7	0.8 -2.9
West- east								0.9-2.2	0.8 -2.9

Notes: Travel times for Study Area B are up to the signalised intersection.
 All speeds measured at approximately 100m from intersections.
 * For inner two lanes only.

8.5 Simulation model issues

Whilst the aim of this process is to achieve a high a level of representative interaction, there are a number of recognised limitations and issues that cannot be resolved:

- Overtaking and random lane-changing that occurs occasionally is (understandably) not specifically catered for;
- Similarly, no unusual manoeuvres (such as U-turns) are catered for; and
- Changes in driving/in-vehicle visibility as a result of the weather are also not specifically catered for.

Aside from the above, and despite the calibration process (which was acceptable in terms of road user speeds and flows), a visual inspection of the simulation animations indicated that, in some instances vehicles ceded priority when they encountered jaywalking pedestrians despite trying the different combinations of shared surfaces available. The opposite is more usual in South African cities, however – empirical evidence shows that vehicles seldom give way to pedestrians even at marked crossings and because of this, pedestrians use individual gap acceptance criteria based on their anticipation of vehicle speeds to either cross at appropriate speeds (i.e. in excess of normal walking speeds), or to stop between lanes to complete their manoeuvre. It is probably these manoeuvres that result in misjudgements and, consequently in incidents.

The software's help files provide some contradictory guidance on this issue, and neither the 'primary' or 'secondary scan area' settings, nor an extension of the 'vehicle aware' envelope to beyond recommended stopping sight distance criteria resolve this issue.

Another issue encountered was the setting of pedestrian compliance levels. The software allows its coding in three different places: at a global level in the core attributes, specifically at a 'blocking region' and in an 'agent space' behaviour tab. Help files that clarify the interaction between these are not provided; and tests show that they clearly do interact. Therefore, in order to simulate representative behaviour, it is necessary to trial many combinations to achieve a satisfactory result and this can only be verified by review of simulated behaviour in the animation files.

8.6 Main simulation results

Safety indicator results are reported on in three ways in this section: firstly through a review of the event data output in terms of the surrogates for safety of speed, headway and volume; secondly through an investigation of proximal indicators; and thirdly through the simulation of potential conflict types, especially the prediction of vehicle-pedestrian conflicts. An overview of the way in which these indicators are used here follows below and their assessment for each study area is detailed from section 8.6.1 onwards.

Apart from the surrogates of safety which are detailed in the previous chapter, safety indicator results can also be obtained by relating post-processed frequencies and severities (using the Required Braking Rate concept) of proximal safety indicator measures including: Time-to-Accident (TTA), Time-to-Collision (TTC) and Post-Encroachment Time (PET) and comparing them to observed values where appropriate. However, it is unlikely that there would be many vehicular conflicts at either of these areas given their layouts and operational characteristics. In addition, there are a number of differences in the way in which conflicts can be determined in a simulation model and the way they are observed or defined using the TTA or TTC techniques. In a simulation model, conflicts require a collision course, whereas, for example, the TCT requires road user behaviour ‘suggesting’ a collision course. This is an important distinction as simulation models exclude the possibility of ‘swerving’ and ‘accelerating’ as evasive actions. Furthermore the TCT defines the point of conflict where and when evasive action is undertaken. In traffic simulation models the defining point can only be determined as a point when the level of deceleration reaches a threshold value (for example a value of -2m/s^2).

A more useful and reliable indicator for safety in this study would therefore be the deceleration rates of vehicles during the simulation period. Using the values for Deceleration-to-Safety (see Table 23) proposed by Hyden (1996) and by referring to the Deceleration Rate to Avoid Collision proposed by Cunto (2008) a modified scale of conflict level is proposed in the following evaluation. (The modification is proposed because since Hyden’s original evaluation, efficiencies and levels of braking systems in modern vehicles are considerably improved and most vehicles now have anti-lock systems as standard, both of which are posited as having helped to increase vehicle speeds and also promoting harsher braking levels than before. In proposing the modification, lower than maximum values have been adopted in recognition of the fact that the average age of vehicles in Cape Town is around 10 years (which is also set as a simulation parameter)).

Table 23: Deceleration-to-Safety braking levels proposed by Hyden (1996)

Conflict Level	Deceleration-to-Safety	Description
No conflict	Braking rate $\leq 0 \text{ m/s}^2$	Evasive action not necessary
No conflict	Braking rate 0 to -1 m/s^2	Adaptation necessary
1	Braking rate -1 to -2 m/s^2	Reaction necessary
2	Braking rate -2 to -4 m/s^2	Considerable reaction necessary
3	Braking rate -4 to -6 m/s^2	Heavy reaction necessary
4	Braking rate $< -6 \text{ m/s}^2$	Emergency reaction necessary

Besides the braking data, a raw-data file containing the variable values for each individual vehicle and its trajectory can be generated during each simulation run. The file contains a row of data for each vehicle at a twice per second interval during simulation, including: simulation time, vehicle number, x y coordinates, vehicle type, vehicle speed, vehicle acceleration, link number, link speed, radius and number of lanes.

From the vehicle trajectory co-ordinates, it is possible to identify their temporal positions and vectors and, from this, a likely safety critical event for emergency braking, which is defined as deceleration rates over -7m/s^2 . A simplified classification of the more common forms of incidents that could occur, at either of these study areas, is indicated in Figure 76, and is used in the following analysis for both study areas (see sections 8.6.1 and 8.6.5). All other types of conflicts are not considered owing to their low frequencies and relevance to this study.

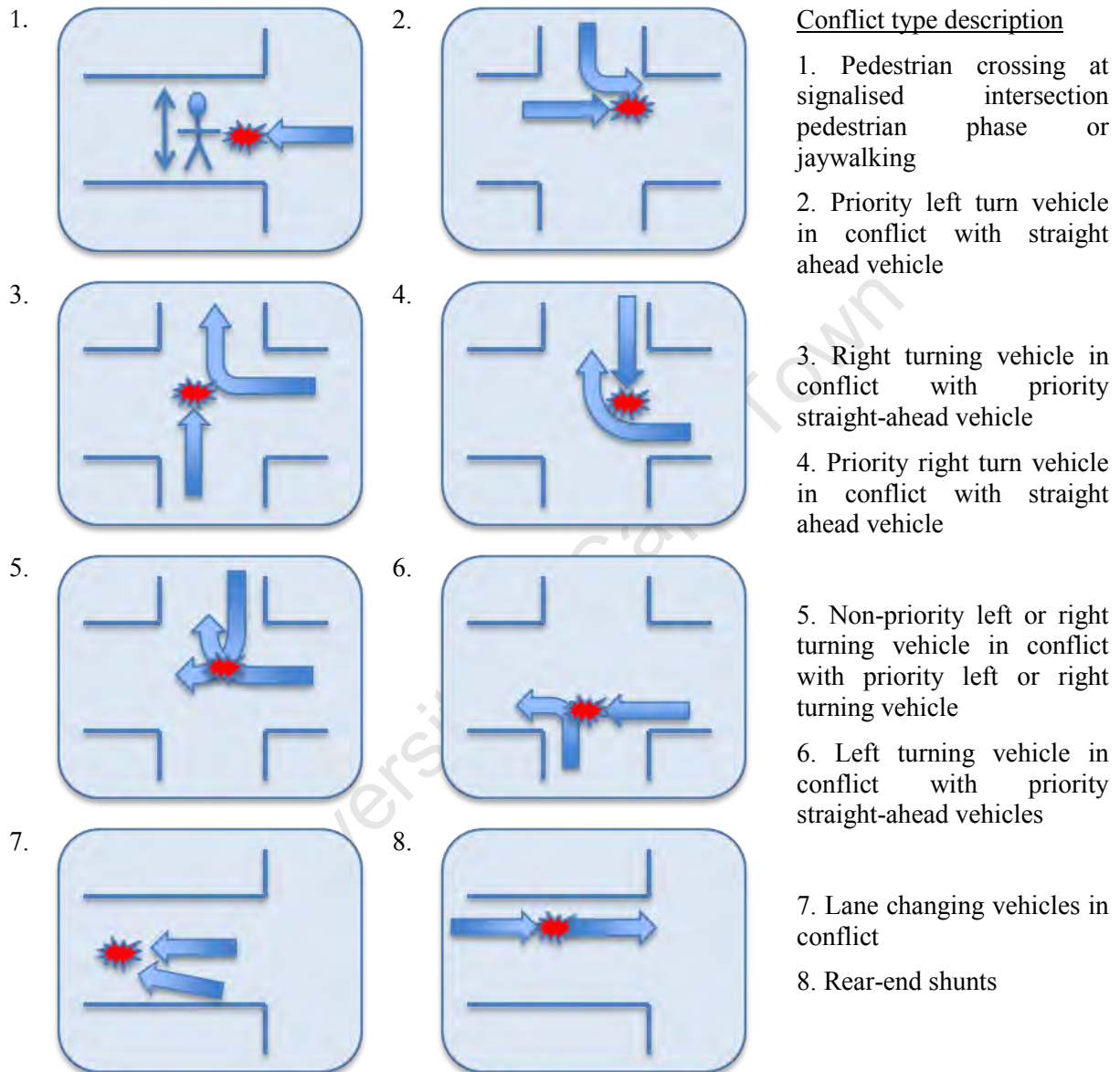


Figure 76: Classification of potential conflict types

To identify vehicle-pedestrian incidents in more detail, a feature of the software - an ‘agent collisions’ viewer is used. As the name implies, it is a graphics file that provides a visual recording of potential vehicle-pedestrian incidents and their locations (see Figure 77 for example). A file logging these events is also generated by the simulation and this in combination with the vehicle trajectory details at the time and place of the predicted incidents provides the requisite details for a thorough review of likely pedestrian incidents.



Figure 77: Screenshot of potential vehicle-pedestrian incidents

Finally, as an extension of the work conducted in Chapter 7, sections 8.6.3 and 8.6.6 detail the results of investigations into possible (and appropriate) modifications to each study area respectively, to establish whether the simulation can provide outputs of safety-critical events, types of vehicle-pedestrian conflicts and surrogate safety details that can be compared to the base case to demonstrate the safety benefit of the modification.

8.6.1 Surrogate safety event data: Study Area A

Event data generated from the simulation software that can be used for safety, ranges from vehicular data on queues, turning movements and link data in terms of speeds, headways, flows, density and travel time.

Data related to vehicle speeds, headways and flows - being the key determinants of the relative safety of this area - are reported on below (see Figure 78 and 79). Vehicle flows are mainly in the eastbound direction in the evening peak but there is also a fairly significant flow in the westbound direction. The density of the flow allows vehicles to travel at between 45 and 60 km/h in both directions with the greater speeds being in the westbound direction. The levels of flow also influence the headways between vehicles which, as can be seen, are at lower values in the eastbound direction. These factors indicate that the eastbound direction should be more critical in terms of vehicle-vehicle safety and also vehicle-pedestrian safety; however, this will also be influenced by the nature, direction and crossing characteristics of pedestrians.

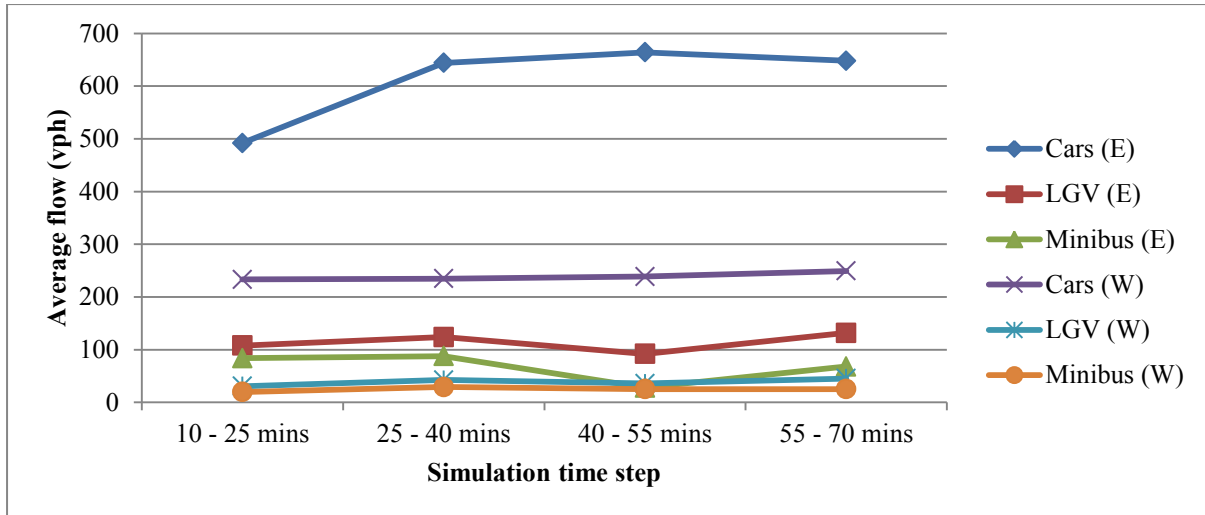


Figure 78: Study Area A- Average flows on Lansdowne Road for different vehicle categories

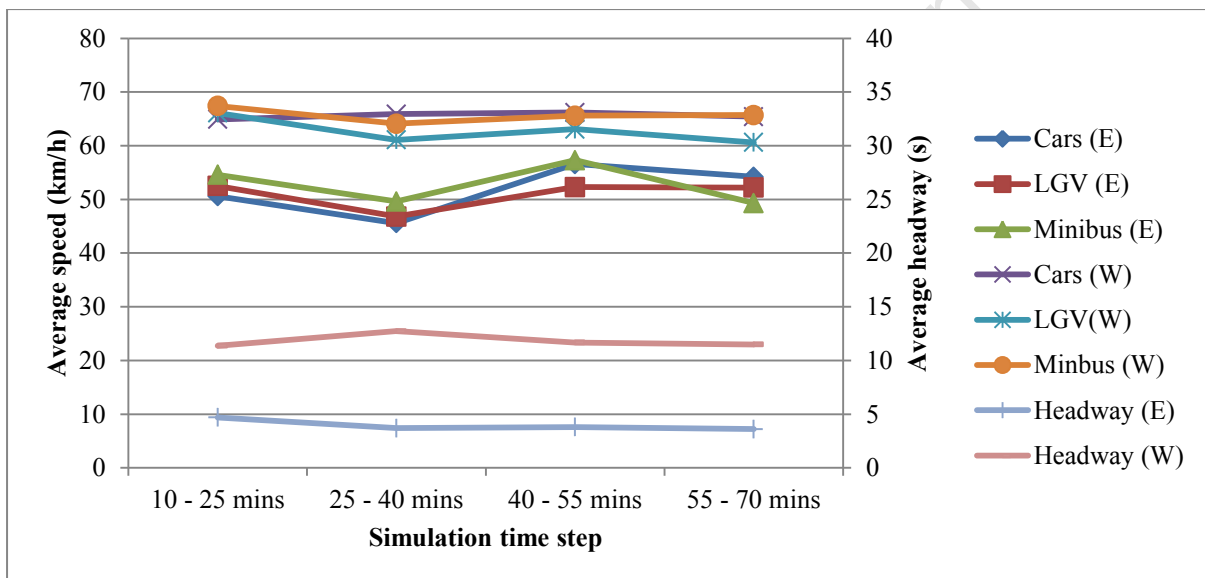


Figure 79: Study Area A - Average speed and headways in each direction on Lansdowne Road

8.6.2 Proximal safety indicators: Study Area A

The output data also includes trajectory files of every vehicle at intervals related to the simulation time step. A scatter plot of the speed and deceleration of each vehicle for rates greater than 0.5m/s allows an evaluation of the likelihood of the occurrence and severity of safety critical events (Figure 80). The number of events is influenced by the fact that the trajectory file output is recorded in accordance with the simulation time step for each vehicle as it travels through the intersection, resulting in multiple recordings for each vehicle over the simulation time period. The cumbersome nature of the output file and the sheer volume of data (over 1 million lines) make it difficult to reduce the data to a single event per vehicle for all braking thresholds; however, as the point of this exercise was to establish whether safety-critical events (i.e. those with a deceleration rate of greater than 7 m/s²) occur on this road, further post-processing of this plot was not undertaken because, despite some duplication, the results clearly show that there would be many hard braking events on this intersection in its current form.

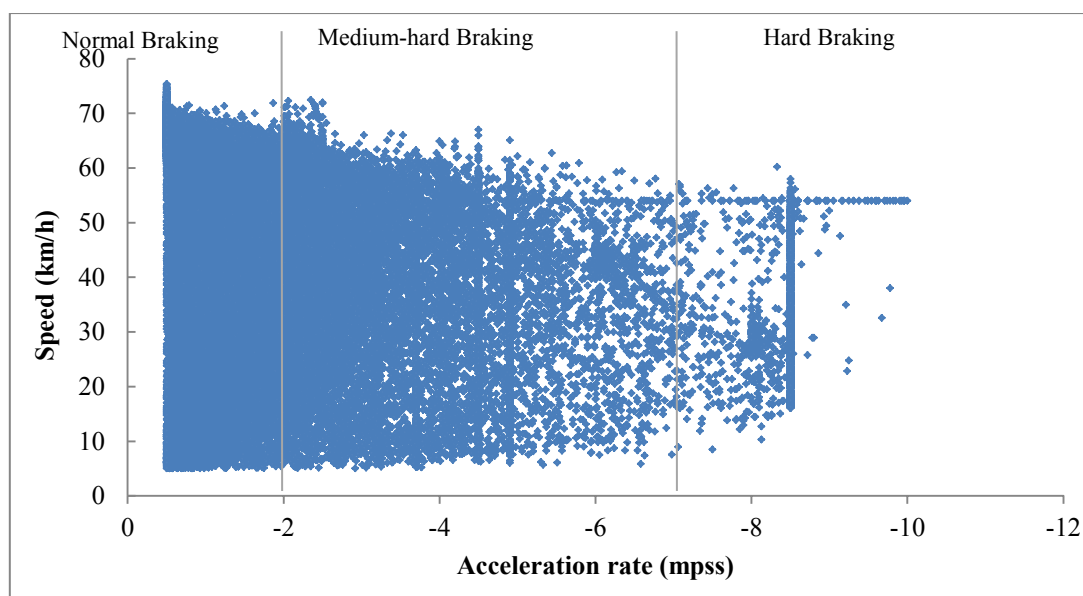


Figure 80: Study Area A - braking events during simulation period

8.6.2.1 Potential conflict types

To establish a likely conflict type, only emergency or hard braking events (i.e. only those with a braking rate greater 7m/s^2) were considered in order to limit the evaluation to events that should be potentially serious or fatal. Coordinates of the trajectory of each vehicle involved were plotted on Lansdowne Road between the two intersections. From these trajectories, it could be deduced that the majority of the safety-critical braking events were taking place mainly due to three possibilities: i) as a result of late braking on the approaches to signalised intersection; ii) because of vehicles slowing down for other lane-changing vehicles; and, iii) vehicles slowing down for jaywalking pedestrians. Relating these events to the conflict types shown in Figure 76, potential numbers of deduced conflict types were derived as detailed in Table 24. From this it can be seen that the majority of conflicts are likely to be those involving vehicle-pedestrian interaction. The animation files confirmed these findings and provided an overall impression of the nature of general safety-conflict events for the whole intersection and thus its performance in terms of safety.

Table 24: Study Area A - summary of simulated conflict types

Conflict Type	Number of events	RBR Severity (m/s^2)
1	60	-7.5 to -8.5
2	2	-8.5
3	1	-7.4
4	1	-8.5
5	2	-8.5
6	1	-8.5
7	20	-8 to -8.5
8	13	-7 to -8.5

However, it is unlikely that the number of hard braking events simulated over this time period would occur in reality during normal driving cycles, especially at the maximum allowed, which indicates that there may be a certain level of coarseness in the simulation. The numbers of conflicts are therefore seen as the degree to which a certain event type is likely, i.e. a vehicle-pedestrian conflict is three times as likely as a lane-changing vehicular impact and so on. This type of assessment fits in with an intuitive assessment of the types of safety critical events that are likely on this stretch of road and provides a numerical confirmation of such an assessment. The following section reviews simulation input and output data in more detail to refine the evaluation.

8.6.2.2 *Re- evaluation of potential vehicle-pedestrian conflicts*

Given that the number of hard braking events simulated as well as the number of pedestrian incidents, are unlikely, three sources of errors are possible - the input data, the simulation process itself and the way in which the output is defined/interpreted. These are investigated separately below.

Input data

Exhaustive tests using the available options for vehicle-pedestrian shared surfaces, as well as accurate coding of visibility and vehicle aware distances (i.e. stopping sight distances) show that vehicle-pedestrian incidents only occur when a '*shared aggressive*' space is specified. In this regard, the performance of the software is true to real-life situations.

The pedestrian in the simulation is essentially a piece of computer code that is goal oriented with attached rules. As it moves through the network, a pedestrian receives updates or directions at various specified points (termed waypoints or dwell points). The updates can be either at the edge of a waypoint, at its centre, or in a random manner. Again through tests of these possibilities, the coding of the update type at each waypoint in the network was individually specified to achieve the most realistic simulation – as confirmed through visualisations.

Simulation process/issues

Given the number of conflicts simulated, an obvious source of error is likely to be the pedestrian behavioural algorithm in relation to gap-acceptance. In real-life situations a pedestrian jaywalking across any two-way road would constantly check the available gap and reassess it along with the remaining crossing distance and, based on this adjust the speed (according to his or her risk level). In contrast, the input data for the simulation only requires an initial gap assessment value which it uses in conjunction with a buffer time. In addition, 'speed-fluxing' values should theoretically allow walking speeds from standstill to 3m/s (or higher if required, and even backwards). Visualisations and the output show that in the simulation, pedestrians once they proceed to cross (using primary and secondary scans), they mostly use normal walking speeds, and there is no re-assessment of the gap available due to any changes to on-coming traffic from their initial assessment direction (which may result from a change in the traffic signal phasing or, from vehicles changing lanes). Furthermore, the software does not account for, and therefore, does not allow pedestrians to stop between traffic lanes- which often occurs in reality in such situations.

Output data

If it is assumed that simulation software cannot capture all possible nuances of pedestrian and driver behaviour (which is entirely likely), then another plausible reason for the large number of incidents involving pedestrians could be the interpretation of the output and, through this the definition of a 'collision'.

As well as braking events, the simulation also provides a pedestrian 'collisions file'. This file gives details of all aspects of 'collisions' involving pedestrians including collision time and vehicle type. These details allow an amalgamation of this file and the vehicle trajectory file which, in turn, allows a more detailed review of the reported 'collisions'. For instance, from the resulting file, it is possible to deduce that a collision is logged by the software even when a pedestrian is in very close proximity to a vehicle (either just touched, even the side or back of the vehicle, the software's help files do not provide any more detail). It is also possible to cross-check vehicular speeds at the time of collision and their rate of deceleration (i.e. the existence of a pedestrian has been recognised and in all probability there would be an evasive action by either or both parties). For the case above, when vehicle speeds are below 20 km/h and also when vehicles are decelerating at their maximum rate it is unlikely that any events fitting these criteria would result in a collision in reality. Recognising this,

and through a more pragmatic analysis of the results, these ‘collisions’ can reasonably be ignored to give a more realistic evaluation.

From this re-evaluation, it is estimated that five incidents could be categorised as possible ‘collisions’ and 16 others where vehicle speeds at the point of ‘collision’ are over the 20km/h threshold.

It is worthwhile recalling the study by Rosen et al. (2010) presented in Figure 36, which identifies the probability of a pedestrian sustaining a fatal injury as a result of impact speed. It ranges from 0% at 35 km/h, to approximately 8% at 52km/h which is the worst case predicted here. Using these values, it can reasonably be surmised that during this simulation period (and therefore during the evening peak hours) serious pedestrian injuries may occur, but the chances of a fatality are low.

To provide a comparative and more numerate method of evaluating the predicted relative safety of any road based infrastructure where collisions are predicted and to enable a comparison of the benefits of improvements proposed, the following index, based on the results of the study by Rosen (Rosen et al , 2010), is proposed (Table 25).

Table 25: Proposed Potential Collision Index (PCI)

Rating	Criteria/description
0	Collision unlikely (vehicle speed <20km/h)
1	Pedestrian recognised swerve or stop likely (vehicle speed <30km/h and decelerating)
2	Collision possible with minor consequences (speed 20-30km/h, no deceleration)
3	Collision possible with medium consequences (speed 30-40km/h)
4	Collision possible with serious consequences (speed 40-60km/h)
5	Collision likely with serious consequences, chance of fatality >50% (speed 60km/h +)

From the simulation results and through the implementation of this index, this study area is assessed as having a PCI of 54 for a one hour simulation period (see Appendix F1 for evaluation).

8.6.3 Possible modifications and their impacts: Study Area A

As it is part of an urban arterial/corridor - albeit the last section - appropriate modifications to this section of Lansdowne Road are limited to those that would not adversely affect the intended function of the road. However, given that it is the last section of the corridor and the adjacent land-uses, a technical case could be made to introduce raised crosswalks at strategic locations, the design of which is commensurate with a 40km/h speed as an optional modification. A second feasible option is the introduction of a kerbside bus/minibus taxi lane on both sides of the road, with some form of enforcement to ensure vehicular compliance whilst retaining the existing speed limit³³. Many other options are possible, such as the introduction of another roundabout, a reduction in the overall road width (road diet), rumble strips on the approaches to the intersection or a change in the horizontal alignment to provide a more sinusoidal one; however, it is unlikely that any of these would be acceptable from a practical (South African) highway engineering perspective and because of the likely impact to adjacent land uses from most of these options. The raised crosswalks option could also possibly be unacceptable from a technical perspective, but if the safety benefits of their introduction are proven to be significant enough a positive case could be made for them.

³³ A bus lane already exists along part of the westbound carriageway; however, it is poorly enforced and usually used by all vehicles. The City of Cape Town are in the early stages of planning a BRT system for the South-east section of the city – a section of the Lansdowne Road corridor would almost certainly be part of it, if and when it is approved.

Based on the general crossing desire lines observed, an appropriate modification for this road would be the incorporation of a series of three raised crosswalks at positions that are in-line with the crossing demand and away from any three lane sections (see khaki coloured crossings on Figure 81). Because of this the crosswalks would not be evenly spaced. To simulate the impact of this modification, a link speed of 40km/h was introduced over the crosswalks only, thereby allowing non-compliant drivers to drive at their desired speed.

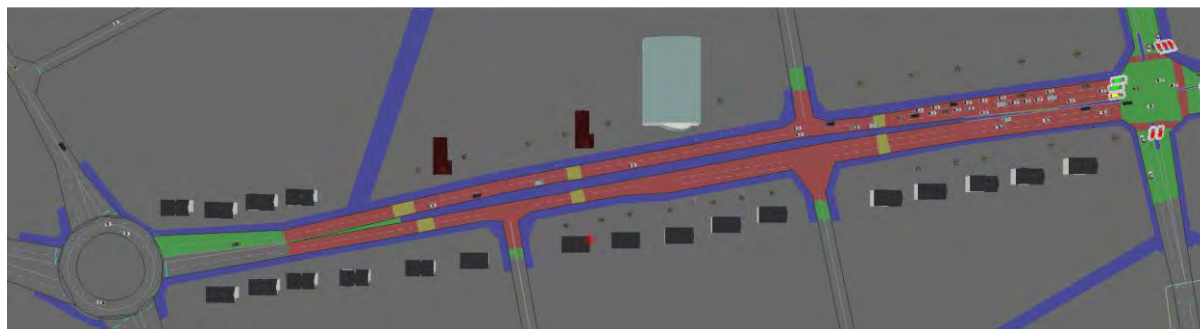


Figure 81: Study Area A - screenshot of raised crosswalk modification

It can be seen from the previous analysis of safety indicators and potential conflict types that vehicle-pedestrian collisions are the most likely type of incident in this area. Therefore, the following analysis is limited to the consideration of vehicle-pedestrian conflicts using the PCI.

The combined simulation output of vehicle trajectories and pedestrian collisions from this configuration is detailed in Appendix F2. Using the same methodology as used in the previous section, it is clear that the introduction of the crosswalks substantially reduces the potential number of collisions. The overall number of incidents predicted is far lower, and only 14 incidents have vehicle speeds over the 20km/h threshold. Based on the PCI method, as a determining factor, the overall total of 29 suggests that this modification would be 45% safer than the existing situation; and, using Rosen et al's. (2011) study outcomes, the probability of sustaining a fatal injury would be reduced given the lower speed values for the incidents predicted.

An issue of note was that during the simulation the behaviour of pedestrians was at times unrealistic. From the animation files, it was clear that despite the introduction of crosswalks and the more 'friendly' shared space definition, pedestrians still chose to cross at a diagonal which in some instances meant that they missed the crosswalk entirely - in some of these cases, this action resulted in a 'collision'. Clearly this is less likely in real-life if crosswalks are provided. The modification of the simulation to avoid this situation is a fairly simple process – the number, size and position of waypoints could be amended, however, this would compromise the integrity of the exercise and would not provide a like-for-like comparison with the base case outcomes (unless of course both cases were modified consistently). Waypoints and pedestrian routes were therefore kept in their original position.

Even with this possible inconsistency, if averaged travel times for all vehicles are compared per 15 minute simulation periods, the modification to incorporate raised crosswalks would have a significant impact on free-flow travel time measured between the two intersections (see Figure 82). As expected, the differences in time are more pronounced in the westbound direction given the greater volume of vehicular flows. If average speed values are considered for the same sections of road over the whole simulation period, an 8-10% difference is predicted for both directions. Compared to the outcomes of the traffic calming measures study for speed (summarised in Figure 82), this reduction would be at the lower range of the results obtained from published reviews, indicating quite clearly that the proposed

modified layout has a major influence on safety and that the simulation is able to adequately capture this effect.

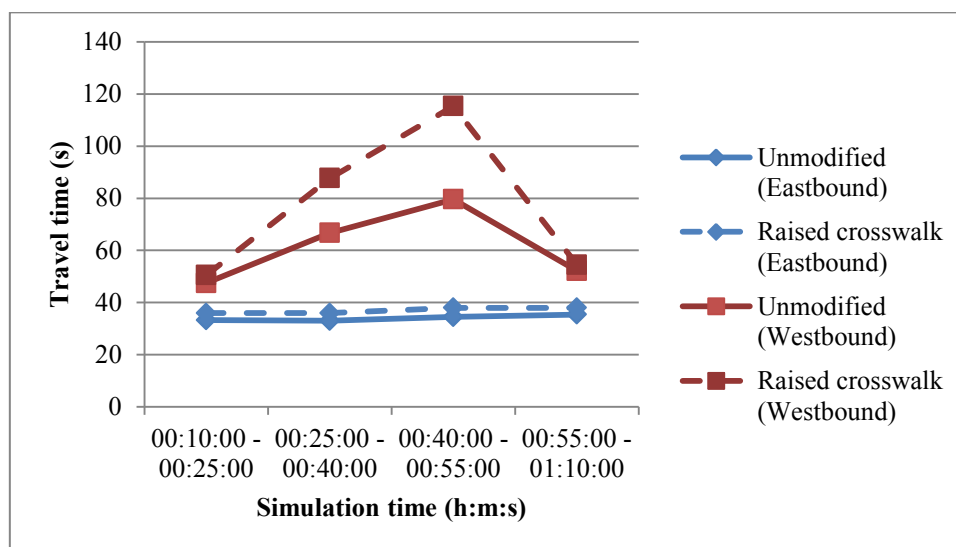


Figure 82: Study Area A- Travel times of base case and raised crosswalk option

8.6.3.1 Modifications to introduce a bus/minibus-taxi lane

Bus/minibus-taxi lanes are a common feature on South African roads in many cities. Their use ranges from urban arterials to major highways, the latter being the case in Cape Town.

The modification tested here was a change to the kerbside lane to a bus/minibus-taxi lane, enforced in the software as a restriction of use for that lane (indicated as a hatched lane in Figure 83). No other changes were made to the layout or operational characteristics of the road.

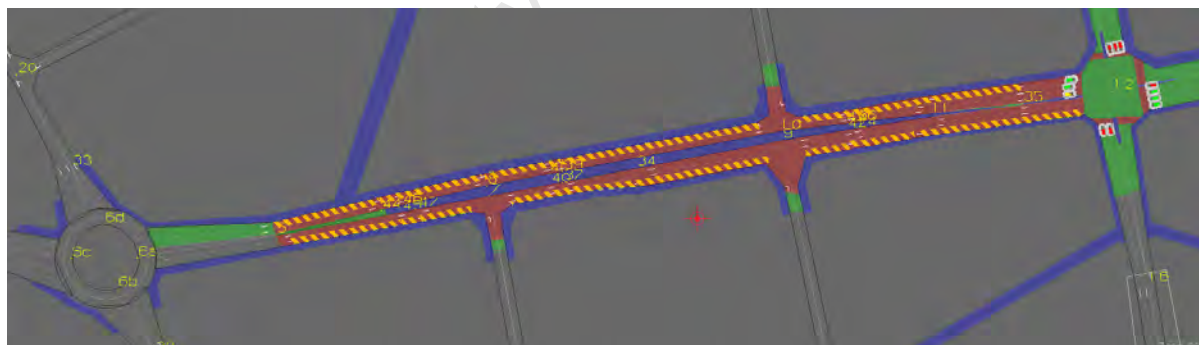


Figure 83: Study Area A - screenshot of bus lane modification option

The results of the simulation again indicate that there would be a substantial reduction in the overall number of predicted collisions compared to the base case (see Appendix F3). However, 21 incidents are predicted where vehicle speeds are in excess of 20km/h. In most of these cases, the vehicle is either accelerating or, despite a decelerating, the vehicle is travelling too fast to avoid a collision (see for example collision at time 02:59 in the table in Appendix F3). Comparing the PCI total, it can be seen that there is no difference between this option and the base case. This is largely as a result of the number of incidents predicted to occur at higher speed levels. The number of higher speed incidents are probably as a direct result of the changed vehicular flows along each lane – because of the lane restriction, there is a larger non-PT flow on the outer lane and a smaller (and thus faster) PT flow on the inner, restricted lane (but which includes minibus-taxis) Given the gap-acceptance model used by the simulation, this could result in pedestrian crossing decisions which are based on the assessment of

gaps between non-PT vehicles in the outer lane, i.e. shorter gaps and slower vehicle speeds (see Figure 84 and 85) and therefore a misjudgement. It could also be an issue with the visibility envelope specification in the software (particularly the vertical plane).

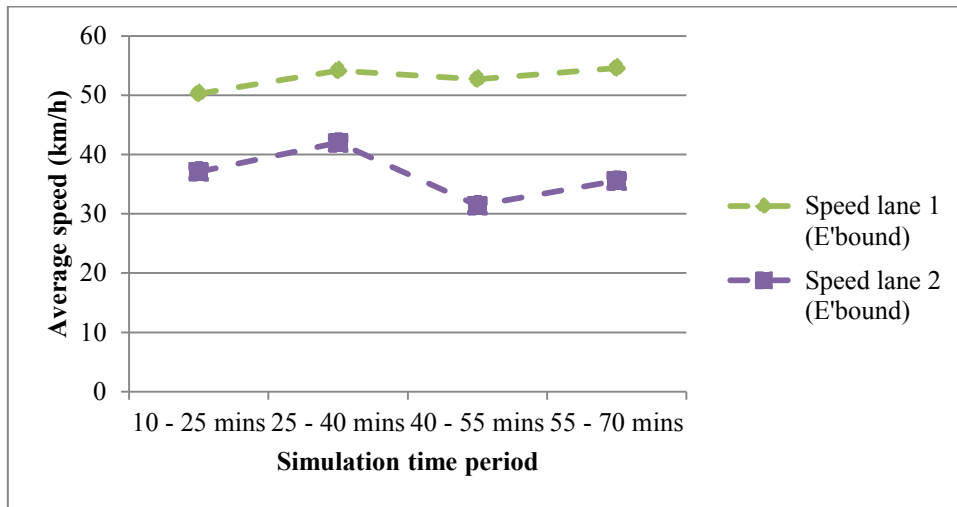


Figure 84: Study Area A - Average vehicle speeds by lane for bus lane modification

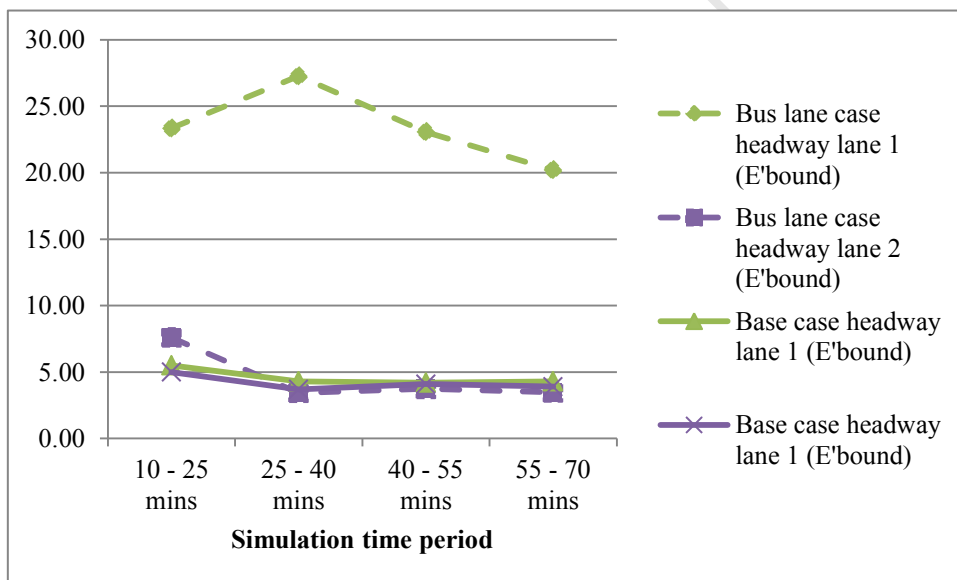


Figure 85: Study Area A- Average headways for eastbound traffic for the bus lane option and the base case

A comparison of eastbound flows (i.e. the main direction) between this option and the base case shows that they are on average 55% lower over this simulation period; a similar comparison of overall link travel time (i.e. both lanes combined and for all modes) shows that on average over the simulation period, vehicles would take around 100 seconds longer to make their journey. In contrast, the westbound flows and travel times remain very similar. These differences are quite stark because of the modelled network size. In reality the impacts would be less significant as vehicles would normally travel over a longer distance which means that the percentage increase in travel time would be considerably less. Variations in flow would also even out over time and over available routes.

The conclusion of the analysis of this option is that although fewer incidents are predicted to occur, when they do occur, they are likely to be more severe than those occurring in the base case. This remark needs to be tempered by the fact that the simulation cannot mimic the random number and

random stopping habits of the minibus-taxis which would have a dampening effect on the speeds of vehicles travelling in the kerbside lane. A further investigation of this effect by simulating an assumed number of taxis and stops would probably provide different event data which would, in all probability, not be as severe.

8.6.4 Surrogate safety event data: Study Area B

As with Study Area A, data related to vehicle speeds, headways and flows are reported in Figure 86 and 87. They are reported for Approach A only as this is the main approach road to the intersection. Pertinent from are that vehicle flows over the period observed were fairly consistent and that speeds varied between 20 and 65 km/h.

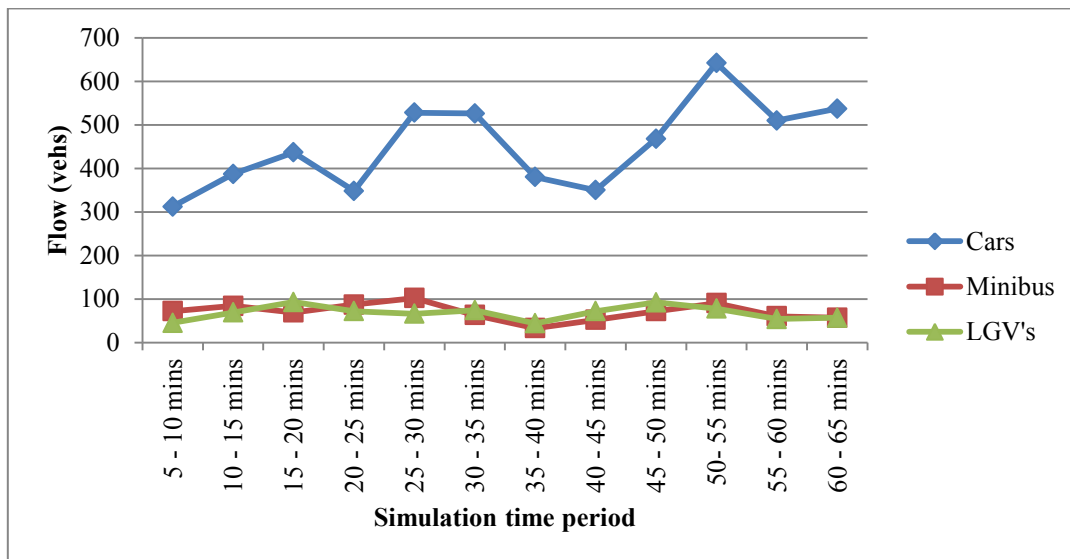


Figure 86: Study Area B – Average traffic flows per vehicle category for Approach A

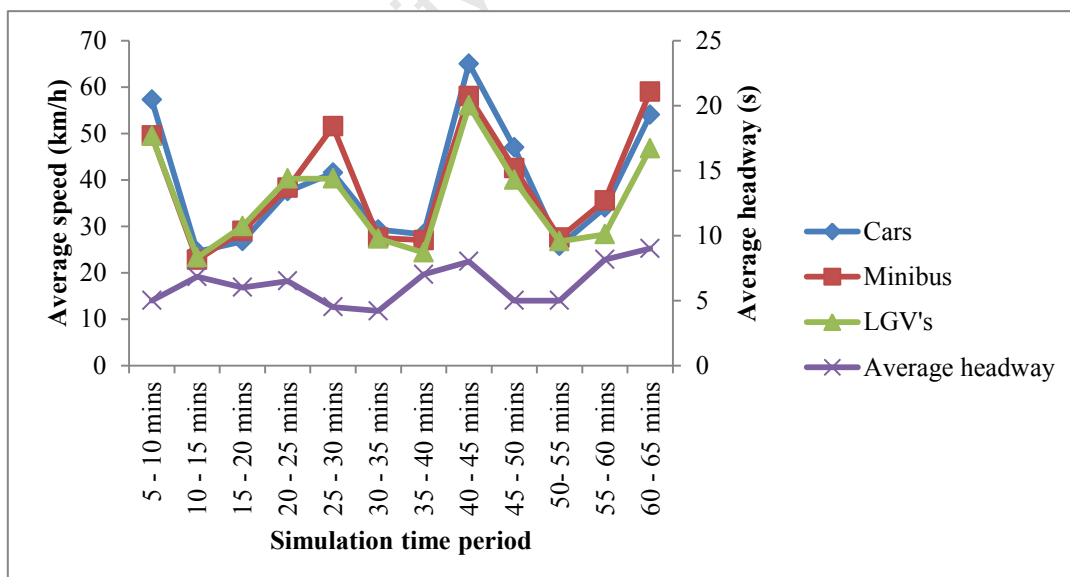


Figure 87: Study Area B - Vehicle speeds per category and average headways

8.6.5 Proximal safety indicators: Study Area B

The simulation output for vehicle trajectories via a scatter plot of the speed and deceleration of each vehicle for rates greater than 0.5m/s (Figure 88) indicates that a number of hard/emergency braking events are predicted to occur. Again, the number of events predicted is influenced by the nature of the

trajectory file recorded – i.e. in accordance with the simulation time step for each vehicle as it travels through the intersection, resulting in multiple recordings for each vehicle over the simulation time period. This file also contains a large amount of data which makes it difficult to reduce the number of points in this format; however, the results clearly show that there would be many hard braking events on the intersection in its current form.

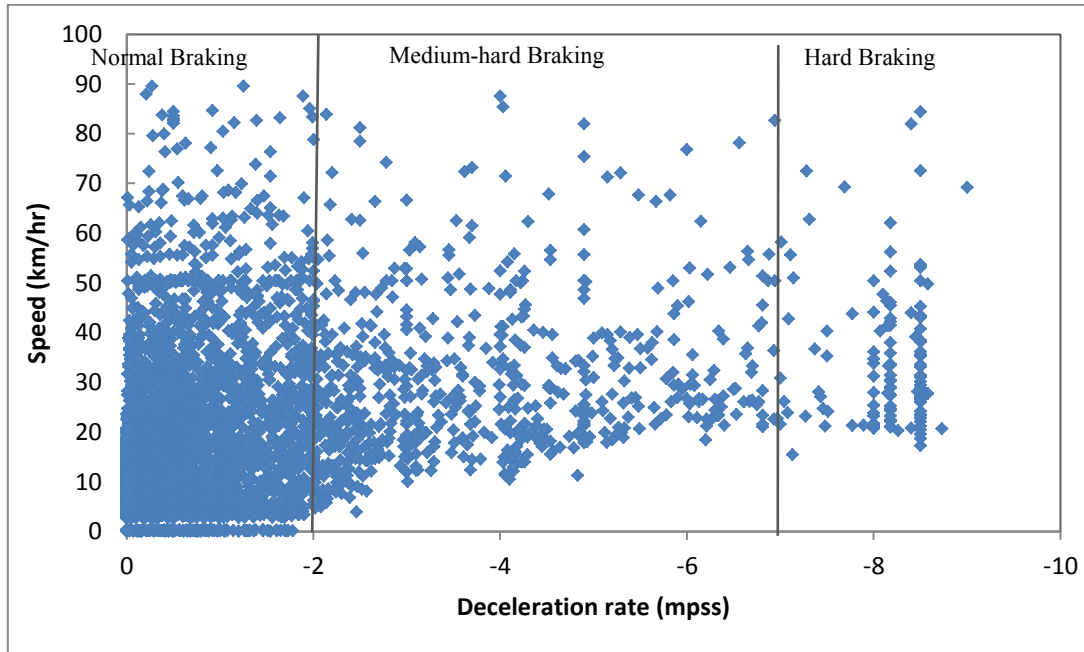


Figure 88: Study Area B - Severity of braking events during simulation period

8.6.5.1 Potential conflict types

As before, coordinates of the trajectory of a random sample set of vehicles involved in hard braking events were plotted on the intersection to establish a likely conflict type. The results were broadly in line with those obtained for the Lansdowne Road area, with the majority of the safety-critical events predicted to be vehicle-pedestrian incidents as a result of late braking to avoid non-compliant or jaywalking pedestrians (see Table 26). The animation files confirmed these findings.

Table 26: Study Area B - Summary of simulated conflict types

Conflict Type	Number of events	RBR Severity (m/s^2)
1	72	-7 to -8.5
2	1	-8.5
3	2	-8.5
4	1	-8.5
5	1	-7
6	2	-8.5
7	16	-7 to -8.5
8	5	-7 to -8.5

The comment made in section 8.6.2.1 apply equally here, i.e. it is unlikely that the number of hard braking events simulated over this time period would occur in reality during normal driving cycles, especially at the maximum allowed. From the data in table 25, it can be implied that vehicle-pedestrian conflicts are most likely and are more than four times as likely as a lane-changing vehicular impact. This assessment fits in with an intuitive assessment of the types of safety critical events that are likely on this stretch of road and provides a numerical confirmation of such an

assessment. The following section reviews simulation input and output data in more detail to refine the evaluation

8.6.5.2 Re-evaluation of predicted vehicle-pedestrian collisions

Using the same approach as the one described in section 8.6.2.2, the analysis indicates that only two incidents could be categorised as being potential ‘collisions’ likely to result in injury, and eight others which have vehicle speeds in excess of 20km/hour (see Appendix F4). Of the latter, six vehicles were decelerating in previous time steps which, in all probability means that a collision would have been avoided.

However, for comparison purposes, two serious conflicts and eight non-serious conflicts are recorded as an indication of the (un) safety of this intersection and its operational characteristics in its current form. This outcome is contrasted with simulated outcomes from two possible modifications to the intersection below.

8.6.6 Possible modifications and their impacts: Study Area B

The nature of this intersection and its location limit appropriate modifications to either a simple modification to the pedestrian signal phase to allow more pedestrian crossing time, and/or textured paving to reduce exit speeds to 40km/h³⁴. Other traffic calming devices or engineering interventions at this location may be impractical and may lead to inappropriate evaluations.

8.6.6.1 Modified signal timing

In theory, a modification of the pedestrian phase to allow more green time for pedestrians should have the benefit of increasing the pedestrian throughput. It should also potentially reduce any collisions at the intersection as well as allow pedestrians crossing mid-block additional time to execute their manoeuvre. On the other hand, traffic efficiencies may be negatively impacted. To test this statement, an additional five seconds of green time and two seconds of ‘flashing red’ time were allowed at the intersection signals. All other aspects remained constant.

The results of the safety analysis (see Appendix F5) indicate that the changes proposed should have a significant safety impact. Compared to the un-modified intersection, the modifications result in a 10% reduction in the overall number of collisions predicted and, only one incident is predicted to have serious consequences (at time stamp 31:13). The evaluation of the PCI shows that this option would improve the safety situation by at least 50%.

As hypothesised, there would be an effect on vehicular flows due to the proposed change in signal timings. Figure 89 details predicted vehicular flows along the main southbound exit of the intersection for both cases during the simulation period. It can be seen from this figure that even over this time period, the difference between the two flows is fairly significant. This may be partly because the intersection forms part of an overall network model of the City, and as such any delay/time costs at the intersection are fed back at regular intervals to all vehicles and this may cause more than a few vehicles to choose different routes to their destination depending on the generalised cost of travel (and despite the application of a perturbation factor to this dynamic assignment).

³⁴ Modifications exclude the possibility of complete reconfigurations and are limited to the consideration of traffic calming style interventions. It should be noted that in mid-2010 a pedestrian overbridge was constructed at this location in recognition of its safety issues.

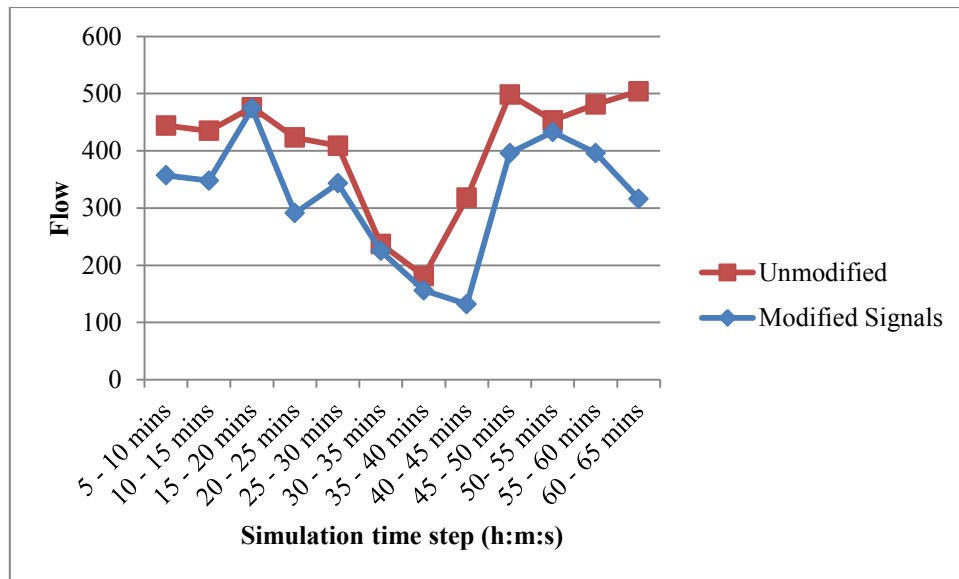


Figure 89: Study Area B - Comparison of traffic flows for southbound exit

8.6.6.2 Textured paving

This option considers a change to the speed allowed on the main southbound exit from the intersection from 60 km/h to 40km/h. This would be equivalent to a change in the paving type from tarmac to, for instance, a block paved surface, which is entirely consistent with the intersection layout, position and functional characteristics.

The safety critical results of this simulation suggest that there would be more incidents as a result of the lower speed at the exit (tables in Appendix F4 compared to Appendix F6). On first sight, this seems counter-intuitive; however, further investigation and reasoning, shows that this may not be the case and that it may be a software interpretation issue. It can be seen from Appendix F6 that the majority of the simulated braking rates for the recorded incidents are at or below 6m/s^2 which indicates that the braking rate used to try to avoid a collision was lower than the allowed maximum braking rate and therefore the ‘collision’, if it occurred, would be minor otherwise a greater braking rate should have been used. Secondly, using the PCI, it can be seen that there are no incidents predicted with a PCI value greater than two indicating that there are no collisions of a serious nature predicted which is consistent with the speed reduction imposed. It seems therefore, that apart from the PCI a severity scale would also be of benefit to the interpretation of the results.

The difference between vehicular flows at the southbound exit of this proposed modification and the unmodified intersection was negligible; as was the change to pedestrian flows, walking speeds and delays (see Table 27).

Table 27: Study Area B -summary of simulation output for pedestrians

Measure	Unmodified intersection	Modified signal timings	Textured Paving
Cumulative mean speed (m/s)	1.08	1.15	1.12
Cumulative mean delay (s)	13.59	12.9	13.01
Cumulative mean time in network (s)	37.69	36.84	37.01
Cumulative mean stop time (s)	12.39	11.78	11.85
Cumulative mean moving time (s)	25.3	25.05	25.16

8.7 Summary and conclusion of study

The aim in this chapter was to take the study of the capabilities of micro-simulation modelling further by examining its potential to predict the relative safety of urban infrastructure with mixed road uses in a South African context. It examines not only the proxies for safety, but also the chances of potential vehicle-pedestrian incidents occurring as a result of their interaction in two different infrastructure settings. A further test involved the consideration of changes to this infrastructure to evaluate whether the simulation is able to predict any differences between the base case and the changes adopted in terms of their relative level of safety.

To do this the study uses two areas of Cape Town with differences in road function and road user behaviour as this would help confirm the robustness of the evaluation methods used.

Study Area A focusses on the last section of the Lansdowne Road corridor, a major arterial route linking the settlements on the periphery of Cape Town to the city centre as well as other areas of employment in the south-eastern part of the city; Study Area B is a major intersection at one of the entrances to the city's CBD – the Coen Styler/Buitengracht Street intersection. Both locations have a history of high pedestrian fatalities, and although the Coen Styler/Buitengracht Street intersection has recently been modified, it does not affect the validity of this exercise.

Several model issues were encountered during this exercise, most of them are related to the non-compliant nature of the road users in South Africa (and probably other parts of Africa). These are summarised as follows:

1. The interaction between jaywalking pedestrians and vehicles could not be fully captured;
2. It was not possible to model non-homogenous flow - although they rarely occur in South Africa there are some instances when they do;
3. Random stopping and lane-changing behaviour cannot be accurately captured;
4. The simulation output of vehicle trajectories indicate that a significant number of vehicles use the maximum allowable braking force which is unrealistic;
5. The pedestrian behaviour algorithm does not allow for stop/start/rapid acceleration between lanes or once road crossing has started;
6. Pedestrians do not seem to constantly review the gap available to cross as would occur in reality; and,
7. The pedestrian visibility envelope may not be set to allow pedestrian to see over the vehicle closest to them.

However, with the exception of non-homogenous flows which seldom occurs in Cape Town, the remainder of these issues need to be addressed in future updates of the model so that a more robust safety analysis can be made. In the intervening time, the resulting simulation of the operational characteristics of the road users confirms the viability of the use of micro-simulation to evaluate the potential safety of vehicle-pedestrian interactions on infrastructure of various types and locations on a comparative basis. To fully confirm the validity of the outcomes of simulations, the following tests were undertaken.

1. A confirmation that the simulation could verify the potential safety issues of such an area through the output of hard braking events categorised as 'emergency' braking. The tests on both study areas confirmed this to be the case.
2. A confirmation that the simulation could successfully predict the types of safety critical events that have previously been recorded at each area. This was done through the use of output vehicle trajectory files for safety critical events with braking forces in excess of 7m/s^2

plotted on the intersection and subsequently compared to usual incident types to establish predicted numbers of each type of incident. The results for both areas correctly predict that vehicle –pedestrian incidents are most likely.

3. Apart from the prediction of the likely incident type, and through the use of absolute numbers of vehicle-pedestrian incidents, a confirmation that the relative differences between the safety characteristics of the study areas (and, by extension other areas which can be similarly calibrated) can be predicted by micro-simulation; and further that the results can provide a distinction between the numbers and severity of predicted ‘collisions’ due to modifications made to the study areas. Through the integration of vehicle and pedestrian trajectories and collision logs, the analysis shows that the simulation successfully predicts differences in safety outcomes between proposed modifications and the base case for both study areas. As these modifications can be categorised as being traffic calming measures, the differences in outcomes were related back to published findings of the benefits of traffic calming and were found to be consistent with them.

It is concluded from these tests that through the application of similar evaluation methods and a more refined scale that has been calibrated, simulation software can be used to test either hypothetical designs or existing infrastructure to evaluate potential vehicle-pedestrian conflict issues for that particular setting.

The successful conclusion of this work shows that it provides a method that would have several benefits: (i) it would be an extremely useful and scientific method of evaluating the potential safety benefits of urban infrastructure for both proposed and existing situations where there is likely to be vehicle-pedestrian conflicts; (ii) it would obviate any possible observer differences or inconsistencies, a criticism levelled at the TCT; (iii) it could be used as a proactive investigative method of assessing the safety performance of most road infrastructure configurations, and; (iv) as the method can be used in a comparative format, as long as existing vehicle and pedestrian characteristics are adequately captured, it does away with the reliance on a reactive analysis of historic crash data and does not require statistically reliable, extensive and accurate crash data records

Finally, it is apparent from this study though, that despite undertaking reasonable numerical calibration, it is vital that a visual check of the simulation output is performed as the consequences of not carrying out adequate visual checks could be far reaching. It is also apparent that in many instances when detailing pedestrian spaces, user integrity is important to achieve consistent results.

9 Synthesis and conclusions

This dissertation was motivated by the record of road traffic fatalities in South Africa, which at around 15,000 fatalities per year, has continued unabated over the last decade and has led to South African cities consistently featuring at the top of the list of worst known locations for road fatalities around the world. Worryingly, these statistics show that more than half of these fatalities are pedestrians. With the increasing rates of urbanisation and motorisation being experienced this record is likely to continue or decline unless greater emphasis is placed on road safety.

The underlying reasons for the fatality rates are complex. They are influenced by a combination of road network planning and design, the settlement patterns and by behavioural and law enforcement issues. In particular, the road network planning and design concepts have led to a hierarchical road infrastructure system of provision that comprises of many arterial and distributor roads where vehicular speeds are high and, there is limited, or no provision for non-motorised travel outside of the central city areas. The historic settlement patterns dictate that the urban poor, who walk or use public transport for their travel needs, travel long distances, mostly along these arterial routes. As a result, pedestrians often have to cross delimiting arterials and distributor routes with the concomitant danger of road crashes.

The legislative and policy environment for planning, transport and road infrastructure provision, and its maintenance in South Africa has considerably improved over the last decade; policy statements are on a par with many developed world practices, and recognising the need to address road safety, South Africa is also a signatory to the goals agreed in the Global Plan for the Decade of Action for Road Safety 2011-2022 (the 'Moscow Declaration'). Many of the pillars of this plan have been followed by the responsible public authorities. Despite these policy improvements and ideological changes, road safety, especially in urban areas, continues to be a persistent problem.

To understand why road safety is such a problem and why it persists, the City of Cape Town was used to represent the safety issues in urban areas in South Africa. A holistic assessment necessitates a review of historic transport policies that have shaped current infrastructure provision in the city, the effectiveness of national and local policies and road safety strategies of the last few years and, the detailed context of the road safety problem.

From a planning perspective, it is clear that infrastructure provision, has continued largely along the lines of the historic car-centric and segregated city plans, plays a role in the road safety record and, that local policies and design manuals that influence road planning and design practices also had, and continue to have, an influence on road safety.

Crash statistics reported for the City of Cape Town provides the overall number of annual crashes, their trends and answered important questions relating to prevalence, the people most affected and whether there are any repetitive trends. The review of these statistics revealed flaws in the crash data collection which, apart from masking the true road safety picture, hamper accurate and detailed road safety investigations. It also noted that road safety investigations, which are almost exclusively carried out on the basis of these flawed records, with a focus on hazardous locations could come to inappropriate conclusions.

Documented responses to the road safety problem (in a broader context) provided further insight – although some progress is being made on reducing fatalities in the Western Cape Province (which

includes Cape Town), it is clear that the Government's response to the problem has been somewhat ineffectual and that some of the pre-requisites for a holistic solution to road safety (such as those advocated by, for example the WHO) are not being addressed.

Changes currently envisaged to road planning and road design standards, developed from well-established and scientifically sound methods and research, may help but these take a long time to come into force and it is unrealistic to assume that they will affect more than a few areas of the existing transport system. However, it is mostly because of this lack of change in planning and design standards that practice has not fully embraced the ideals of newer policies; this plays a significant role in the poor quality and piecemeal nature of the infrastructure provided for other road-based modes.

Behavioural issues, especially the culture of speeding and lawlessness with regard to road usage indicate that there is a need for more law enforcement and reinforce the need for guidelines and standards that accommodate all road users from a safety and sustainability perspective.

Examples of more holistic road safety strategies employed in many countries show that a systematic and cross-disciplinary approach to road safety yields tangible results. From these strategies, proactive investigative methods to road safety, in particular, and the application of engineering counter-measures have been effective. This study therefore reviewed the concepts, theories and methods related to road safety assessments and the prediction of likely numbers of crashes from statistical methods, and concluded that complementary road safety methods could help compliment current methods in use. The study then focuses on techniques related to proximal or surrogate indicators of safety and their use as safety estimation methods via micro-simulation modelling. Because micro-simulation assessments can be carried out off-line, without the need for statistically significant and accurate historic crash records, simulation could be used to complement traditional post-event analyses and road safety audits at an early stage to influence the configuration of proposals.

Micro-simulation modelling of transport though, is mainly aimed at the assessment and efficiency of traffic. Furthermore, the simulation of pedestrians within the traffic environment is a relatively new development - as pedestrian movement and behaviour is complex and the interaction between pedestrians and vehicles adds further complexities to models. However, recent advances in technology have meant that a broader range of issues and users can be more readily assessed.

Therefore, the hypothesis developed was that:

'In order to try to positively influence road safety, there is a need for road safety professionals and authorities in South Africa to foster complementary safety evaluation methods and predictive modelling techniques. The innovative use of micro-simulation modelling will provide a better understanding of the interaction between the human-vehicle-environment variables, and from this the safety risk at a particular situation can be reduced.'

To evaluate this hypothesis, three case study areas in Cape Town were modelled. The modelling was undertaken with as much empirical data as possible, with a view to obtaining important scientifically based knowledge concerning the influences of various traffic parameters, behavioural parameters and the interaction between these and their effect on road user safety. Using the empirical data to model and calibrate user-defined parameters, modelling approaches using dynamic micro-simulation were developed for traffic safety assessment and prediction purposes. The method ultimately developed employs a range of techniques that focus on surrogate and proximal measures of safety as well as a method of ranking the relative safety of the infrastructure under consideration. Through the use of

these techniques, the relative risk of the case study situations, as well as modifications considered appropriate to them, were investigated. The findings showed that traffic calming measures could be successfully simulated and that the outputs of speed and volume changes could be distinguished between measures and were comparable to internationally researched and published benefits. They also showed that simulation modelling could be used to predict the relative (un)safety of a road environment and the likely types of collisions. Lastly, through the use of vehicle and pedestrian trajectory output files and predicted ‘collisions’ a ‘Potential Crash Index’ (PCI) was developed; this PCI could be used to assess and rank road environments in terms of their safety risk.

These methods and outcomes demonstrate that, despite not being its main intention and despite some limitations, micro-simulation models can be used to provide a better understanding of the role of infrastructure and the human-vehicle interaction and their combined contribution to road safety.

9.1 Answer to Research Questions

Several questions needed to be answered to understand the background to the subject, and from this to support the hypothesis proposed and to develop responses to the objectives set out for this research.

1. *What is Cape Town’s road safety record and how does it compare to international standards?*

Developing nations worldwide are reported to contribute the largest proportion of global road traffic mortality numbers (around 90% see for example, WHO, 2009). These nations face particular transport challenges usually because social inequities result in inappropriate or inadequate transport planning for some; this often results in the most vulnerable users suffering the greatest travel risks and a variety of travel perceptions. Further, the rapid increase in motorisation being experienced in developing nations, and the lack of suitable infrastructure or transport systems bring about their own set of problems. Through an investigation of published data on road safety, this chapter shows that these developing world challenges apply to South Africa as well.

With around 30 fatalities per 100,000 population per annum, South Africa has one of the worst road traffic fatality records in the world and has this record has continued unabated over the last decade (see for example RTMC, 2010).

The majority of these fatalities occur in South Africa’s urban areas. As a representative of these urban areas, Cape Town, despite being a comparatively wealthy medium sized city (population circa 3.8 million), and despite having a fairly well developed and extensive transport network, mirrors these issues.

Over the last four years, the local authority road safety statistics show that a high number of pedestrian deaths (>50%) and pedestrian casualties (>30%) were characteristic (see Figure 17). The ratio of fatalities compares poorly with the national ratio for the years 2009 and 2010, at around 33% of the total fatalities (RTMC, 2010), and even more unfavourably with the data provided for the OECD’s 26 member countries – ranging between 8 and 37% of all road fatalities (ITF, 2011).

2. ***What are the particular motorised and non-motorised characteristics that have influenced the road safety record?***

In most South African cities, land-use patterns, which characterise the form and densities of cities and influence travel distances and modes, are generally along the lines of historic apartheid planning which followed the principle of locating workers away from the centre of the city, resulting in a low-density 'fringe' type city. Although the majority of cities included a green buffer between the city centres and 'worker' residential settlements, some of these are now being developed but changes in settlement and commuting patterns over time are limited and, if anything, commuting volumes on historic paths have increased as the cities have grown.

From their initial development, transportation modelling, in particular, those related to road infrastructure provision, has relied on analytical methods that forecast future traffic flows and efficiencies on existing corridors, based on a number of development options. Planning horizons usually span the medium to long term, owing to the large capital costs and complexity of outcomes; this means that commitments once made have a lasting effect, and are difficult to influence. Analytical transport planning tools rely heavily on mathematical models that, despite calibration against empirical observations to minimise predictive errors, inevitably use assumptions and generalisations to simplify their complexity. The focus on traffic efficiency is a dominant factor (based on the premise that efficient motorised transport is an economic necessity), and consequently; the concerns around the negative social and environmental impacts of motorisation, and the role of public transport (PT) and non-motorised transport (NMT) in promoting an efficient, balanced transport system, are not adequately addressed. Despite these concerns and limitations of these tools, forecasting methods and decision making are almost completely reliant upon them.

Furthermore, road design, in particular, is mostly determined by a set of manuals and guidelines that outline best practices for a range of generic situations. In South Africa, these manuals and guidelines, are outdated and have been drafted from practices drawn mainly from the car-dominant era in the United States. As such, they seek to continue to improve the levels of service for private motorised transport and fuel the growth in car use. In addition, modes tend to be planned in isolation from each other, and this often results in PT and NMT being inadequately planned for, or not planned for at all.

Significantly, these practices have resulted in a hierarchical linked system of roads with levels of service that permit high traffic speeds on freeways and arterials (except in close proximity to the city centre).

In addition to this system, the legacies of apartheid planning and in-migration mean that many of the less formal areas have roads which are narrow with few, or no, sidewalks even near schools; and many unpaved roads. Research on average walking commutes in Cape Town shows that the mean and 95th percentile walking trip lengths can be considerably longer than those conventionally assumed in practice (around 800m as assumed in traditional road hierarchy philosophies), and that a significant proportion exceed conventional parallel arterial or distributor frequencies of 1.5km. Despite this, and despite walking being the dominant mode of transport for the vast majority of people, there is a dearth of sidewalks and formal crossing facilities, which inevitably leads to conflict with motorised transport. Furthermore, the inconsistent nature of infrastructure provision means that pedestrian routes, in particular - if they exist at all - are not interconnected systems which would allow safe, efficient passage coinciding with desire lines.

3. *What are the legal, policy and regulatory framework responses to the road safety issue? Are they appropriate for the situation?*

Legislation and regulation covering South Africa's roads is comprehensive and compares favourably with many best practices from around the world. Road safety strategies are published regularly, and include recommendations from the World Health Organisation (see WHO, 2011).

From a legal perspective, the National Land Transport Act (NLTA) of 2009 (RSA, 2009) is the overarching document in terms of transport planning and land transport delivery by the three spheres of government. The National Land Transport Strategic Framework (NLTSF) for the period 2006 to 2011 is a legal requirement in terms of Section 21 of the NLTA (NDoT, 2006b). Among other functional areas, this document details areas that cover traffic safety and enforcement.

Key Performance Indicators (KPIs) are identified for each policy area and defined for customer-based KPIs relating to each policy area. For traffic safety, customer based KPIs are defined as numbers of road fatalities for vehicles and pedestrians and the number of road traffic fatalities per 100 million vehicle kilometre per vehicle type.

The National Road Safety Strategy (NRSS) (NDoT, 2006) includes many of the internationally accepted strategies that address road safety challenges. Although a number of the strategies proposed by this document have been effected, some have not and there has been a notable failure – the demise of the lead and implementing agency (which is seen as one of the key pillars of an effective road safety strategy by many including the WHO), the RTMC, is no longer functioning at an independent and efficient level. In addition, law enforcement of traffic offences and fine payment is poor; the planned introduction of a driving licence penalty system for traffic offences (which is commonplace in many countries and known to be an effective deterrent to unsafe driving) has been postponed indefinitely; and, even the annual publication of KPIs by the RTMC acknowledges the presence of vehicles that are not roadworthy and unlicensed, as well as the presence of significant numbers of unlicensed drivers.

The NRSS (NDoT, 2006) implies education and enforcement are the answers to most of the road safety challenges, as crashes are mainly caused by the way the roads are being used. This may be partly the case, but it is clear from the assessment in this document that systemic failure influences the problems being faced.

4. *In conjunction with policy and regulatory responses to the road safety problems, what else can be done to assess, evaluate and reduce the road safety risks?*

Historic crash data is typically used to measure road safety, its relative level and acceptability criteria. It is also used to formulate different models and approaches to safety. The dimensions of risk, exposure and consequences form the three main components of road safety. A change in each one has a consequence on the others. There are many measures of risk, all of which provide a descriptive and comparative method of assessment. However, its accurate assessment requires comprehensive and accurate historical crash data.

Investigations of crashes typically relate the causes of crashes to the human-vehicle-environment triptych or, in some cases, to the temporal categories of pre-crash and post-crash. The former is the approach traditionally adopted in South Africa, although, data collection, its reliability issues, the lack of geo-references for crashes and temporal variations in crash locations mean that this form of evaluation may lead to inappropriate conclusions.

More proactive assessments do not rely on historical data as the key sources of information - they use them as informants as to the likely level of road safety risk of particular areas, streets or even intersections. Indicators, such as traffic speeds, differences between traffic speeds, traffic flow and composition and, exposure to traffic can equally be used as determinants of road safety. Equations formulated from historic evaluation of crash data and the nature of crashes, have been in use for some time now to provide an estimate of the potential safety of particular situations. The requirements of these road safety performance indicators are that the indicator should have a level of validity and that known correlations must exist between the trends of the indicator and the number of fatalities and/or injuries.

Predictive modelling can also be used to evaluate and reduce road safety risks. It commonly makes use of inferential statistics applied mainly to historical data for a given traffic site through observational analysis. Measures in common use include Time-To-Collision (TTC), Post-Encroachment-Time (PET) and deceleration rate.

Evaluation of road safety through the use of Naturalistic Driving Simulators is a fairly recently developed method. It uses data from instrumented vehicles that provide continuous data on near crash (and possibly even crash) events; this allows for a much more sensitive analysis.

Transport simulation models were traditionally developed to support decision-making in the transport planning process. With the recent advances in programming skills and the availability of more powerful processors, these transport models have evolved into much more than decision-making tools.

Microscopic traffic simulation models predict the space-time behaviour of individual road users, as well as their interaction on a per second basis. The models use characteristics and behaviours of road users combined with detailed infrastructure characteristics, resulting in an overall simulation of the traffic stream within the modelled area. They are now extensively used to analyse new and existing traffic facilities, including the performance of new designs before they are implemented. These tools are extremely valuable in analysing the relative performance of one design against another, in the ex-ante calculation of the effects of redistribution of traffic across networks and consequently the road safety effects. In terms of measurement of safety, the normal use of microscopic simulation models is for traffic efficiency, and thus models provide little guidance to analysts with regards to safety. However, statistical models based on historical data are not always able to consider the interaction between the crash causation factors that are influential in determining the overall level of safety at a particular traffic facility; thus, increasingly, commercial software vendors as well as researchers have become aware of the potential use of microscopic traffic simulation models in safety analysis. Through the use of these models, it is possible to calculate conflicts using the position and speeds of respective road users, and the relative safety of infrastructure can be measured by the output of the safety indicators of TTC, PET as well as user speeds and volumes. Current commercial software allows the possibility of tailoring models to road user situations with high levels of details that encompass most of the factors that have direct or indirect influence on safety.

Further, models can be developed and tested without implementation as their use can be as a preliminary form of analysis in the early stages of research, development, and design. Given the scope of the traffic safety problem in terms of fatalities and injuries and their related socio-economic values, this type of assessment can be used for comparative before-and-after type study scenarios to establish the effects of new and alternative safety enhancements or safety influencing measures in the roadway environment, at specific locations and in relation to specific road-user groups.

5. *If predictive modelling can help reduce road safety risks, which road safety method would be appropriate for evaluation of vehicle-pedestrian and infrastructure interaction risk in South Africa?*

The traditional method of evaluating road safety in South Africa is one that relies on a reactive assessment of historical hazardous locations, with the bias on an assessment from an engineering countermeasure perspective.

The use of techniques such as Naturalistic Driving Simulators relies on the availability of equipment and research budgets. Techniques which use observational analysis to determine, for example TTC, PET or TCT, require suitably trained and experienced professionals to carry out the observations necessary for analysis. The resources for required for both types of investigation are short, as is the availability of qualified professionals with a specific focus on road safety.

The use of microscopic simulation software on the other hand, is quite widespread in South Africa, but mainly for traffic efficiency analysis and predictions. Simulation methodologies allow the possibility of performing sensitivity analyses based on standard roadway designs, where the safety influence of various traffic parameters (such as changes in averages speeds, speed variation or flow-rates) can be estimated. They can also be used to generate many types of data simultaneously (safety, traffic performance and capacity and environmental impacts). This allows the analyst to get a more complete and comprehensive picture of the many different operational effects related to a particular area of study. Another advantage is the possibility to ‘tailor’ a model to meet the specific criteria of an existing real-world traffic situation and to incorporate those factors that have been identified as having a direct or indirect influence on traffic safety.

Given its existing use and possibilities, the use of micro-simulation for safety analysis should be considered as an appropriate tool for practitioners in South Africa. The lack of reliable historic crash data with sufficient detail, the knowledge that the levels of reporting underestimate the current safety problem, and the ability of simulation models to develop and test possible interventions in an off-line manner without incurring any implementation costs, add to the attractiveness of its use as a tool for safety evaluation.

6. *If micro-simulation is used for safety evaluation, can it be applied to assess the relative safety of the road system through the interaction between its components, and how can the results derived be adequately validated for a broader local context?*

In general, a significantly higher level of modelling detail is required for safety assessment than for other traffic system objectives. This is particularly evident for pedestrian and behavioural sub-models that describe the interactive processes and provide the simulation output. For safety analysis, it is of critical importance to ensure the accurate representation of interactive behaviour between road-user entities and their interaction with the environment. It is also important to ensure that the values of road-user behaviour and vehicle performance are appropriate to the local conditions. These higher levels of modelling fidelity require the collection of more detailed empirical data and demand greater stringency in the processes of model calibration and validation.

The simulations can be developed to provide a functional and representative approach to safety, where the dynamic and complex interactive behaviour of modelled entities (i.e. road-users and the traffic environment) reproduces incidents which correspond to those found in a real-world (local) situation by the use of surrogate and proximal safety measures. To ensure this, models require the collection

and use of detailed empirical data, and a calibration and validation process that especially considers critical safety-relevant processes and traffic parameters.

To test the utility of the simulation approach to road safety, three criteria for the simulation output were proposed in this study: i) discrimination between the safety of two design alternatives in a simulation; ii) correlation of the surrogate safety measure with real world traffic conflict studies; and, iii) correlation of surrogate safety measure reductions with predicted reductions in traffic conflicts. Simulated safety performance measures are not required to correlate directly to the actual number of crashes, but the relative difference of various intersection designs measured by simulated safety performance must be consistent with similar studies of real world conflict measurements.

The areas selected to investigate the hypothesis and to answer this research question, were located in the urban areas of Cape Town, where the majority of the safety critical events occur. Two of the areas selected are known to have a history of pedestrian fatalities and are sufficiently different in their location and function to present many user and behavioural differences. This ensured that the context was broad enough to adequately capture the diversity of users and uses in the city, and provided a reasonable test for the simulation output.

The results of the first case study using road-based traffic calming measures confirmed that simulated outputs of vehicle speeds and volumes were comparable to findings in the literature which fulfilled the first of the criteria established. To evaluate whether the simulations could meet remaining criteria, the following tests were undertaken on two case study areas with different properties and uses.

1. The simulation output of vehicle trajectories from both case study areas was investigated to check whether safety-critical braking events (i.e. those classified as emergency braking and close to actual vehicular limits specified (-8 m/s^2)) occurred where expected. The output for both study areas confirmed this to be the case.
2. To verify whether the simulations could successfully predict the types incidents reported at each area, safety critical braking data for vehicle trajectories were plotted on each intersection and compared to several incident types that usually occur on areas of this nature to establish predicted numbers of each type of incident. The results for both areas correctly predicted that vehicle - pedestrian incidents would be most likely.
3. To ascertain whether the simulation output would predict the relative differences between the safety characteristics of each study area and, further, that the results could provide a distinction between the number and severity of predicted 'collisions' due to modifications made to the study areas, vehicle and pedestrian trajectories, and collision logs were integrated and reviewed. The analysis and the development of a 'potential crash index' to provide a comparative index, shows that the simulation can successfully predict differences in safety outcomes. In addition, as the modifications considered were essentially traffic calming measures, the differences in outcomes between measures modelled were related back to published findings of the benefits of traffic calming and were found to be consistent with them.

Given the successes of these tests, it can be concluded that simulation software can be used to test either hypothetical designs or existing infrastructure, to evaluate potential safety issues through an evaluation of the interaction between the components of the road system for a particular setting. By extension, it should be possible for the method to be used for area-wide analysis, intersections and sections of roads of any type. It can also be used to rank existing and hypothetical layouts in terms of their likely safety performance.

9.2 Reflections

The extensive body of research in road safety prediction underscores its importance to the field of transportation and to the nation as a whole. Most of this work uses historical crash data to estimate safety through the use of statistical models. The underlying assumption of these studies is that crashes are individually unpredictable, but that groups of crashes observed at a given location can produce predictable statistical patterns. Understandably, the absolute number of crashes and crash rates are still difficult to accurately estimate, mostly because of data reliability and availability, as well as methodological challenges posed by the random and unique nature of crashes. It is mainly for these reasons that the development of safety indicators has become a widely researched and practiced area.

It is clear that a better understanding of the sequence of events prior to a crash should provide a more rational basis for the development of engineering countermeasures. However, this type of knowledge requires real-time monitoring of vehicles and pedestrians in the traffic stream (including detailed vehicle speed/spacing profiles and pedestrian movements/ decision making systems), for the unusual combination of events that lead to crash occurrences to be determined. Unfortunately, this type of information is not readily available and, even if it was, it may not be possible to accurately simulate the complexities of such interactions.

Microscopic traffic simulation was essentially developed to assess traffic systems and apply changes that affect its operational performance. Recent advances in processing power and programming skills have fostered developments in microscopic behavioural algorithms and traffic data acquisition techniques which, in turn, have enabled a few systematic studies in the use of such a tool to investigate safety. These developments have important implications for traffic planning and engineering work, as there is an increasing need for methods and modelling approaches that support site-specific safety impact assessments. However, most of the work previously undertaken has not fully addressed some of the fundamental issues of microscopic modelling applied to safety studies, such as the need for a sound measure of safety performance, appropriate calibration/validation using safety indicators and, establishing a reliable link between safety performance measures and ‘real world’ high risk situations.

The work undertaken in this research addresses these issues and contributes to a more advanced understanding of the use of micro-simulation modelling in a complex environment, where the interaction of the road system as a whole in terms of its relative safety is considered. In doing so, it uniquely captures elements missing in many safety analyses. The study therefore has the potential to influence and improve the current thinking around road safety in South Africa and, through the application of the techniques developed; it can help address the road safety situation in a more scientific manner. The techniques used to assess road safety employ the novel use of both vehicle and pedestrian trajectories to identify potential collisions as a result of their interaction and the enabling infrastructure. A ranking system is also suggested to enable like-for-like comparisons to be made for many hypothetical or existing infrastructure situations.

The research did, however, show that micro-simulation has a number of methodological issues related to its use for road safety, and although it may not be possible for any micro-simulation model to capture all aspects of human behaviour, researchers agree that some refinements need to be investigated further (see for example: Bonsall et al., 2005 and Morsink et al., 2008). These are:

1. Traditional microscopic car-following, gap acceptance, and lane changing algorithms have not been developed specifically to account for the full range of factors that explain potential

for crashes. Outputs from these models may not be representative of real-life behaviour, especially when drivers are experiencing stressful situations.

2. The behaviour sub-models generally have possibilities for variations of behaviour between drivers by vehicle category; however, they rarely have the possibility for variation within the behaviour of individual drivers. In addition, models need to be developed to allow for errors to occur as a result of less-than-perfect perception, decision-making, and actions that lead to different levels of risk in the interactions between road-users and the environment.
3. These 'more realistic' models must have their inputs accurately determined based on observational data, and simulation models must produce estimates of safety performance that can be verified from field observations (model calibration and validation).

Several studies have investigated improvements to the behaviour models in order to use more realistic behaviour that, for instance, allows drivers to commit errors. This extension to behaviour with cognitive functions within micro-simulation models is often referred to as a step towards nanoscopic simulation (Morsink et al., 2008). Further, several studies have investigated driver behaviour using, among others, simulator studies (Hogema, 2000), video observations, and floating car data (Tate et al., 2006). All of these studies have reported improvements in modelled behaviour, which indicates that their incorporation into simulation models would be beneficial.

The principle of validation against historic crash data (where it is considered necessary to establish a statistically sound relationship between simulated conflicts, in this case, and crashes) has been questioned by some researchers (see for example: Hauer and Garder, 1986 and Chin and Quek, 1997a). They contend that the greater need is to prevent a crash rather than predict frequencies, and that safety studies should be used as diagnostic and evaluative tools. These contentions suggest that the question of validity should relate to a construct validity, rather than product validity and should reflect how well the safety analyses can be used to identify safety problems and improvements in the system. This is the direction followed in this dissertation.

One area that seems to be absent from most safety evaluations is the relationship between evasive actions and conflicts and, from this, the relationship between conflicts and crashes. This area is difficult to account for as data on events which do not necessarily lead to crashes, is not kept. It is, however, an area that could develop with the onset of automated video recordings of many infrastructural situations, especially major roads.

A final issue concerns the effects of weather in micro-simulation. It is well known that bad weather can cause reduced visibility; slippery surfaces and so on, which can affect safety. These effects could potentially be simulated through the development of user program interfaces or algorithms. Although this would be an extremely time-consuming exercise, it would add to the range of assessments that could be undertaken through the use of simulation software.

9.3 Final discussion and potential future developments

The requirements of modern-day traffic planning and engineering work mean that fast, reliable, efficient and effective methods of evaluation are required, not only in relation to safety, but also from a performance and environmental perspective, to ensure that sustainability goals are complied with. Infrastructure is expensive, and changes to the infrastructure and/or the consideration of new infrastructure is probably inappropriate, unless these changes have safety impacts grounded on a scientific evaluation, through the consideration of locally calibrated conditions and requirements.

Given that cost-benefit analyses are used as a foundation for most decisions in relation to road infrastructure investment, the cost benefits of safer roads present a compelling case.

The limitations and potential of many safety indicators and prediction methods have been considered and discussed in this research from a theoretical and practical perspective, and has led to the evaluation of micro-simulation as another technology that could help assess road safety issues in South Africa, especially concerning pedestrian fatalities. These techniques and future automated video-analysis techniques should remain important qualitative and quantitative parts of future safety analysis methodologies.

The methods developed in this research can provide outcomes through which practitioners can evaluate and justify options for either infrastructure modifications or hypothetical cases. Their usefulness is reinforced as they can be used without accurate and reliable historical data for road safety campaigns, and for pro-active consideration of issues in existing situations. Furthermore, the techniques employed show that options can be evaluated and ranked through the use of the proposed PCI; although this could benefit from a further refinement/ modification process to allow for a severity index and a calibration process through before-and-after studies to ensure its robustness and acceptability.

Detailed modelling like this takes into consideration many site-specific values which allow sensitivity analysis of the safety influence of many different traffic parameters such as those due to changes in speed and traffic flows, and can allow an investigative sensitivity analysis on the effect on other important objectives, for example accessibility, capacity and environmental issues, which are an important part of transportation planning work.

The consideration and further development in automated post-processing systems for simulation outputs would help alleviate the requirements for manual evaluations of simulated outcomes, and enable the consideration of longer simulation periods for assessment; these would ultimately provide better and more averaged reviews of safety performance.

The work presented here has also pointed to the need for a greater understanding of the relationships between safety indicators, variables such as speed and speed variance, traffic flows, traffic compositions and turning percentages, and important behavioural processes (such as gap-acceptance and road-user behaviour), in order to ascertain a more comprehensive safety perspective. Developing statistical models that adequately predict the number of crashes based on safety indicators will also add to the value of safety analysis work in the future. To develop such models, a suitable national database that is accessible to safety analysts and modellers should be developed.

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APPENDICES

Appendix A: Road Environment

Table A- 1: Operational effects of freeway lane widths

Lane with (m)	Reduction in free-flow speed (km/h)
3.6	0
3.5	1
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Source: Federal Highway Administration. Retrieved January 2013, from www://safety.fhwa.dot.gov/geometrics

Table A. 2: Operational effects of lane and shoulder width on two-lane highways

Lane width (m)	Reduction in free flow speed (km/h)			
	Shoulder width (m)			
	$\geq 0.0 < 0.6$	$\geq 0.6 < 1.2$	$\geq 1.2 < 1.8$	≥ 1.8
2.7<3.0	10.3	7.7	5.6	3.5
$\geq 3.0 < 3.3$	8.5	5.9	3.8	1.7
$\geq 3.3 < 3.6$	7.5	4.9	2.8	0.7
≥ 3.6	6.8	4.2	2.1	0

Source: Federal Highway Administration. Retrieved January 2013, from www://safety.fhwa.dot.gov/geometrics

Appendix B: Statistical analyses of crash frequency data

Table B-1: Data and methodological issues associated with crash-frequency data

Data/Methodological Issue	Associated Problems
Overdispersion	Can violate some the basic count-data modelling assumptions of some modelling approaches
Underdispersion	As with overdispersion, can violate some the basic count-data modelling assumptions of some modelling approaches
Time-varying explanatory variables	Averaging of variables over studied time intervals ignores potentially important variations within time intervals – which can result in erroneous parameter estimates
Temporal and spatial correlation	Correlation over time and space causes losses in estimation efficiency
Low sample mean and small sample size	Causes an excess number of observations where zero crashes are observed which can cause errors in parameter estimates
Injury severity and crash type correlation	Correlation between severities and crash types causes losses in estimation efficiency when separate severity-count models are estimated
Under reporting	Under reporting can distort model predictions and lead to erroneous inferences with regard to the influence of explanatory variables
Omitted variables bias	If significant variables are omitted from the model, parameter estimates will be biased and possibly erroneous inferences with regard to the influence of explanatory variables will result
Endogenous variables	If endogenous variables are included without appropriate statistical corrections parameter estimates will be biased and erroneous inferences with regard to the influence of explanatory variables may be drawn
Functional form	If incorrect functional form is used, the result will be biased parameter estimates and possibly erroneous inferences with regard to the influence of explanatory variables
Fixed parameters	If parameters are estimated as fixed when they actually vary across observations, the result will be biased parameter estimates and possibly erroneous inferences with regard to the influence of explanatory variables

Source: Lord and Mannering, 2010

Table B-2: Summary of existing models for analysing crash-frequency data

Model Type	Advantages	Disadvantages
Poisson	Most basic model; easy to estimate	Cannot handle over- and under-dispersion; negatively influenced by the low sample mean and small sample size bias
Negative binomial/Poisson-gamma	Easy to estimate can account for overdispersion	Cannot handle under-dispersion; can be adversely influenced by the low sample mean and small sample size bias
Poisson-lognormal	More flexible than the Poisson-gamma to handle over-dispersion	Cannot handle under-dispersion; can be adversely influenced by the low sample mean and small sample size bias (less than the Poisson-gamma); cannot estimate a varying dispersion parameter
Zero-inflated Poisson and negative binomial	Handles datasets that have a large number of zero-crash observations	Can create theoretical inconsistencies; zero-inflated negative binomial can be adversely influenced by the low sample mean and small sample size bias

Source: Lord and Mannering, 2010

Appendix C – Summary of evaluation of time-based safety measures

Table C-1: Summary of evaluation of time-based safety measures

Technique	Definition	Methods of Analysis	Evaluation
Time-to-Accident (TTA)	An observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movement remain unchanged (Amundsen and Hyden, 1977)	By trained conflict observers or via post processing of video footage	<ul style="list-style-type: none"> i. Event uses the point at which evasive action is first undertaken as basis ii. Measurement of conflict based on subjective assessment, meaning that there may be intra-observer differences iii. An arbitrary scale of conflicts is used to define events iv. Definition of conflict may not be compatible with processes that lead to crashes v. Limited application as diagnostic and evaluation tool, better for crash prediction vi. Limited application in studies focused on severity vii. Suitable for angled vehicle – vehicle crashes and rear –end crashes through time or distance based calculations viii. Can be used for vehicle-bicycle potential crash evaluations (Sources: Hauer & Garder, 1986; Chin & Quek, 1997 & Archer, 2005)
Time-to-Collision (TTC)	The time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained (i.e. as above but includes reaction time) (Source: Hayward, 1972)	Visual observations/ traffic loop detectors/Video	<ul style="list-style-type: none"> i. Event uses an arbitrary scale of danger which may not be compatible with processes that lead to crashes ii. Limited application as diagnostic and evaluation tool, better for crash prediction iii. Limited application in studies focused on severity iv. Suitable for angled vehicle – vehicle crashes and rear –end crashes through time or distance based calculations v. Can be used for vehicle-bicycle potential crash evaluations (Sources: van der Horst, 1990;Chin & Quek, 1997 & Cunto, 2008)
Time-to-Zebra (TTZ)	Variation of TTC to estimate safety at pedestrian crossing	As TTC	<ul style="list-style-type: none"> i. Event uses an arbitrary scale of danger which may not be compatible with processes that lead to crashes ii. Limited application as diagnostic and evaluation tool, better for crash prediction iii. Limited application in studies focused on severity iv. Used for vehicle-pedestrian crash evaluations
Post Encroachment Time (PET)	The time difference between the moment that the first road user leaves the path of the second and the moment that the second road user reaches the path of the first	As TTC	<ul style="list-style-type: none"> i. Often used without collision course or evasive manoeuvre ii. Event uses an arbitrary scale of danger which may not be compatible with processes that lead to crashes iii. Limited application as diagnostic and evaluation tool, better for crash prediction iv. Limited application in studies focused on severity v. Suitable mainly for crossing trajectory evaluations vehicle– vehicle and VRU crashes vi. Rear-end conflicts too complex to analyse (Source: Based on Allen et al., 1978 & Cunto, 2008)
Gap Time (GT)	The time lapse between the completion of an encroachment	As TTC	<ul style="list-style-type: none"> i. Requires definition of conflict area for each manoeuvre ii. Requires precise measurements for time intervals and speeds of ‘offending’ and

	by a turning road-user and the arrival time of a crossing road-user if they continue with the same velocity and trajectory (Gettman and Head, 2003)		right-of-way vehicles iii. Event uses an arbitrary scale of danger which may not be compatible with processes that lead to crashes iv. Limited application as diagnostic and evaluation tool, better for crash prediction v. Limited application in studies focused on severity vi. Suitable mainly for crossing trajectory evaluations – vehicle crashes (Source: Based on Gettman and Head, 2003 and Cunto, 2008)
Deceleration Rate	A measure of the highest rate at which a vehicle must decelerate to avoid a collision	Video/ Loop detectors, Speed guns/ Simulation	i. Uses an intuitive scale of danger which may not be wholly compatible with events that lead to crashes ii. Can be used for any conflict type iii. Can be used as diagnostic tool
Encroachment Time	The time duration during which the turning of one road-user infringes the right-of-way of a mainline road-user (Gettman and Head, 2003)	As TTC	i. Requires definition of conflict area for each manoeuvre ii. Requires precise measurements for time intervals of ‘offending’ vehicles iii. Event uses an arbitrary scale of danger which may not be compatible with processes that lead to crashes iv. Limited application as diagnostic and evaluation tool, better for crash prediction v. Limited application in studies focused on severity vi. Suitable mainly for crossing trajectory evaluations – vehicle crashes (Source: Based on Gettman and Head, 2003 and Cunto, 2008)
Initially Attempted Post-encroachment Time	The time lapse between the commencement of an encroachment by a turning road-user plus the expected time for the mainline road-user to reach the common conflict point, and the completion time of encroachment by the turning road-user (Gettman and Head, 2003)	As TTC	As PET
Headway	Time headway is the elapsed time between the front of a lead vehicle and the front of a following vehicle passing the same point	As TTC	i. Uses an intuitive scale of danger which may not be wholly compatible with events that lead to crashes ii. Main use as indicator of potential rear-end, vehicle- vehicle crashes iii. Limited use as diagnostic tool

Appendix D: Examples of 'woonerfs' and 'liveable' streets

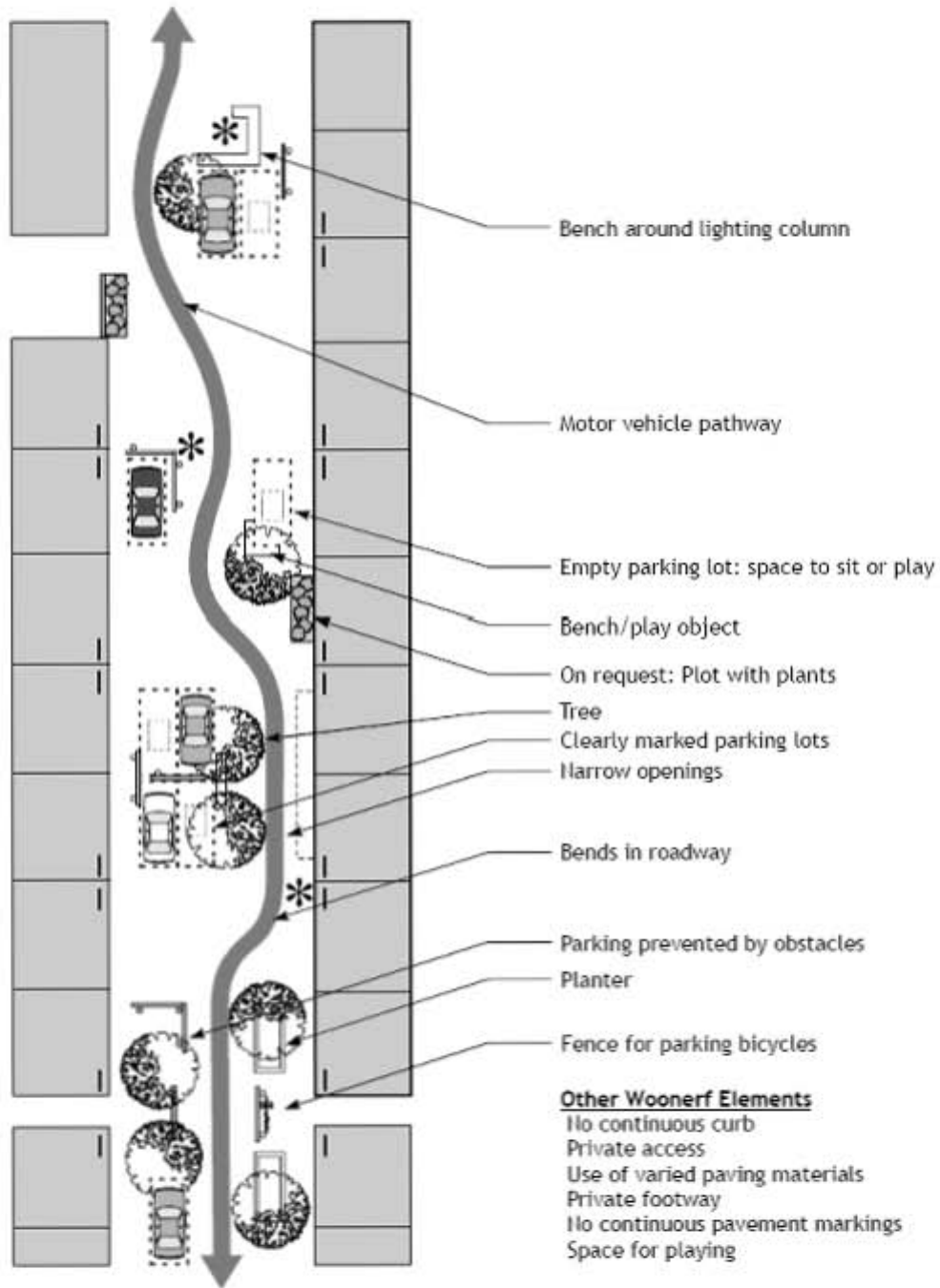


Figure 90: Typical layout of a 'woonerf'.



Figure 91: Examples of 'woonerfs' and a 'Home Zone' in UK
Source: <http://www.flickr.com/photos> (accessed May 2013)

Appendix E: Accident Modification Factors

Table E-1: Injury and fatal crash AMFs based on initial speed and speed changes

Non-fatal injury crashes							Fatal injury crashes						
ΔV (mph)	V_0 (mph)						ΔV (mph)	V_0 (mph)					
	30	40	50	60	70	80		30	40	50	60	70	80
-5	0.57	0.66	0.71	0.75	0.78	0.81	-5	0.22	0.36	0.48	0.58	0.67	0.75
-4	0.64	0.72	0.77	0.80	0.83	0.85	-4	0.36	0.48	0.58	0.66	0.73	0.80
-3	0.73	0.79	0.83	0.85	0.87	0.88	-3	0.51	0.61	0.68	0.74	0.80	0.85
-2	0.81	0.86	0.88	0.90	0.91	0.92	-2	0.66	0.73	0.79	0.83	0.86	0.90
-1	0.90	0.93	0.94	0.95	0.96	0.96	-1	0.83	0.86	0.89	0.91	0.93	0.95
0	1.00	1.00	1.00	1.00	1.00	1.00	0	1.00	1.00	1.00	1.00	1.00	1.00
1	1.10	1.07	1.06	1.05	1.04	1.04	1	1.18	1.14	1.11	1.09	1.07	1.05
2	1.20	1.15	1.12	1.10	1.09	1.08	2	1.38	1.28	1.22	1.18	1.14	1.10
3	1.31	1.22	1.18	1.15	1.13	1.12	3	1.59	1.43	1.34	1.27	1.21	1.16
4	1.43	1.30	1.24	1.20	1.18	1.16	4	1.81	1.59	1.46	1.36	1.28	1.21
5	1.54	1.38	1.30	1.26	1.22	1.20	5	2.04	1.75	1.58	1.46	1.36	1.27
V_0 (mph) = initial mean speed ΔV = change in mean travel speed							V_0 (mph) = initial mean speed ΔV = change in mean travel speed						

Source: NHCRP (2008)

Appendix F: Study Areas A and B – Assessment of possible vehicle-pedestrian incidents

Appendix F1

Table F- 1: Study Area A - Assessment of possible vehicle-pedestrian incidents

Collision time (m:s)	Vehicle Speed (m/s)	Vehicle Type	Acceleration from Trajectory file (m/s ²)		PCI	Notes
			At collision	Previous step		
12:00	12.6	Car	-8.5	-6.5	0	Speed < 20km/h at 'collision' point.
12:52	40.53	Car	-6.3	-4.3	4	Pedestrian recognised, swerve or pedestrian stop possible.
15:24	14.38	Minibus	2	1	0	Speed < 20km/h at 'collision' point.
13:41	26.91	Minibus	3	3	2	Speed at previous step 16km/h .
19:16	25.41	Car	3	2.5	2	Accelerating in lane. Potential collision.
19:48	9.82	OGV2	1	0	0	Stationary at previous step.
24:23	30.38	Car	1	-8.5	1	Hard brake/direction change in trajectory.
25:15	52.46	OGV1	1.1	1.1	4	Potential incident
25:19	11.49	Car	0	-8	0	Speed < 20km/h at 'collision' point.
27:07	55.57	Car	-4	-2	4	Pedestrian presence recognised, further braking force available.
28:27	37.15	Car	-6.5	-4.5	3	Pedestrian presence recognised, further braking force available.
26:51	15.51	Minibus	2	-4.5	0	Speed < 20km/h at 'collision' point.
27:56	17.63	Car	0	-8	0	Speed < 20km/h at 'collision' point.
33:01	29.48	Car	-8.1	-6.1	1	Probable avoidance of collision.
31:43	14.84	Car	0	-8	0	Speed < 20km/h at 'collision' point.
34:18	42.93	Car	-6	-2	4	Pedestrian presence recognised, further braking force available.
34:40	39.63	Car	-6	-2	3	Pedestrian presence recognised, further braking force available.
36:52	22.01	LGV	2	-4.9	1	Deceleration evident
37:42	29.07	Car	-8	-6	1	Probable avoidance of collision.
41:34	23.57	Car	3	3	2	Speed at previous step 12km/h
41:09	44.19	Car	0	-6	4	Potential collision.
45:38	23.67	Car	2	-8.5	1	Speed at previous step 18km/h
48:16	42.21	Car	-6.2	-2.2	4	Pedestrian presence recognised, further braking force available.
51:57	28.46	Car	0	-6	1	Probable avoidance of collision.
51:15	44.58	Car	0	-2	4	Speed at previous step 63km/h.
55:02	11.4	Car	-8.5	-8.5	0	Speed < 20km/h at 'collision' point.
55:03	14.86	Car	-8.5	-8	0	Speed < 20km/h at 'collision' point
57:31	26.85	Car	-8.1	-6	1	Probable avoidance of collision.
63:28	16.22	Car	-8.5	-8	0	Speed < 20km/h at 'collision' point.
63:13	26.55	Car	-8.1	-6.1	1	Probable avoidance of collision.
64:06	13.02	Car	-8.5	-8	0	Speed < 20km/h at 'collision' point.
64:27	28.53	Car	-8	-4	1	Pedestrian presence recognised, further braking force available.

64:27	14.33	Car	3	0	0	Speed < 20km/h at 'collision' point.
66:21	41.47	Car	-6	-2	4	Pedestrian presence recognised, further braking force available.
69:29	28.34	Car	-8	-4	1	Probable avoidance of collision.
Total PCI					54	

Appendix F2

Table F-2: Study Area A – Assessment of possible vehicle-pedestrian incidents for raised crosswalk modification

Collision Time (mins)	Vehicle Speed (km/h)	Vehicle Type	Acceleration from trajectory file		PCI	Notes
			At collision	Previous step		
10:32	15.65	Car	0	-8.5	0	Speed < 20km/h at 'collision' point.
11:43	37.77	Car	2	-8.5	3	Pedestrian recognised, swerve or pedestrian stop likely.
18:48	42.47	OGV1	1.1	1.1	4	Potential collision
19:52	18.3	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
20:32	39.08	Car	0	-6.2	3	Pedestrian recognised, swerve or pedestrian stop likely
19:20	9.42	Car	-8.5	-8.5	0	Speed < 20km/h at 'collision' point.
21:10	14.73	Car	-8.5	-6.5	0	Speed < 20km/h at 'collision' point.
21:54	11.25	Car	0	-8.5	0	Speed < 20km/h at 'collision' point.
24:52	44.73	Car	1	-6	4	Pedestrian recognised, swerve or pedestrian stop likely
24:51	30.66	Car	1	-8	1	Pedestrian recognised, swerve or pedestrian stop likely
29:58	16.2	Car	0	-8.5	0	Speed < 20km/h at 'collision' point.
35:07	6.37	Car	1	-0.5	0	Speed < 20km/h at 'collision' point.
33:16	12.72	Car	-8.5	-6.5	0	Speed < 20km/h at 'collision' point. Discounted from further analysis.
39:15	27.9	Car	-8.5	-4.5	1	Pedestrian recognised, swerve or pedestrian stop likely
39:50	23.98	Car	-6.1	-4.1	1	Pedestrian recognised, swerve or pedestrian stop likely
41:50	11.02	Car	-8.5	-6.4	0	Speed < 20km/h at 'collision' point.
42:59	15.54	Car	-8.5	-6.4	0	Speed < 20km/h at 'collision' point.
45:23	29.54	Car	-8	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
46:43	54.46	Car	-0.5	-0.5	4	Potential collision
50:04	27.36	Car	0	-3.5	1	Pedestrian recognised, swerve or pedestrian stop likely
50:40	20.88	Car	-8.5	-2.5	1	Pedestrian recognised, swerve or pedestrian stop likely
58:19	36.83	Car	-6.5	-4.5	3	Pedestrian recognised, swerve or pedestrian stop likely
61:31	24.22	Car	0	-2	1	Pedestrian recognised, swerve or pedestrian stop likely
61:43	12.37	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
69:57	23.58	LGV	1	-5	1	Pedestrian recognised, swerve or pedestrian stop likely
Total PCI					29	

Appendix F3

Table F-3: Study Area A – Assessment of possible vehicle-pedestrian incidents for narrowing to allow for a bus/minibus-taxi lane

Collision Time (m:s)	Vehicle Speed (km/h)	Vehicle Type	Acceleration from trajectories		PCI	Notes
			At collision point	Previous time step		
02:59	61.27	Car	1	-2	5	Potential collision
06:03	30.00	Car	0	-6	1	Pedestrian recognised, swerve or pedestrian stop likely
09:00	15.03	Car	0	-1.8	0	Speed < 20km/h at 'collision' point.
12:48	27.68	OGV2	1.4	0.9	2	Potential collision
11:28	30.35	LGV	2	-5	2	Pedestrian recognised, swerve or pedestrian stop likely
13:38	15.92	OGV1	-3.2	-3.2	0	Speed < 20km/h at 'collision' point.
14:58	40.74	Car	1	-0.5	2	Potential collision
16:37	15.94	Car	-8.5	-6	0	Speed < 20km/h at 'collision' point.
14:04	31.32	OGV1	0	-3.2	2	Pedestrian recognised, swerve or pedestrian stop likely
14:53	44.95	Car	0	-4	4	Pedestrian recognised, swerve or pedestrian stop likely
26:07	25.58	Minibus	3	2.2	2	Potential collision
23:25	21.6	Car	3	3	2	Potential collision
25:35	12.35	Car	3	-4.1	0	Speed < 20km/h at 'collision' point.
27:53	29.8	Car	0	-6.1	1	Pedestrian recognised, swerve or pedestrian stop likely
40:40	6.28	Car	1.67	0.7	0	Speed < 20km/h at 'collision' point.
42:54	52.38	LGV	-4.9	2	4	Pedestrian recognised, swerve or pedestrian stop likely
44:01	32.75	Car	-8	-6	3	Pedestrian recognised, swerve or pedestrian stop likely
46:57	13.02	Car	-8.5	-6	0	Speed < 20km/h at 'collision' point.
44:02	17.45	Car	-8.5	-8	0	Speed < 20km/h at 'collision' point.
44:13	49.27	LGV	0	-4.9	4	Pedestrian recognised, swerve or pedestrian stop likely
48:44	21.6	Minibus	3	2	2	Potential collision
49:00	55.67	Minibus	3	3	4	Potential collision
54:32	29.7	Minibus	3	1	2	Potential collision
54:01	22.65	OGV1	1.1	1.1	2	Potential collision
54:47	16.89	Minibus	2.54	1.44	0	Speed < 20km/h at 'collision' point.
58:33	53.7	OGV1	1.1	1.1	4	Potential collision
62:00	23.45	Car	3	3	2	Potential collision
62:29	29.34	Car	1.16	1	2	Potential collision
66:16	55.53	LGV	0	0	4	Potential collision
Total PCI					56	

Appendix F4

Table F-4: Study Area B – Assessment of possible vehicle-pedestrian incidents

Collision Time (min)	Vehicle speed (km/h)	Vehicle Type	Acceleration from Trajectory file (m/s^2)		PCI	Notes
			At current time step	At previous steps		
04:28	28.92	Car	2.5	2.4	2	Potential collision
11:16	12.35	LGV	1.0	-4.9	0	Speed < 20km/h at 'collision' point.
11:38	14.4	Car	2.5	2.0	0	Speed < 20km/h at 'collision' point.
13:14	21.6	Car	1.0	-3.1	1	Pedestrian recognised, swerve or pedestrian stop likely
18:33	10.8	Car	1.0	-8.5	0	Speed < 20km/h at 'collision' point.
19:00	12.06	OGV1	1.1	-5.2	0	Speed < 20km/h at 'collision' point.
20:04	32.49	Minibus	2.0	-8.5	1	Pedestrian recognised, swerve or pedestrian stop likely
22:00	16.15	Car	2.5	-8.5	0	Speed < 20km/h at 'collision' point.
22:32	22.5	Car	2.0	-8.5	1	Pedestrian recognised, swerve or pedestrian stop likely
23:35	15.3	Car	1.0	-8.5	0	Speed < 20km/h at 'collision' point.
24:36	7.7	Minibus	-0.1	-3.4	0	Speed < 20km/h at 'collision' point.
25:05	9.83	LGV	1.8	-4.9	0	Speed < 20km/h at 'collision' point.
25:56	21.37	Car	1.0	1.0	2	Potential collision
26:10	9.64	Minibus	2.0	-8.0	0	Speed < 20km/h at 'collision' point.
26:23	12.88	Car	1.0	-8.5	0	Speed < 20km/h at 'collision' point.
28:11	50.4	Car	0.0	2.5	4	No/late braking. Potential collision.
29:06	19.06	Minibus	0	-3.6	0	Speed < 20km/h at 'collision' point.
43:03	13.6	LGV	1.8	-4.9	0	Speed < 20km/h at 'collision' point.
44:11	16.17	Car	2.0	-8.5	0	Speed < 20km/h at 'collision' point.
45:58	15.12	Car	2.9	-8.5	0	Speed < 20km/h at 'collision' point.
55:04	14.02	Car	2.0	-8.5	0	Speed < 20km/h at 'collision' point. Discounted from further analysis.
55:30	52.73	LGV	-3.4	1.0	4	-3.1 m/s^2 before, swerve to avoid collision. Potential collision
58:06	19.62	LGV	1.0	-4.9	0	Speed < 20km/h at 'collision' point.
59:21	18.2	LGV	1.0	-4.9	0	Speed < 20km/h at 'collision' point.
62:12	19.23	Car	2.0	-8.5	0	Speed < 20km/h at 'collision' point.
63:14	22.36	Car	-8.5	2.5	1	Pedestrian recognised, swerve or pedestrian stop likely
63:32	16	Car	-8.5	2.2	0	Speed < 20km/h at 'collision' point.
Total PCI					16	

Appendix F5

Table F-5: Study Area B – Assessment of possible vehicle-pedestrian incidents for modified intersection (signal timing)

Collision Time (min)	Vehicle Speed (km/h)	Vehicle Type	Acceleration from trajectory file		PCI	Notes
			At collision time	Previous step		
05:22	15.74	LGV	1.27	1.8	0	Speed < 20km/h at 'collision' point.
06:16	12.6	Car	0	-8.5	0	Speed < 20km/h at 'collision' point.
06:24	8.82	Minibus	0	-8	0	Speed < 20km/h at 'collision' point.
09:17	7.15	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
09:29	17.81	Minibus	2.1	-7.9	0	Speed < 20km/h at 'collision' point.
11:59	22.57	Car	-8.5	-4.6	1	Pedestrian recognised, swerve or pedestrian stop likely
14:27	13.96	Minibus	2.1	-1.3	0	Speed < 20km/h at 'collision' point.
13:58	19.8	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
18:42	14.09	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
21:50	26.28	Car	1	-8.5	1	Pedestrian recognised, swerve or pedestrian stop likely
25:16	9.54	Car	1.96	4.5	0	Speed < 20km/h at 'collision' point.
26:40	18.03	Car	2.5	-8.5	0	Speed < 20km/h at 'collision' point.
27:51	6.3	Car	0	-8.5	0	Speed < 20km/h at 'collision' point.
28:10	30.09	LGV	1	-4.9	1	Pedestrian recognised, swerve or pedestrian stop likely
29:27	19.13	Minibus	0	2.1	0	Speed < 20km/h at 'collision' point.
31:09	7.34	OGV2	-5	1.4	0	Speed < 20km/h at 'collision' point.
31:13	30.89	LGV	-4.9	2	2	Late brake/swerve
31:29	21.71	Car	1	-6.4	1	Pedestrian recognised, swerve or pedestrian stop likely
48:17	9.46	Minibus	0	-8	0	Speed < 20km/h at 'collision' point.
49:57	16.68	Car	2	-8.5	0	Speed < 20km/h at 'collision' point.
50:19	19.64	Car	1	-2.8	0	Speed < 20km/h at 'collision' point.
51:19	9.9	Car	1	-5.5	0	Speed < 20km/h at 'collision' point.
52:44	10.78	Minibus	0	-6.7	0	Speed < 20km/h at 'collision' point.
54:05	22.43	Car	2	-3.3	1	Pedestrian recognised, swerve or pedestrian stop likely
54:09	9.9	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
62:17	9.9	Minibus	2	-8	0	Speed < 20km/h at 'collision' point.
Total PCI					7	

Appendix F6

Table F-6: Study Area B – Assessment of possible vehicle-pedestrian incidents for modified intersection (textured paving)

Collision Time (min)	Vehicle Speed (km/h)	Vehicle Type	Acceleration from trajectories		PCI	Notes
			At collision	At previous time step		
06:54	18.28	LGV	1.8	-4.9	0	Speed < 20km/h at 'collision' point.
08:47	21.89	Car	2.5	-4.7	1	Pedestrian recognised, swerve or pedestrian stop likely
08:57	17.14	Car	2.5	-1.1	0	Speed < 20km/h at 'collision' point.
10:18	5.13	Car	-8.4	-6.4	0	Speed < 20km/h at 'collision' point.
11:38	16.7	Car	2.5	2.5	0	Speed < 20km/h at 'collision' point.
11:58	30.32	Minibus	2.1	2.1	2	Accelerating
12:44	18.12	Car	-6.4	-4.4	0	Speed < 20km/h at 'collision' point.
13:57	8	Minibus	-8	-4	0	Speed < 20km/h at 'collision' point.
14:47	21.76	Car	2	-8.1	1	Pedestrian recognised, swerve or pedestrian stop likely
16:13	33.5	Minibus	-4	0	2	Pedestrian recognised, swerve or pedestrian stop likely
19:01	19.93	Car	-6.5	-0.5	0	Speed at previous section 44m/s
19:20	22.8	Car	0	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
20:29	20.5	Car	-6	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
20:37	19.13	Car	0	-6	0	Speed < 20km/h at 'collision' point.
21:07	21.54	Car	0	-6	1	Pedestrian recognised, swerve or pedestrian stop likely
22:04	22.13	Car	2.5	0.5	2	Potential collision
22:32	6.27	Car	-8	-6	0	Speed < 20km/h at 'collision' point.
26:00	33.92	Car	-4.2	-2.2	2	Pedestrian recognised, swerve or pedestrian stop likely
27:05	21.04	Car	-6.4	-4.4	1	Pedestrian recognised, swerve or pedestrian stop likely
27:26	12.34	Minibus	-8	2.1	0	Speed < 20km/h at 'collision' point.
27:51	20.46	Car	-6.2	-0.2	1	Pedestrian recognised, swerve or pedestrian stop likely
28:23	25.9	Car	2.5	2.4	2	Potential collision
29:49	40.4	Car	-2.3	-0.3	3	Pedestrian recognised, swerve or pedestrian stop likely
32:42	31.95	Car	0	-2.2	2	
37:04	21.24	Car	-6.2	-0.4	1	Pedestrian recognised, swerve or pedestrian stop likely
40:39	4.24	LGV	-4.5	-4.9	0	Speed < 20km/h at 'collision' point.
41:11	21.1	Minibus	0	-4	1	Speed at previous section 43m/s
41:25	35.28	Car	-4	-2	2	Pedestrian recognised, swerve or pedestrian stop likely

41:34	9.22	Minibus	-8	-6	0	Speed < 20km/h at 'collision' point.
42:12	22.08	Car	-6	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
43:21	8.1	Minibus	0	-6.5	0	Speed < 20km/h at 'collision' point.
44:22	16.2	Car	2.5	1.9	0	Speed < 20km/h at 'collision' point.
44:45	11.96	Car	2	-3.9	0	Speed < 20km/h at 'collision' point.
45:30	5.89	Car	-8.4	-6.4	0	Speed < 20km/h at 'collision' point.
46:54	20.13	Minibus	0	1	2	Potential collision
48:20	21.18	Car	-6	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
50:36	9.56	Minibus	-8	-4	0	Speed < 20km/h at 'collision' point.
50:35	23.96	Minibus	-6	-4	1	Pedestrian recognised, swerve or pedestrian stop likely
50:48	23.1	Car	-6.1	-4.1	1	Pedestrian recognised, swerve or pedestrian stop likely
53:02	21.34	Car	-6.3	-4.3	1	Pedestrian recognised, swerve or pedestrian stop likely
53:11	33	Car	1	-8.5	2	Pedestrian recognised, swerve or pedestrian stop likely
56:04	16.21	Car	-3.4	-1.7	0	Speed < 20km/h at 'collision' point.
57:08	21.01	Car	-6.5	-4.5	1	Pedestrian recognised, swerve or pedestrian stop likely
59:06	19.68	Car	2	1	0	Speed < 20km/h at 'collision' point.
59:04	17.11	Car	2.9	2	0	Speed < 20km/h at 'collision' point.
60:28	35.14	Car	0	-4	2	Pedestrian recognised, swerve or pedestrian stop likely
60:29	19.84	Car	-8.5	0	0	Speed < 20km/h at 'collision' point.
61:25	32.91	Minibus	-4	-2	2	Pedestrian recognised, swerve or pedestrian stop likely
64:50	10.7	Car	1	-8.5	0	Speed < 20km/h at 'collision' point.
Total PCI					40	