MICRO-SIMULATION MODELLING OF THE IMPACT OF INFRASTRUCTURE PROVISION AND VEHICLE AND PEDESTRIAN BEHAVIOUR ON ROAD CRASH RISK.

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ABSTRACT

Microscopic computer models provide the opportunity to simulate vehicle and pedestrian behaviour under varying infrastructure conditions. Pre-crash and crash involvement risk at street, or even suburb level, can be explored and modified through various scenarios, such as: traffic calmed streets, pedestrian crossings, technology based infrastructure and other physical interventions. Models can simulate behavioural variation of both pedestrians and drivers by varying criteria such as: compliance levels (i.e. attitude to risk), headway distances, acceleration profiles, aggression, awareness and speed. These characteristics affect the outcomes of modelled existing and hypothetical scenarios and can be used to assess the potential crash risk at street level, for various states of behaviour of aggregated or disaggregated groups. Outcomes provide measures of road safety via proxies (or surrogate measures). The road safety risk for specific urban contexts should, therefore, be better predicted through an improved understanding of the interactions between infrastructure and vehicle and pedestrian behaviour.

This paper outlines the road safety situation in South Africa and evaluates the use of micro-simulation software as a tool to analyse the road safety risk of various local infrastructure scenarios through vehicle and pedestrian interaction.

Keywords: Micro-simulation modelling, road safety assessment, pedestrian behaviour, crash risk, surrogate measures of safety.

BACKGROUND

The statistic that road traffic crashes claim the lives of some 1.2 million people every year, and that about 50 million people are injured or disabled worldwide is now well known (WHO, 2004). Even in Organisation for Economic Development and Co-operation (OECD) countries, approximately 125,000 people die every year on the roads (OECD, 2002). In other words, globally, more than 2 road crash victims die every minute.

Low-income and middle-income countries account for about 90% of global mortality due to road traffic crashes. In contrast to developed nations, these countries have shown an increase in the number of fatalities, especially pedestrian fatalities, since the 1980's (WHO, 2004).

The real tragedy is that, to a large extent, these crashes and the resultant deaths and injuries could have been prevented. The argument for road safety investment is not simply an emotional one - road crashes represent a serious economic burden: their cost is estimated to represent up to 4% of GDP in some countries and around 3% in GDP of South Africa. Fatalities across all countries could be significantly reduced if all governments were fully committed to improving road safety by implementing and enforcing appropriate countermeasures (OECD, 2002).

Significantly, at about 30 fatalities per 100 000 population, per year, South Africa's road crash record is one of the worst in the world (derived from RTMC, 2010). Of these fatalities, more than 40% were pedestrians, the majority being young and breadwinners for their families and more than 90% of crashes were as a result of lawlessness - pedestrian and driver negligence and ignorance being key components of this statistic (Arrive Alive, 2009).

Apart from negligence and ignorance, other factors which influence the statistics above are that travel mode in South Africa, as in the rest of Southern Africa, is highly dependent on economic means- it is dominated by walking and public transport among the poorer sectors of the population, who undertake the majority of transport trips (NDoT, 2005). Added to this, roads provide a mixture of 1st and 3rd world traffic conditions with limited pedestrian facilities, especially in outlying urban and more rural areas where there are few or no paved footpaths or footbridges. These factors create variations in the public's perception and expectation – on the one hand travellers used to 1st world conditions and behaviour and on the other hand travellers unfamiliar with the urban environment, vehicle speeds and thus, the capacity to cope with, or recognise, potentially hazardous situations. Poor vehicle maintenance is also a significant contributor.

From an investigation and prevention perspective, general locational details of the majority of fatal crashes are recorded for most urban incidents, albeit related to the nearest intersection. Details of the more rural incidents are also captured in terms of incident type but are known to be unreliable. The majority of pedestrian fatalities are known to occur on roads not preventing high speed differentials and, observations relating to the nature of pedestrian crashes and information capture, are either sparse or unreliable, making safety evaluation difficult.

The results of these safety investigations – the causes of crashes – are traditionally, aggregated under human, vehicular and environmental factors but, their interaction is seldom investigated and safety programmes, safety initiatives and infrastructure retro-fits continue to be derived mostly from the focus on historic crash statistics as well as 'black-spot' or clusters analysis of incidents. Additionally road safety audits prior to implementation of new infrastructure are not mandatory.

Despite the intuitive link between road safety and observed crashes, a good understanding of the sequence of events prior to the crash, along with detailed crash investigation, can provide a more rational basis for the development of engineering countermeasures. Evidence from some highly-motorised countries shows that an integrated approach to road safety has produced a decline in road deaths and serious injuries (Trinca et al, 1988; Lonero et al, 2002). But the practical realisation of an integrated systems approach (as advocated by Haddon, 1968) remains the most important challenge for road safety policy-makers and professionals.

Issues related to data availability and reliability, as well as methodological challenges posed by the random nature of crashes, have fostered many complementary approaches to improve road safety assessments, such as the simulation of traffic conflicts and the use of computer based collision predictors or infrastructure safety indicators.

Furthermore, 'black-spot' analyses are known to have the disadvantage that, although these locations have peculiarities which lead to a high numbers of incidents, crashes are random events and can occur anywhere given a certain set of antecedent conditions (Peltola, 2009). They may, therefore, be an unreliable method for future incident prediction.

Given its safety record, especially the disproportionate pedestrian fatality rate, and the successes of alternative approaches elsewhere, it seems as though some additional/complementary methods of assessing road safety may yield better results.

This paper, briefly, outlines some of these complementary safety evaluation techniques and looks in more detail at the applicability of microscopic simulation software as a tool to analyse road user safety risk via surrogate measures of safety.

SAFETY EVALUATION TECHNIQUES

To estimate the safety of various traffic facilities, including those that have not yet been built, research in road safety has largely focused on the establishment of safety performance indicators that relate the number of crashes or crash rate to a number of 'operational' (for example, average annual daily traffic (AADT) and average speed) and 'non-operational' independent variables via a regression equation(s), including AADT, occupancy, Volume to capacity (V/C) ratios, products of crossing volumes, etc. Calibration is then required to choose the equation parameters for the best statistical fit to the available data (FHWA, 2003).

Research has also been undertaken on statistical techniques for revising crash estimates based on observations as a way to develop safety estimates for facilities with no crash data as well as into various other methods for combining crash rates and other measures into safety level of service measures (FHWA, 2003).

The Swedish Traffic Conflict Technique (TCT) is perhaps the most developed indirect measure of traffic safety. The technique itself is grounded in the ability to register the occurrence of near-accidents directly in real-time traffic and therefore offers a faster and, in many respects, more representative way of estimating expected crash frequency and outcomes (Archer, 2001).

In addition, many other techniques have evolved in response to growing awareness of the road safety problem. Techniques such as: the development of an index used for assessing and monitoring road safety – 'The Road Safety Index' (Cidaut, 2008); Collision Prediction Models (which is similar to the TCT) produce an estimate of the collision frequency for a location based on the site-specific characteristics of the location (British Columbia, 2008) and internet based evaluation techniques which, inter alia, allow retro-active evaluation of infrastructure are now more readily available (for example: www.roadsafetyevaluation.com/index.html).

Despite the large body of safety modelling research, absolute numbers of crashes and crash rates are still difficult to predict accurately. Over time this has led to increased interest in obtaining *surrogate measures* that reflect the safety of a facility, or at least the increased probability of higher than average crash rates for a facility (FHWA, 2003). Evaluation techniques are moving towards and encompassing the application of video data collection and analysis, as well as microscopic simulation of traffic conflicts.

MICRO-SIMULATION MODELS

With the increases in computer processing power and advances in programming skills, an array of transportation and urban planning computer models are now available to the profession. They are extensively used in developed nations to model complex transport scenarios and interactions. Models vary from macroscopic, which focus on the system as a whole, to more complex microscopic models which allow the modelling of individual road users and behaviour to obtain more realistic representations at a local level and can thus be used for safety assessments.

A variety of different microscopic simulation models have been developed by researchers and some have become commercially available to the transport profession. The majority of models are based on the principles of either: Cellular Automata, Social Force or are Agent-based models. In addition models based on the use of Geographical Information Systems are also commercially available.

The models, to varying degrees, give researchers and practitioners the ability to analyse the effectiveness of interventions on a disaggregated level, as individual vehicles and/or pedestrians are simulated in detail as they move through the road network with the goal of reaching their destination by the most cost effective or shortest route (Harney, 2002). Road users interact with the road network, the control systems, with other vehicles and pedestrians. Models capture the majority of interactions of real-world road traffic through a series of algorithms.

Researchers indicate that to date, the majority of microscopic traffic model development and simulation has essentially focused on the analysis of transportation efficiency, such as signalised intersections, arterial networks, freeway corridors or crowd evacuation or dynamics (Cunto, 2008).

The development by the US Federal Highway Administration and Siemens of the Surrogate Safety Assessment Model, or SSAM, demonstrates a successful adaptation. SSAM is a technique which combines micro-simulation and automated conflict analysis - analysing the frequency and character of narrowly averted vehicle-to-vehicle collisions in traffic to assess the safety of traffic facilities without waiting for a statistically above-normal number of crashes and injuries to actually occur (www.itssiemens.com/research/ssam/).

The SSAM software application was developed to automate conflict analysis by directly processing vehicle trajectory data. Researchers specified an open-standard, ‘universal’ vehicle trajectory data format designed to provide the location and dimensions of each vehicle approximately every tenth of a second. The trajectory file format is currently supported as an export option by four commercially available traffic micro-simulation models namely: VISSIM, AIMSUN, Paramics, and TEXAS. Output from the software for particular locations provides details of eight potential vehicle-vehicle conflict measures such as: Time-To-Collision, Post-Encroachment Time, Speed differentials etc. (www.itssiemens.com/research/ssam/).

The focus of SSAM is essentially on vehicle-vehicle conflicts. However the potential of microscopic simulation in traffic safety and traffic conflict analysis can be extended further to investigate multi-modal conflicts because of recent developments in pedestrian modelling (human behaviour algorithms) and real-time vehicle data acquisition capabilities. The adaptation for assessing safety of all road users depends on the ability of these models to capture complex behavioural relationships that could lead to crashes and to establish a link between simulated safety measures and crash risk (Cunto, 2008).

Most researchers agree that multi-agent simulations are the appropriate technique for pedestrian modelling (Bierlaire, Antonini, and Weber, 2003; Dijkstra and Timmermans, 2002). Apart from the microscopic and dynamic modelling they offer, the fact that pedestrians (agents), may be given a variety of vision, cognition and learning capabilities renders these systems far more advantageous than ordinary simulation environments. Moreover these systems may accept complex and very detailed rules and their properties are in full accordance with those of discrete choice models (Papadimitriou et al, 2009).

However, researchers also indicate that most proposals for agent-based pedestrian simulations to date have only dealt with collision free, goal-oriented movement (Rindsfüser and Klügl, 2007) and not transport friction caused by multi-modal road use. Examples are crowd dynamics, evacuations, as well as, models related to the resolution of urban transport issues such as: pedestrian levels-of-service, railway station concourse designs, gate designs etc.

Examples of other (more closely related) work in the transport safety field, ranges from area-level models and their implication on transport plans (Wier et al, 2009) to modelling pedestrian crossing behaviour and crosswalks in general (for example: Yang et al, 2007; Isahque et al, 2009; and Zhang et al, 2006). Additionally, the feasibility of the use of agent based simulation for traffic safety assessment was tested by Conradie et al in 2009 and found to be a promising method.

Based on these reviews, it seems as though the use of multi-agent micro-simulation software to assess transport safety risk for all users is rarely undertaken but the indications are that it should provide a good estimate if transport friction can be adequately modelled with respect to local conditions and, if complex road-user behavioural relationships can also be adequately captured.

Given its capability of simulating multi-agent and vehicle-pedestrian interaction on the road network (including collisions) and the ability to vary behavioural parameters to suit local conditions within the modelling suite, the micro-simulation software package, Paramics, was selected to investigate its capability in assessing safety for all road users.

SIMULATION STUDIES

To enable the assessment of the capability of micro-simulation software as a tool to enable the prediction of safety risk for all road-users, this study was initially restricted to the analysis of safety via the investigation of two scenarios: broad safety surrogates for infrastructure- speed and volume - and vehicle/pedestrian conflicts via simulations of a busy intersection in Cape Town.

Furthermore it is suggested that validation of the simulation process would be reflected if the results: i) discriminated between different infrastructure measures in terms of surrogate safety (in this case speed and volume and not conflicts) and; ii) correlated high frequencies of vehicle-pedestrian conflicts with real-world scenarios.

Data Requirements/Modelling Parameters and Calibration

The major steps in reliable simulation modelling are to ensure that important model inputs have been accurately determined based on observational data and that simulation models produce estimates of performance that can be verified from real-world observations (in this case verification is tested by correlation as per item ii) above).

Default values are usually provided in transportation modelling programs for vehicular parameters such as: desired speed, acceleration/deceleration rates, driver reaction time, desired headway, gap acceptance, lane changing rules, driver aggressiveness and awareness and levels of compliance. In addition, agent-based models provide default pedestrian behavioural values, for instance for: blocking compliance, average walking speeds and speed fluxing etc. (Quadstone, 2011).

However, to achieve accurate results, normal modelling datasets and default values need to be supplemented with, or modified by, measurements or assessments of local road user behavioural parameters, as well as, information on vehicle kinematics, because all of these characteristics have an impact on the model's accuracy and safety.

Of the vehicular parameters listed, desired speeds and acceleration/deceleration related to maximum vehicle speeds and age are easily modified to suit local fleets. The remainder are strongly influenced by, or dealt with the use of suitable values for mean target headway (MTH) and mean driver reaction time (MDR) (Gardes et al, 2002). Default values of 1 second are provided for both parameters (Quadstone, 2011).

Studies by Innovative Traffic Solutions (in South Africa, unpublished), Vreeswijk (2004) and Vanderschuren (2006) concluded that driver behaviour in South Africa is more aggressive and possibly less 'aware' than behaviour commonly encountered in developed nations.

Based on trial and error evaluation by varying MTH and MDR values, the authors found that MTH and MDR values of 0.55 and 0.35 seconds provided modelling results which were similar to actual measured vehicular flows. A similar study in the US found these values needed to be adjusted to 0.625 and 0.45 respectively (Chu et al, 2004). Validation of the headway value was obtained by a visual survey of vehicles using a highway in Cape Town over a period of 1 hour in the morning peak. This confirms the more aggressive driving style reported in South Africa.

Local pedestrian walking speeds, composition and compliance levels were gathered from surveys in three suburbs of Cape Town – Rondebosch, Nyanga and Kenilworth. These areas were selected to ensure that a broad cross-section of pedestrian characteristics was obtained so that values appropriate to the investigation location were obtained.

The surveys consisted of visual origin/destination counts and average walking speeds details and a questionnaire designed specifically to ascertain behavioural characteristics such as compliance levels and whether this attitude was informed by race, education levels, job function, familiarity or time pressures, so that any future estimates of modelling parameters could be related to this work. In addition, video surveys were undertaken in the City centre to supplement data on walking speeds and observe crossing behaviour.

The analysis of the random respondents and observations showed that the gender balance (n=297) was almost equal, their ages were as anticipated-the majority in Rondebosch and Kenilworth were below 30, whereas ages of respondents in Nyanga were fairly evenly spread. These results correspond well with the national census data and given the random nature of the sampling undertaken, the responses were deemed to be statistically representative of these areas.

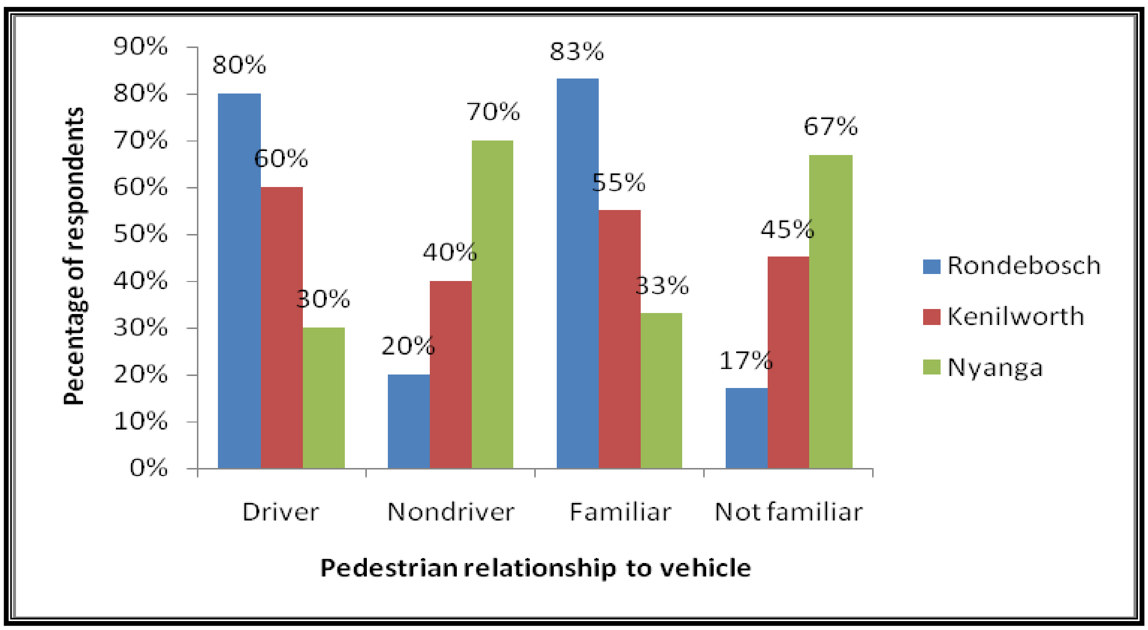

Figure 1: Proxy for driving familiarity levels

The results shown in Figure 1 indicate that the majority of respondents in 2 of the 3 areas were either regular drivers or had vehicles in their family. As the road network in Cape Town is not overly extensive and normal peak hour driving follows regular routes, this result can be taken as a value the driver familiarity level setting in Paramics for peak hour simulations (between 60 and 80% depending on location). The levels of both non-drivers and not-familiar with vehicles (i.e. no vehicles in the family) also provide an insight into some behavioural issues as these pedestrians can be deemed to be less aware of the capabilities of vehicles in terms of speed and potential impact.

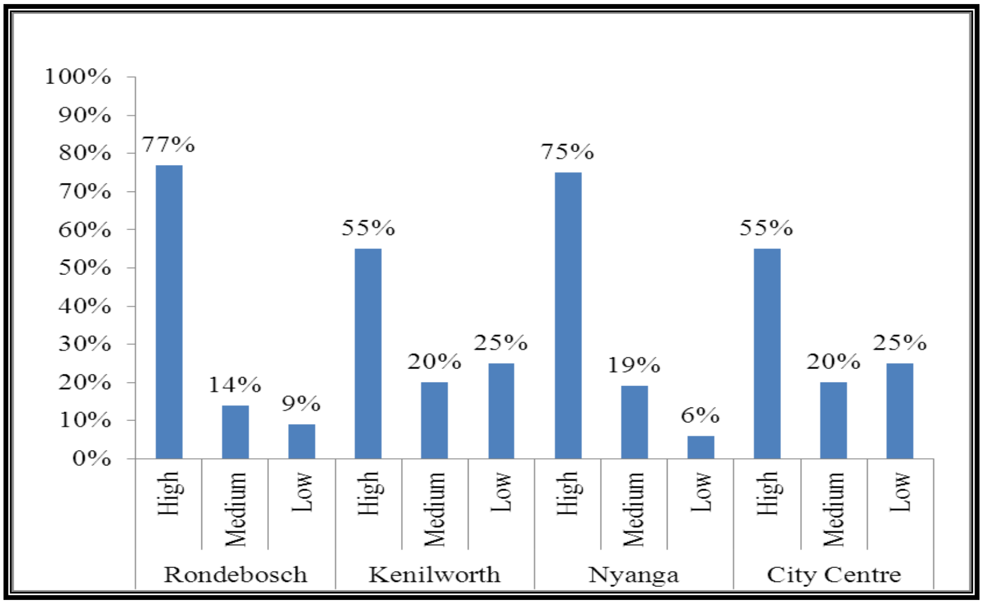

Figure 2: Assessed pedestrian attitude to risk

Assessed pedestrian attitude to risk from questionnaires and observations is fairly high as shown in Figure 2. Mid-block crossings, crossing during a green signal phase and low gap acceptance crossings were fairly common observations at all sites. Compliance levels for pedestrians can, therefore, be assumed at between 25-50% for most locations in Cape Town.

Average walking speeds were fairly similar at: 1.3m/s in Rondebosch, 1.4m/s in Kenilworth, 1.1m/s in Nyanga and 1.4m/s in Cape Town City centre. Large variations of up to +1.5m/s were observed at crossings and intersections at all locations reflecting risky crossing behaviour. A video based study at railway station concourses in Durban and Cape Town found similar pedestrian speeds (0.97 to 1.61m/s for males and 0.72 to 1.19m/s for females) although these differences were mostly gender based and not related to road traffic (Hermant et al, 2010).

The walking speed and compliance level results therefore show a need to investigate and calibrate the model appropriately. In addition, default pedestrian related parameters for search angles (maximum angle related to obstacles), obstacle angle step value (sweep in front of agent in angular increments in order to find a way around the obstacle) as well as the scan area factor (a unitless way of specifying how large the scan area is for vehicles when they are looking for agents) also require analysis to ensure proper calibration.

Further Model Calibration and Sensitivity Analysis

An extensive investigation of the remaining parameters as detailed in Table 1 was undertaken by modelling a typical 4-way signalised intersection with the following characteristics:

- Approach and exit lanes 7.3m wide 2 lane;
- Signals, 5-phase 113s cycle;

- ‘Agent-only’ footpaths around the intersection; 1 exit leg modelled as ‘shared aggressive’, the others with blocking regions;
- ‘Vehicle-aware’ space set to typical stopping sight distance values, i.e. 30m in this case (Quadstone, 2011);
- Four zones with a total of 3600 vehicles in the peak hour distributed 60/40 north to south;
- A total of 1600 pedestrians randomly distributed during the peak with four origin/destinations.

Multiple simulation runs were carried out for all the parameters indicated in Table 1 and were compared to a base case consisting of default values.

Table 1: Sensitivity checks for calibration values

Parameter	Default Value	Modified Value	Effect	
			Vehicles	Agents
Obstacle Angle Step	15°	30°	Negligible	Mean delay increases by 3%.
Search Area Angle	110°	180°	Mean speed increases by up to 25%. Total travel time decreases by 12%.	Maximum speed increases by 7%. Mean delay reduces by 30%.
Scan Area Factor	0.35	0.5	Total travel time decreases by 28%. No. of vehicles in network reduces by 6%.	Maximum speed increases by 4%. No. of agents in network increases by 6%.
Blocking Compliance	100%	50%	Mean speed increases by up to 30%. Total travel time decreases by 13%.	Maximum speed increases by 5%. Mean delay reduces by 6%. No. of agents in network decreases by 9%.
		25%	As above	As above
Base Speed Deviation	0.25m/s	0.5m/s	Negligible change	Maximum speed increases by 6%. Mean delay reduces by 4%. No. of agents in network increases by 8%.
		1.5m/s	Mean speed decreases by 5%. Total travel time decreases by 5%.	Maximum speed increases by 36%. Mean delay increases by 100%. No. of agents in network increases by 57%.

Although there is some interdependence between the variables, each parameter was tested individually whilst leaving all others at default values to ascertain its sensitivity. Modified values indicated for Obstacle Angle Step, Search Area Angle and Scan Area Factor were determined by taking an incremental approach to determine an optimum value for the intersection. The values are discussed below.

The obstacle angle step value should be retained as the default as larger values increase the coarseness of evaluation of the agents' path and therefore introduces unnecessary delay into the system. The search area angle seems more appropriate at the higher value to allow for urban contexts where 'jaywalking' is prevalent and larger vehicles are more likely to be encountered at intersections. The scan area factor should be set at the higher value (0.5) in this context, as vehicles would be more aware of agents in urban situations and thus drivers' peripheral focus would be greater. Further increases in the scan area value were not considered as the vehicle visibility trapezium would be too large to be realistic.

Effects for both vehicles and agents of the modified value for Search Angle can be explained by the increased 'awareness' of agents. The modification of the Scan Area angle to a higher value leads to an increase in the number of agents being able to cross and a corresponding reduction in vehicles during the simulation period.

Blocking compliance values set at surveyed values indicates that there would be little difference between the upper and lower values. This is clearly due to the nature of the intersection, signal settings and volumes of both pedestrians and vehicles as lower compliance levels should, in theory, lead to more risk-taking behaviour, fluctuations in flows and possible collisions. Values therefore need to be set at a level appropriate for the area under consideration.

Similarly, Base Speed Deviation values should be set at appropriate values for disaggregated agents based on observational surveys. The results show that a large global deviation for all agent types can result in a disproportionate increase in the number of agents in the network during the analysis period.

Safety Assessments

1. Potential Infrastructure Retro-Fits

Road-based traffic calming measures have been proven to be successful throughout the world in improving crash risks of infrastructure by reducing either vehicle speeds or through-traffic volumes and by allowing enhanced non-motorised facilities. The potential range of measures varies depending on the desired effect and application area (see Table 2). Projects can vary from a few minor changes to local streets to area-wide strategies.

A significant amount of research has been undertaken over the last few decades into reviewing the effectiveness of traffic calming measures or strategies. From this body of research it is clear that the effects of traffic calming vary depending on application type. For example: The TRL (www.trl.co.uk, accessed 1/2010) and Department for Transport, UK (www.dft.gov.uk/pgr/roads, accessed 1/2010), amongst many others, report that reducing traffic speeds and volumes can reduce the severity of vehicle crashes, particularly those involving pedestrians and cyclists. Each 1 mph traffic speed reduction typically reduces vehicle collisions by 5% and fatalities by an even greater amount. Stuster and Coffman (1998) report that fatality risk increases with speed to the fourth power; a 1% reduction in speed provides a 2% reduction in the risk of injuries and a 4% reduction in the risk of fatalities.

Table 2: Traffic Calming Measures – Types & Uses

Speed control measures				Volume measures
Vertical deflection	Horizontal deflection	Horizontal narrowing	Others	Divertive/ restrictive
• Speed hump • Speed table • Raised crosswalk • Raised intersection • Textured pavements • Speed cushion • Rumble strips	• Traffic circle • Roundabout • Chicanes • Realigned intersection • Tight radii	• Neckdowns • Centre island narrowing • Chokers • 'Road diets' • Bike lanes	• Speed Limits • Speed alerts, enforce • Perceptual design • Warning Signs • Landscaping	• Full closure • Half closure • Diagonal diverters • Lateral shift • Median barriers • Neo-traditional design

A study of a range of measures in the US by Ewing (1999) found that traffic speeds were reduced by 23% for humps, 11% for circles, 4% for narrowings etc. Another study by DKS (2002) indicates that for every 1m increase in width the 85^{th} percentile vehicle speed increases by 1.6km/h.

Various studies on volumes indicate an elasticity of vehicle travel with respect to travel time of -0.5 in the short run and -1.0 in the long run, meaning that a 20% reduction in vehicle speeds will reduce total vehicle travel by 10% in the short term and up to 20% in the longer term (www.vtpi.org).

Other studies found that road based traffic calming measures that result in a speed reduction of 14.4 km/h reduce traffic accidents by 60–70%. Furthermore fatal or serious injury accidents are significantly reduced when road based traffic calming measures are implemented (Webster and Mackie, 1996). Garder (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.

In general roundabouts are also reported to have a favourable effect on traffic safety, at least for accidents causing injuries (Daniels at al., 2008). A meta study of 28 projects in eight different countries estimated a reduction of injury accidents by 30-50% (Elvik, 2003). A Dutch road safety study regarding the replacement of controlled intersections with roundabouts, also revealed a decrease in accidents after a six month period amounting to 51% (www.swov.nl).

For the purposes of this study, a modelling exercise of a selection of the above-mentioned measures was undertaken using a small section of Cape Town's road network outside the city centre. This selection was based on the premises that the road(s) could be reasonably traffic calmed and because the network provided opportunities for alternative routes to be used and therefore both volume and speed effects could be measured from the simulations.

Traffic flows obtained from Cape Town Municipality's database for the morning peak were distributed via an O/D matrix linked to various zones around the network. Vehicular traffic included buses and mini-bus taxis (informal/paratransit), typical of South Africa's public transport conditions. Modelled road speeds reflected actual speed limits at 60 km/h and road widths were consistent with existing widths. The road selected to test measures is approximately 1.5km in length, single-lane 7.3m wide and starting and ending with a signalised intersection (see highlighted area in Figure 3).

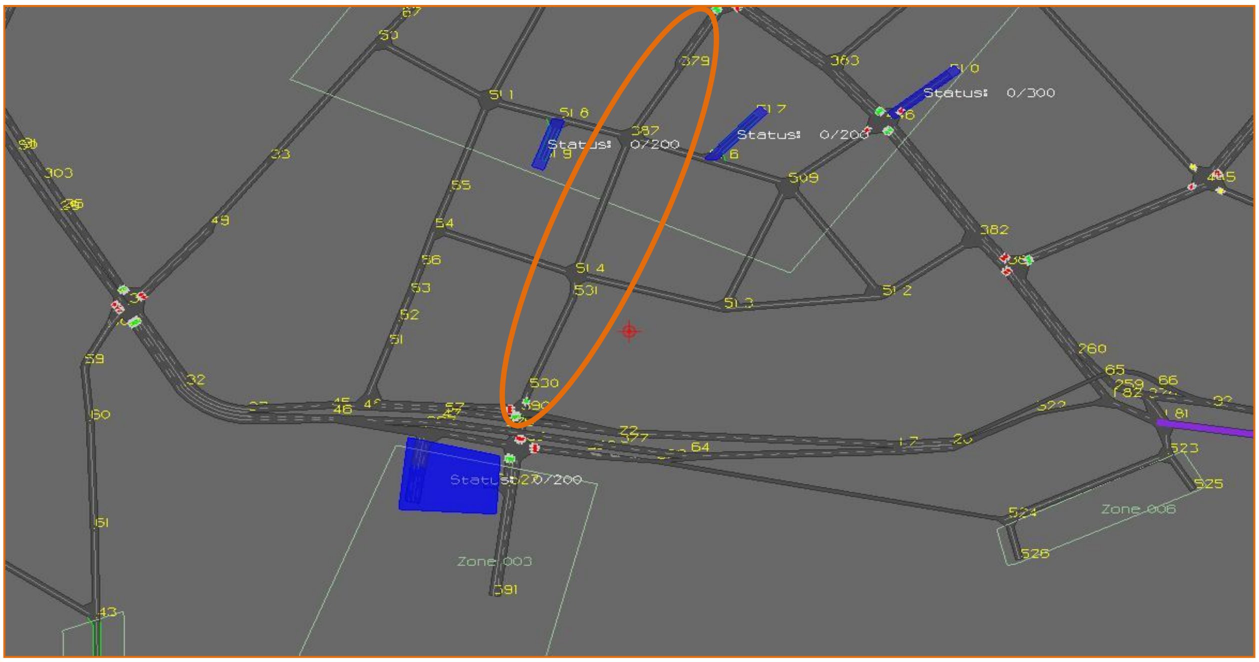

Figure 3: Screen shot of model network

The following measures were modelled: choker – realignment of kerbs at mid-block location to narrow the street; chicane – realignment of kerb to block half lane with suitable entry and exit radii; traffic circle – insertion of a 30m diameter circle at the midpoint; road diet – reduction of the road width to 5m, and; tight radius – realignment of the road to incorporate a 100m radius bend.

Modelling work was calibrated by the collation of field data on speeds for speed humps, a speed table, a raised intersection and a mini-roundabout at various local locations in the City. MTH and MDR values were kept at the values assessed for local conditions. In keeping with normal modelling practices, each simulation was run 10 times to average out any errors associated with the random nature of vehicle generation by the software.

Outputs from the simulations include dynamic vehicle speed profiles as well as volume changes, both of which are assessed as being surrogates of safety measures or risk reduction (WHO, 2004). (Volume reductions in this instance are viewed as providing the ability for pedestrians to cross or cyclists to move in greater safety).

Resulting simulation speed and volume reductions (in terms of percentage change) of devices by category are illustrated in Figures 4 and 5 and, are compared to a summary of the findings of the literature review. Changes reflect the average change over the morning peak period.

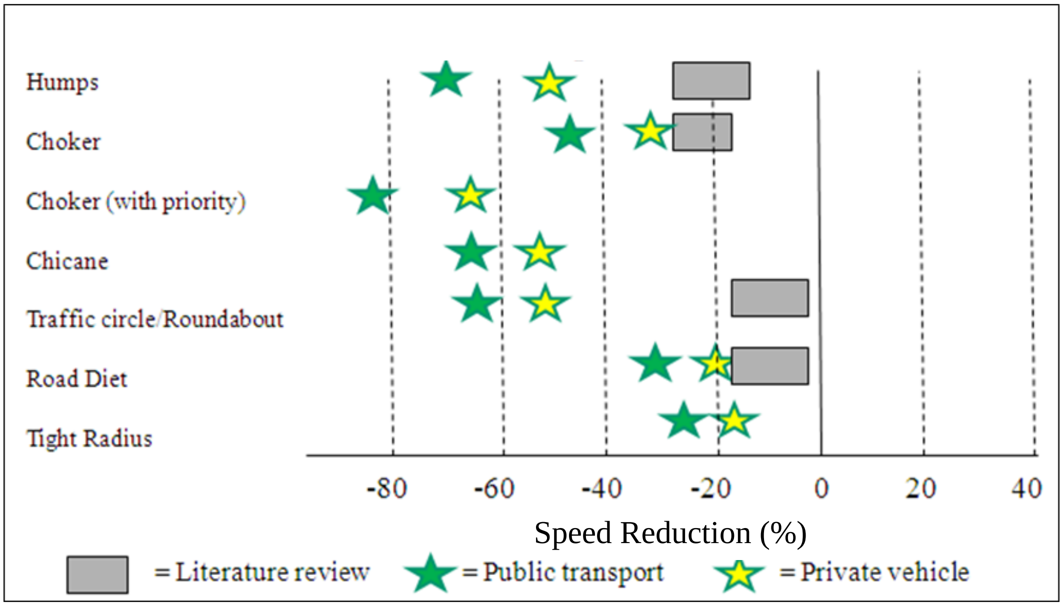

Figure 4: Traffic calming retro-fit speed comparison

As can be seen, in comparison to published results, the simulations indicated speed reductions would be significantly lower for almost all measures (Figure 4). Some reasons for these differences are immediately apparent: boundary conditions, differences in the before and after speed limits, the point at which speeds were measured, the time of day, the physical design of the measure, generalised driving behaviour as well as levels of enforcement. Despite the differences and, because the modelling was calibrated using local data, the modelling output is felt to be reliable. In terms of safety, it can be seen that the simulation output for each measure indicates different levels of risk. Therefore the model does discriminate between measures and can be usefully used to predict the anticipated performance of measures before installation by the use of micro-simulation software.

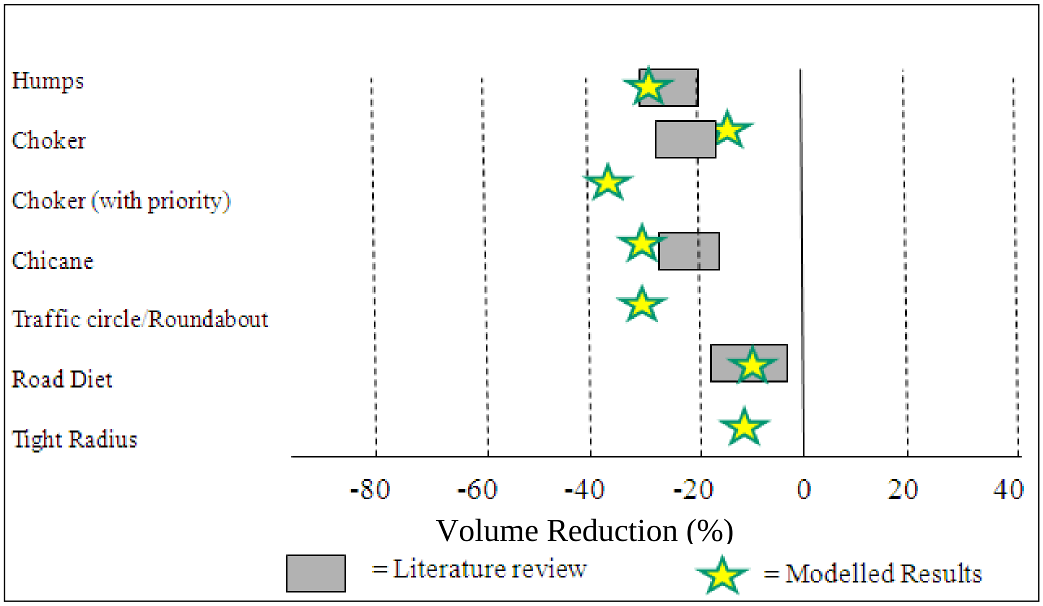

Figure 5: Traffic calming retro-fit volume comparison

Computed volume reductions were found to be much more in line with those obtained from literature (Figure 5). These results also show that the software does discriminate between different infrastructure measures and can be equally used to predict performance. Additionally, it was apparent during the simulation that the diversionary impact of traffic calming on other routes was not that significant as vehicles sought the most cost-effective routes throughout the network, mimicking real life scenarios.

2. Vehicle-Pedestrian Interaction

Using vehicle and pedestrian behaviour values from measurements and the calibration exercises described above, the intersection shown in Figure 6 was modelled to identify potential collision points. The intersection is controlled by a 4-stage signal system and all approach/exit legs are limited to 60km/h speed. Despite the levels of pedestrian and vehicular flows and low compliance levels by both vehicles and pedestrians, resulting in 206 pedestrian crashes and 27 fatalities in the period 2000-2008 (City of Cape Town, unpublished), this intersection existed in Cape Town until mid-2010.

Pedestrian flows are mainly in the direction (to/from) indicated by the lighter shading. Waypoints (used to direct agents) were extended to allow for alternative routes which brought pedestrians to the same crossing area and also to allow for the potential of crossing which often occurs at a distance away from the actual intersection edge. From the range of options available in the software for the shared surfaces related to signalised intersections - vehicle aware, shared courtesy, shared aggressive or blocking modes- the road surface at this crossing point was coded as shared aggressive (between waypoints 3 & 4 in Figure 6). This allows both vehicles and agents to move closer to their destination whilst avoiding each other and closely resembles the existing situation (Quadstone, 2011). Sensitivity testing using the 'blocking' and 'shared courtesy' modes confirmed this to be the best option based on visual observations of the simulations.

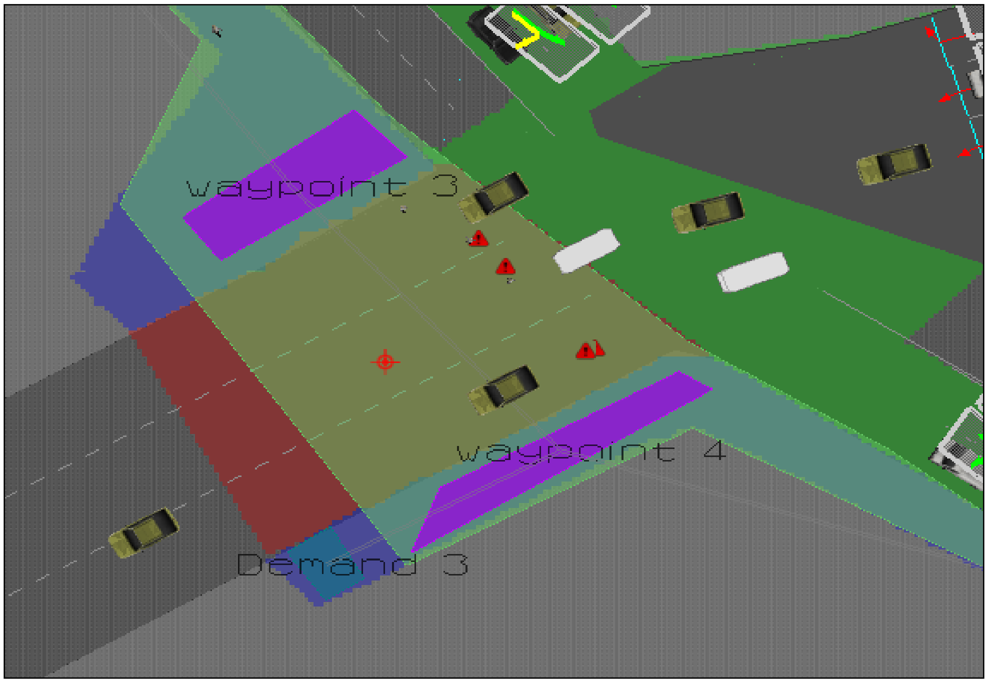

Figure 6: Screenshot of potential vehicle-pedestrian collisions

The simulation runs of this intersection show that collisions are likely to occur (as signified by the triangles with an exclamation mark in Figure 6) indicating a level of safety risk. Although the simulations are not wholly representative of the number of likely real-life incidents, they are felt to be sufficiently indicative as they correlate to existing high frequencies of vehicle-pedestrian collisions. The model therefore fulfils the second criteria of the validation statement above. Hypothetical designs and control options could therefore be tested in a similar manner to further validate parameter settings, to indicate and/or to reduce levels of safety risk without the need to wait for crash statistics.

CONCLUSIONS

South Africa's traffic injury record is amongst the worst in the world, especially for vulnerable road users. The fatality and injury rates have increased over the years and, with increased motorisation, it is likely to get worse and is becoming a major strain on public resources (RTMC, 2010). In contrast, most developed nations have shown sharp reductions in crashes and casualty numbers over the past couple of decades by adopting systematic approaches to road safety that emphasises the investigation of the environment as a whole, from pre-crash to post crash risks (WHO, 2004).

Road Safety investigations in South Africa have continued largely along the lines of aggregating crash attributes, reactive investigation and retro-fitting of known hazardous locations. However as crashes are random events and can occur anywhere given a certain set of antecedent conditions, they are an unreliable method for future incident prediction and could lead to a waste of public resource on modifications. Alternative road safety assessment techniques in use elsewhere could be adopted in South Africa but rely on large amounts of local data or specialist investigative units/professionals which could be a stumbling block. The technique therefore considered in this study is the use of microscopic simulation methods to assess the safety risk of road infrastructure via surrogate measures.

A review of literature on micro-simulation modelling indicates that it has mostly been used to optimise traffic efficiency and that there has been a limited amount of work on its capabilities for assessing safety. One successful adaptation is the development of the SSAM model by FHWA. The approach suggested in SSAM is to investigate and collect detailed data on all conflict events that occur between two vehicles at an intersection. It accepts open standard vehicle trajectory details which are currently supported as an export option by four popular traffic micro-simulation packages. The use of this type of software for particular locations provides outputs of potential conflict measures such as: Time-To-Collision, Post-Encroachment Time, differences in car following speeds etc.

However, because of the high rates of pedestrian incidents in South Africa and the evolution of multi-modal simulation software, modelling that allows the assessment of safety risk for all road user interactions was considered more appropriate for this study.

Most researchers agree that multi-agent simulations are the appropriate technique for modelling pedestrians (Papadimitriou et al, 2009), and, by extension, all road users. To date, most proposals have only dealt with collision free, goal-oriented movement, however, there has been related work demonstrating the use of micro-simulation modelling in road safety.

This study investigates the use of micro-simulation further, to see if it can help with the assessment of safety risk for all road users. It does so by analysing safety of infrastructure via the surrogates of speed and volume and vehicle-pedestrian conflicts via simulations of an existing intersection in Cape Town.

Modelling work requires adequate local calibration and possibly, the coding of plug-ins to ensure accuracy. Surveys carried out in Cape Town illustrate the fact that standard default values incorporate in software packages require modification to ensure local behavioural factors are accurately defined.

Simulation studies of potential infrastructure retro-fits and vehicle-pedestrian interaction at a busy intersection in Cape Town were carried out. Summaries of the results of the work are presented in Figures 4 and 5 for the retro-fits and, the screenshot in Figure 6 indicates the likely scenario from simulation runs of the intersection.

It is suggested that the simulation process is validated by achieving the two criteria: i) the model discriminates between different infrastructure measures in terms of surrogate safety (in this case speed and volume and not conflicts) and; ii) it correlates high frequencies of vehicle-pedestrian conflicts with real-world scenarios. The simulation results show that both of these criteria were met. A further criterion that could be investigated is that surrogate measures produced by the simulation model would predict (be correlated with) the difference in traffic conflicts, as experienced in the real world, between a 'before' condition of a section of infrastructure and its 'after' condition following changes made to improve the safety of the facility.

Overall the study indicates that, notwithstanding the fact that actual behavioural microscopic algorithms have not strictly been developed to model crashes, they are able to replicate several factors directly related to risky situations that could lead to crashes with reasonable accuracy (Cunto, 2008). With the existing upward trend in computing power, modelling techniques and increasing availability of detailed data such as: behavioural criteria through vehicle tracking and video surveillance, it is likely that safety studies will be carried out using a more inclusive approach based on simulation and capture of road user behaviour rather than on the unpredictable and restrictive crash events. This approach also circumvents the need to wait for crash statistics or investigate known hazardous locations, allows assessments of hypothetical designs and control alternatives, and is applicable to facilities where other traditional, volume-based crash-prediction models or safety audits have not been undertaken.

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