THE SUITABILITY OF MICRO-SIMULATION MODELS TO ASSESS THE RELATIVE SAFETY OF ROAD INFRASTRUCTURE FOR VEHICLES AND PEDESTRIANS

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ABSTRACT

South Africa's road crash record for fatalities is one of the worst in the world according to various sources and statistics. Of additional concern is that a significant proportion of these fatalities (35% or more) are pedestrians and that they have suffered disproportionately in comparison to vehicle drivers.

The results of safety investigations – the causes of crashes – are traditionally aggregated under human, vehicular and environmental factors, but their interaction is seldom investigated as safety programmes, safety initiatives and infrastructure retro-fits continue to be derived mostly from the focus on historic crash statistics and on 'black-spot'/cluster analysis of incidents. However, issues related to data availability and reliability, methodological challenges posed by the random nature of crashes and the fact that the number of crashes, per location is low, have fostered many complementary approaches to improve road safety assessments. The simulation of traffic conflicts and the use of computer based collision predictors or infrastructure safety indicators are examples of such approaches.

With recent increases in computing power and programming skills, a variety of simulation software is now available to the transport profession. To date, the majority of micro-simulation models have been used mainly to improve vehicular transport efficiency, but there is a recognition that they can be used to help assess safety risks. Some applications have been developed and used to successfully assess vehicle-vehicle safety. Recent developments in simulation models are now allowing more accurate modelling of pedestrians and, by extension, their interaction with vehicles and the road infrastructure. However, their use in the field of safety analysis is still very limited and depends on their ability to capture complex behavioural relationships that could lead to conflicts and to establish a link between simulated measures and crash risk.

Studies of various infrastructure scenarios in Cape Town were undertaken using a suitable simulation model to assess the possibility of its use in the safety field. The results show that the model is able to simulate the difference between different infrastructure measures but that it is unable to accurately capture vehicle-pedestrian interaction for shared surfaces where pedestrians jaywalk.

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1 INTRODUCTION/ BACKGROUND TO STUDY

At around 29 fatalities per 100 000 population (derived from RTMC, 2010), per year, South Africa's road crash fatality record is one of the worst in the world (see Figure 1). More than 90% of crashes are reported as being as a result of lawlessness - pedestrian and driver negligence and ignorance being key components of this statistic by Arrive Alive in 2011. A review of these fatalities reveals that pedestrians have suffered disproportionately in comparison to vehicle drivers (see Figure 2); the majority being young and often the breadwinners for their families. Since the risk of injury as a pedestrian is about four times more than that for a car driver (Elvik, 2009), the number of pedestrian fatalities underscores the seriousness of the pedestrian traffic safety problem.

Police records of crashes, used for investigation and prevention purposes, give general locational details of the majority of crashes related to the nearest intersection, not the actual location. From these, it can be relatively easily deduced that the majority of fatal crashes occur on high speed arterials at the periphery of cities. However, observations relating to the pedestrian and nature of crashes are either sparse or unreliable, making a more detailed safety evaluation difficult.

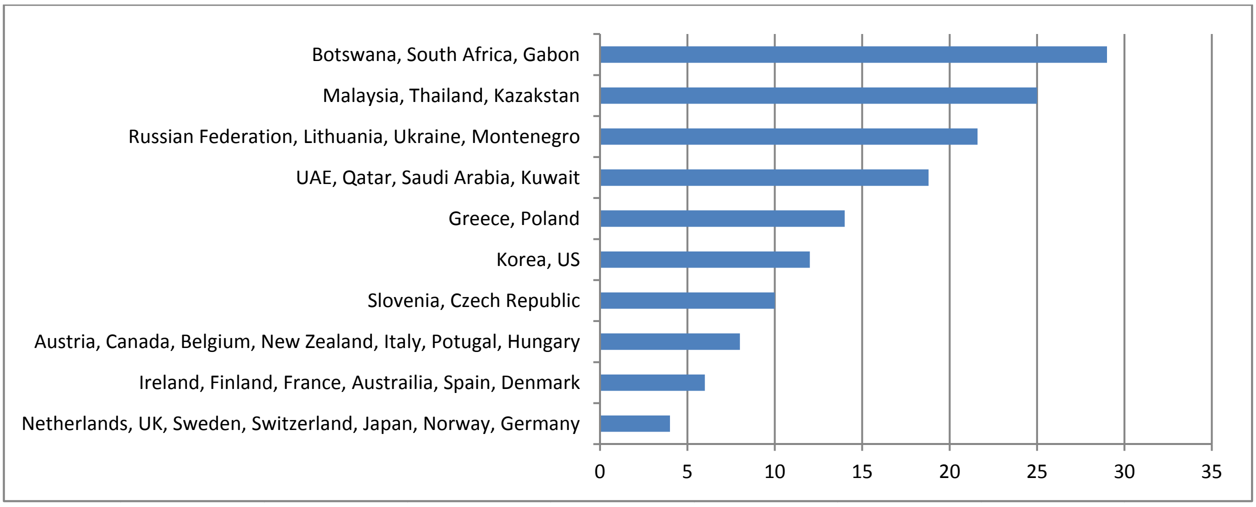

Figure 1: Fatality Rates per 100 000 population
Source: IRF, World Bank, Various.

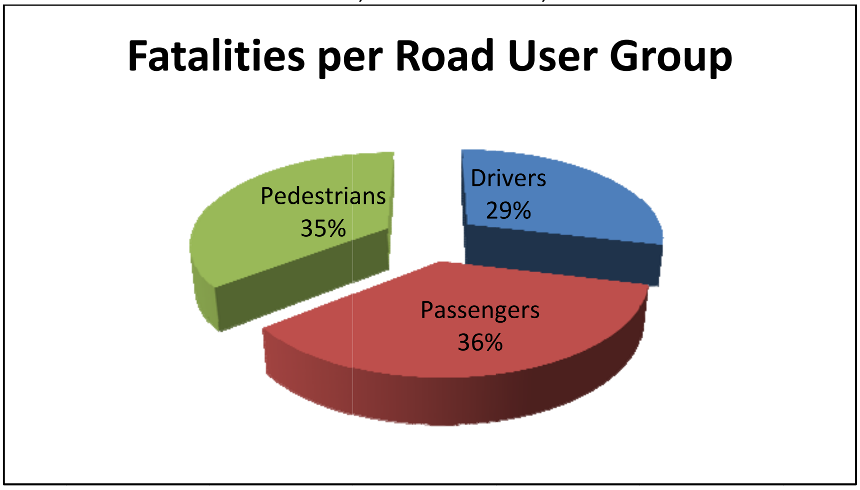

Figure 2: Fatalities per Road User Group
Source: RTMC, 2010

Despite this annual safety investigations are conducted, the results of which – the causes of crashes – are traditionally (RTMC, 2010), aggregated under human, vehicular and environmental factors by Road Safety Authorities (see Figure 3) but, their interaction is seldom investigated despite the fact that the road, the environment and vehicle condition all have a role to play in human perception which has led to the large proportion of crashes being aggregated under the 'human' factor.

Additionally, safety investigations and potential changes to infrastructure focus on the retrospective assessment and analysis of locations with a high density of incidents. Although there is an intuitive link between road safety and recorded crashes, 'black-spot' analyses are known to have the disadvantage that, 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 and, the number of crashes at each site may be quite low in comparison to the overall figure (Peltola, 2009). They may, therefore, be an unreliable method for future incident prediction. A good understanding of the sequence of events prior to the crash along with detailed crash investigation and analyses seems a more rational basis for the development of engineering countermeasures. Evidence from some highly-motorised countries shows this integrated approach to road safety has produced a decline in fatalities and serious injuries (Trinca et al, 1988; Lonero et al, 2002).

Issues related to data availability and reliability, as well as the methodological challenges posed by the random nature of crashes, have fostered many complementary approaches to the problem elsewhere. The simulation of traffic conflicts and the use of computer based collision predictors or infrastructure safety indicators are some examples of these approaches.

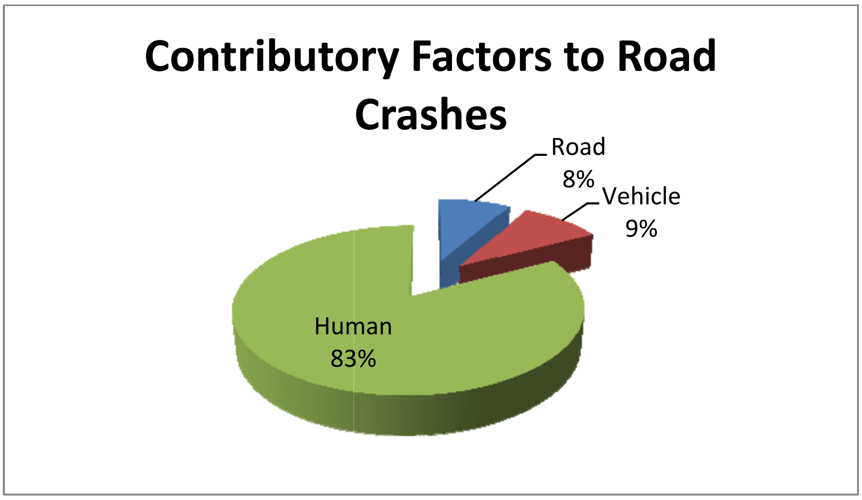

Figure 3: Contributory Factors to Road Crashes
Source: RTMC, 2010

Given South Africa's poor road safety record, the possibility that countermeasures can be developed and investigated without requiring accurate crash statistics or implementation, the disproportionate pedestrian fatality rate and the successes of alternative approaches elsewhere, it would surely be beneficial to look at some additional/complementary methods of assessing road safety.

This paper presents a brief review of some of these approaches and, analyses the use of micro-simulation software as a potential tool to assess road user safety.

2 SAFETY EVALUATION TECHNIQUES

In general terms, the FHWA (2003) states that, for 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 and average speed) and 'non-operational' independent variables (for example: blood alcohol) via a regression equation(s).

Research has also been undertaken on statistical techniques for predicting 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 (road geometry etc.), 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 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 along similar lines. 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 above, and 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, therefore, moving towards and encompassing the application of video data collection and analysis into, inter alia, microscopic simulation of traffic conflicts.

3 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, their behaviour and interaction to obtain more realistic representations at a local level. and can thus be used for safety assessments.

Despite this abundance and the flexibility of modern simulation software, to date, the majority of microscopic traffic model development and simulation work has essentially focused on the analysis of transportation efficiency, such as signalised intersections, arterial networks, freeway corridors or crowd evacuation or dynamics (Cunto, 2008). 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. This adaptation depends on the ability of 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).

The development, by the US Federal Highway Administration and Siemens of the Surrogate Safety Assessment Model (SSAM), demonstrates a successful adaptation whereby trajectory output from simulation software can be post-processed to analyse 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. Eight potential vehicle-vehicle conflict measures, such as: Time-To-Collision, Post-Encroachment Time, Speed differentials, are supported (FHWA, 2008).

Other studies into modelling pedestrian crossing behaviour and crosswalks in general (see for example: Yang et al, 2007; Isahque et al, 2009; and Zhang et al, 2006) confirms microsimulation's potential in more multi-modal safety applications. Additionally, the feasibility of the use of agent based simulation for traffic safety assessment was tested by Conradie et al, (2009) and found to be a promising method.

A similar study to this, measured potential vehicle-pedestrian conflicts, for various intersections in the US, using a micro-simulation model and a surrogate for safety, time-to-collision (TTC). It reported on the potential number of conflicts for various forms of intersections in relative terms (Agarwal, 2011). The study used default model values for all vehicles, pedestrian and geometry characteristics in an attempt to create a 'standard' conflict model for each type of intersection. (This may be a shortcoming of the work as the conditions for all input parameters will vary according to location, as suggested by this study).

In summary, it is clear from published work that the use of micro-simulation models to assess transport safety for all users, has rarely been undertaken but, the indications are that it should prove to be a useful tool, if transport friction can be adequately modelled with respect to local conditions and, if complex road-user (vehicle and pedestrian) behavioural relationships can be adequately captured.

4 SIMULATION STUDIES

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 SMARTEST project commissioned by the European Commission in 1997 (SMARTEST, 1997). This report compared over 30 different software tools using various tests to examine capabilities only. More recent but limited studies focus upon particular aspects that are 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. These studies show that there are no definitive conclusions as to which package is best. Yang and Ozbay selected Paramics for their safety analysis because of the ability to customise it. Similarly, because of this aspect, its agent-based ability to model pedestrians, to vary behavioural parameters to suit real-life local conditions for all road users and visualisation of vehicle-pedestrian interaction on the road network (including collisions), the use of Paramics was a good proposition for this investigation.

4.1 Data Requirements, Modelling Parameters and Calibration

The major steps in reliable simulation modelling are to ensure that important model inputs have been accurately determined either using observed data or by assessment, and that simulation models produce estimates of performance that represent real-world observations.

Default values are usually provided in all transportation modelling programs for ‘adjustable’ 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, Paramics provides default pedestrian behavioural values, for instance for: blocking compliance, average walking speeds and speed fluxing (Quadstone, 2011).

To ensure that simulations reasonably represent real-life situations, normal model datasets and the ‘adjustable’ parameters need to be specified because all of these values have an impact on the model’s accuracy, which will have a corresponding impact on the model’s ability to adequately simulate potential conflicts or to evaluate risk.

4.2 Safety Assessment Limitations

As with almost all studies of this nature, it is clearly not possible to model actual crashes as they are random and unpredictable events. Therefore, micro-simulation models can only be used to assess the risk of crash occurrences via surrogate measures of safety.

The use of vehicle trajectory data from simulation models into FHWA’s SSAM software to investigate surrogates for safety, such as TTC and PET, has already been established and is accepted as a complimentary approach to safety analysis. However, as already stated, their focus is on vehicle-vehicle crash risk only and mainly for crossing/turning conflicts. The literature shows that this development has, clearly, gone some way to proving that micro-simulation models can be used to simulate safety risk for vehicular interaction. However, it does not address other possible crash risk reduction, which can be assessed by two other surrogate measures: speed and volume (detailed below), nor does it address the capabilities of newer simulation models to simulate and visualise potential vehicle-pedestrian conflicts for various types of infrastructure. The FHWA’s work is outside the scope of this study but the latter two aspects are addressed below.

The working criteria used for this study are that, it is acceptable to use micro-simulation models for safety analysis if the results: i) discriminate between different infrastructure measures in terms of surrogate safety (in this case speed and volume and not conflicts) and; ii) correlate with high frequencies of vehicle-pedestrian conflicts from real-world scenarios.

4.3 Surrogate Safety Measures

To be useful for transportation safety applications, a surrogate measure should satisfy two conditions: it should be based on an observable non-crash event that is physically related in a predictable and reliable way to crashes, and, there exists a practical method for converting the non-crash events into a corresponding crash frequency and/or severity. The first condition emphasises the crucial aspects of crash surrogacy that enable meeting the second condition: development of a method of converting the surrogate outcomes into the meaningful outcome – frequency and severity of crashes (Tarko et al, 2009).

A significant amount of research has been undertaken over the last few decades into highway safety and its relationship to infrastructure provision. 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. Similarly, in a meta-analysis, Elvik et al (2004) reported that risk increases with speed to an exponential power - a 10% reduction in mean traffic speed should result in a 37.8% reduction in the risk of fatalities and a 24% reduction in the risk of injuries. In other studies, Milton and Mannering (1998) found that network extensions and increased number of lanes increase crashes and fatalities and that narrower lane widths reduce accident frequency. The WHO (Peden et al, 2004) has also widely reported on the relationship between speed and fatality risk. The relationship between traffic volume (i.e. exposure) and speed with crash risk is quite clear from these studies and, therefore, it is reasonable to consider these factors as surrogates for safety.

4.4 Infrastructure Studies

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. Projects can vary from a few minor changes to local streets to area-wide strategies.
Given these successes, traffic calming measures were the obvious choice to study whether micro-simulation models could their mirror the impact of different measures on the safety surrogates of speed and volume. For the purposes of this study, a modelling exercise of a selection of 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 that the network provides opportunities for alternative routes to be used. Therefore, both volume and speed effects could be measured from the simulation outputs.

The test area (1.5km long, 7.3m wide) forms part of an overall model of the outer part of the city of Cape Town (see highlighted area in Figure 6). Traffic flows along this stretch of road are generated from O/D matrices for various zones around the network. Global and local parameters were set to match known conditions and observations.

The following measures were modelled:

- Speed humps – various sizes to match field measurements;
- 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.

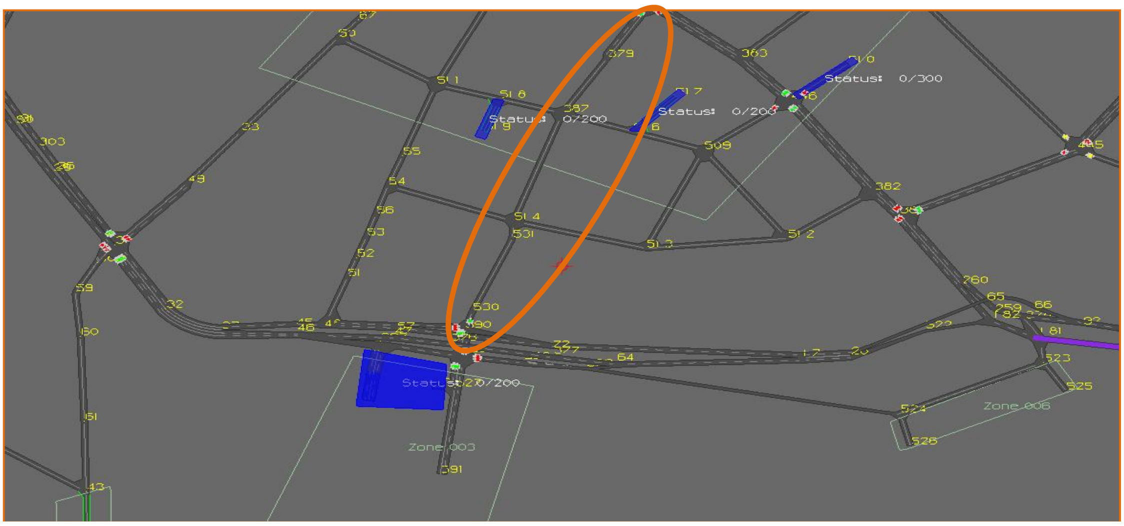

Figure 6: Screen shot of model network

Models for these scenarios were built by assigning new speeds for either the whole link (in the case of road diets and tight radius) or by assigning new speed to links (limited to a minimum of 5m) that contained the measure being modelled. Speeds used were obtained from field measurements at actual locations of various measures in the City. The model was then allowed to run with all input data for each measure and was not re-calibrated to match observed speeds for measures, to check if the simulations discriminated between measures, keeping all inputs constant.

Outputs from multiple[1] simulations include headways (dynamic and static), dynamic vehicle speed profiles (see for example Figure 7 for speed humps), as well as acceleration/deceleration profiles, headways (both static and dynamic) volume changes.

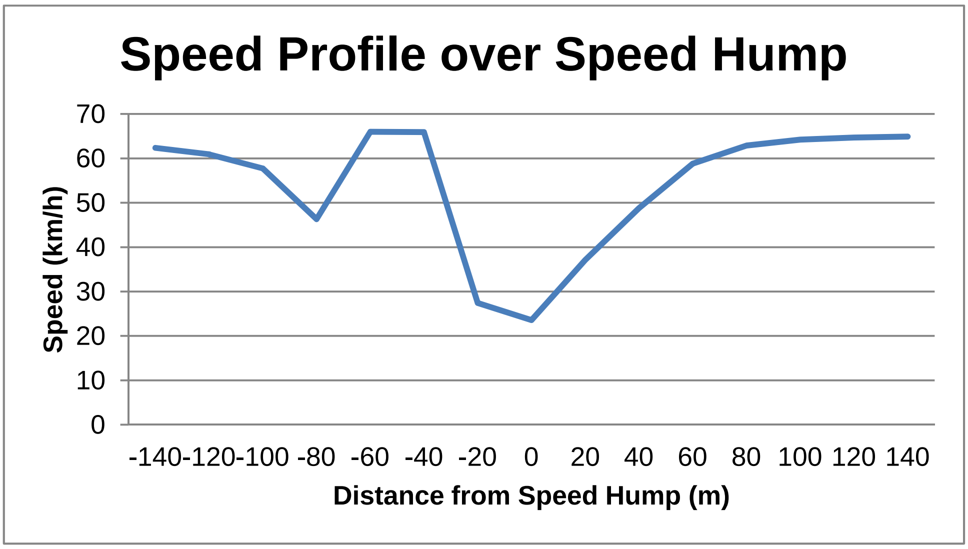

Figure 7: Model Output of Vehicular Speed Profile over Speed Hump

Simulated speed and volume reductions due to the inclusion of particular calming measures are illustrated in Figures 8 and 9 (indicated by the stars) and, are compared to a summary of findings from a literature review. The reductions simulated reflect the average

[1] The number of simulations vary depending on confidence levels set and a statistical process (see FHWA, 2004)

change over the morning peak period, whereas the times of the results from the literature review are not specifically published.

In comparison to published results, simulated speed reductions are significantly higher for almost all measures (Figure 8). 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 that results were obtained, the physical design of the measure, generalised driving behaviour as well as levels of enforcement. Despite these differences and, because the modelling input used local data, the output is felt to be reliable.

In terms of safety assessment, it is clear that the model does distinguish between different measures and that the different levels of speed reduction for each measure can be equated to different levels of risk for each measure. Furthermore, the output of dynamic vehicle speeds both before and after a device can be used to help locate a series of devices to maximise the effect of a calming strategy.

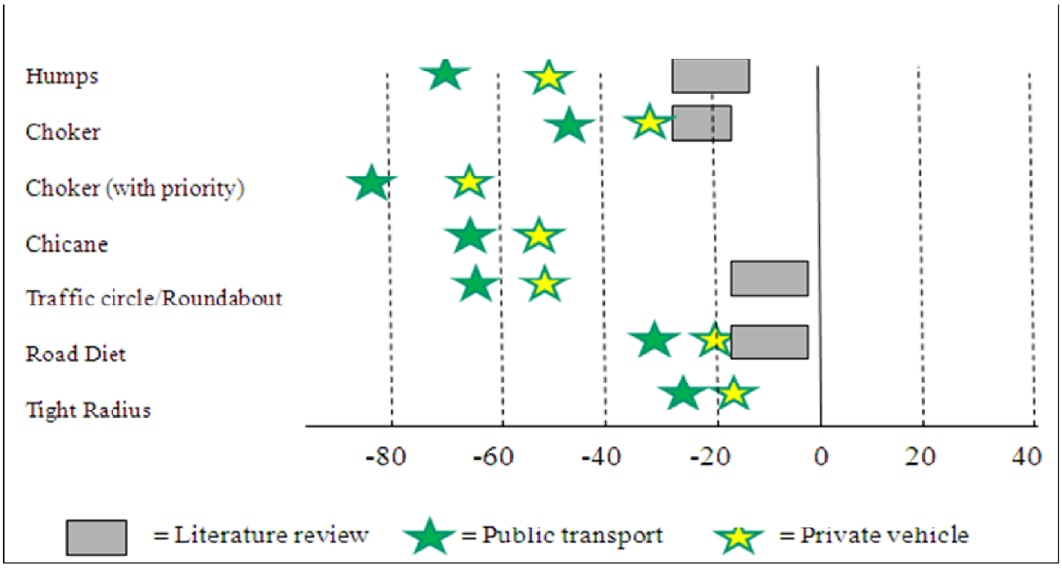

Figure 8: Traffic calming retro-fit speed comparison
Source: Jobanputra, 2010.

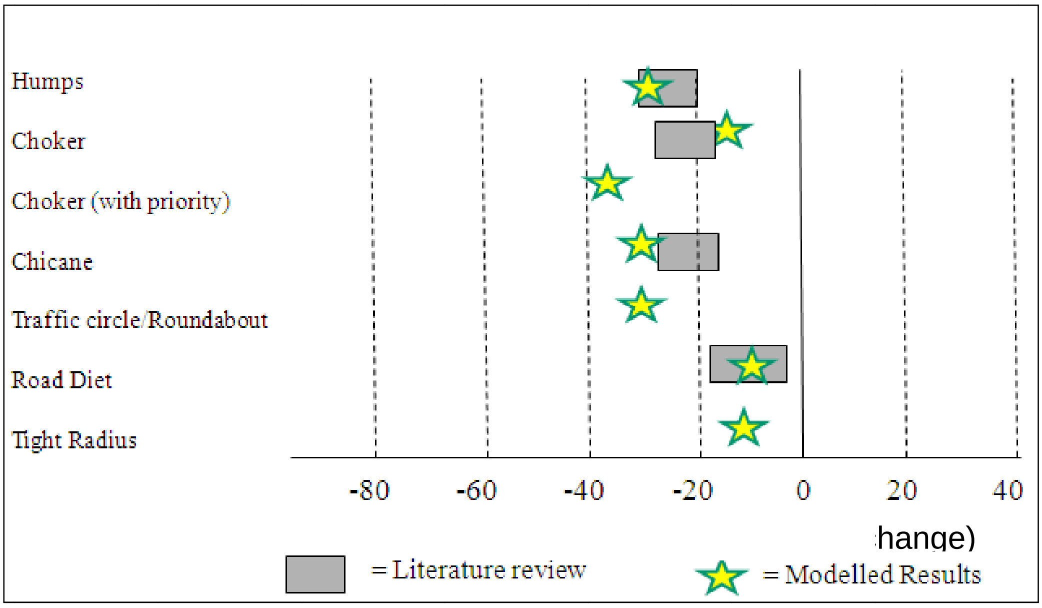

Figure 9: Traffic calming retro-fit volume comparison

Source: Jobanputra, 2010.

Computed volume reductions were found to be much more in line with those obtained from literature (Figure 9). These results also show that the software discriminates between different infrastructure measures for volume and that it can be used to predict performance. Notably, because of the size of the network, the diversionary effect of the calming measures on the immediate nework was insignificant (as it probably would be in real-life) because vehicles are programmed to seek the most cost-effective route(s) from their origin.

To fulfil the second working criterion of the safety assessment, a separate study area - an intersection in Cape Town - was modelled using vehicle and pedestrian behaviour values from field observations and calibrated as described above to identify potential road user conflicts (see Figure 10). 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), the intersection existed in its illustrated form until mid-2010 when a footbridge was added to it.

Pedestrian flows were mainly in the directions (from/to) Demand 3/Waypoint 4 and Waypoint 3. The pedestrian space coding allows for alternative routes to bring pedestrians to the intersection and also to allow for the potential of 'mid-block' crossing. The developers of Paramics have made it possible to specify shared road user space (i.e. where the space is used by both vehicles and pedestrians) – '*shared aggressive'* and '*shared courtesy*'. In aggressive shared space agents and vehicles will try with equal effort to move forward whilst avoiding each other, similar to an opposed right turn with traffic sneaking through crossing pedestrians. In *'courtesy*' shared space vehicles will avoid entering the shared space until all agents are outside their field of view, similar to a mid-block un-signalised pedestrian crossing (Quadstone, 2011). Furthermore, at signalised intersections, modellers can set up a *'blocking region'* which forces compliant pedestrians to cross at the appropriate signal phases. For this study, specifically at the exits to signalised legs of the intersection, a '*shared aggressive'* space was found to be the best approximation of field observation of behaviour (and it is actually how exits are used).

Despite this coding, as stated, pedestrian and vehicle behaviour was not consistent with observed behaviour, especially pedestrian crossing behaviour.

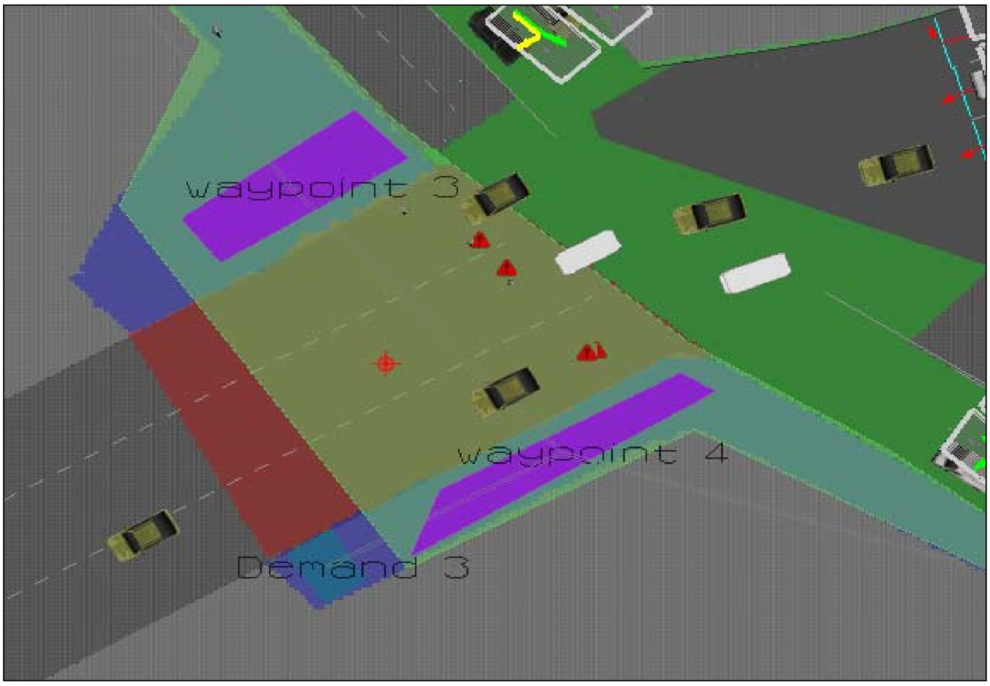

Figure 10: Screenshot of potential vehicle-pedestrian collisions

Paramics' 'Collision Viewer' allows the visualisation of predicted conflict points. Vehicle/pedestrian conflict points shown in the software are based on the time and actual collision point within the model. Both vehicles and pedestrians attempt to avoid each other, but where they are unable to do so a conflict point is shown. The conflict point is where a pedestrian's walking path comes into contact with a vehicle's travelling path and vice versa. Although the software is able to output vehicle trajectories, it is not currently possible to output pedestrian trajectories (despite being able to trace them) without considerable manipulation of the simulation output outside of the this software. It is, therefore, not possible to use trajectories of both vehicles and pedestrains to calculate safety indicators (such as TTC), in a manner similar to the SSAM software, from the output.

The temporal screenshot, Figure 10, indicates that collisions are likely to occur (as signified by the triangles with an exclamation mark) and thus, a level of safety risk. Although these are not representative of real-life incidents, they provide a sufficient indication of the safety risk of the intersection and, because they correlate to the high frequency of vehicle-pedestrian collisions previously experienced show that it is possible to use this type of modelling to assess safety risk. However, in keeping with good calibration practice, reviews of the animations revealed that both vehicle and pedestrian behaviour was not wholly consistent with observed/known road user behaviour – in many instances, vehicles gave way to pedestrians if pedestrians were already in the road rather than the pedestrian assessing a 'crossable' gap and then entering the carriageway which would be the normal course of events. This shortcoming is problematic in areas where 'jaywalking' is prevalent and where this type of surfacing ('*shared aggressive*') needs to be specified. The issue was investigated further by reviewing the possibility of modifying the underlying algorithms (which was one of the reasons for the software selection) with the developers of the softare. However, they confirmed that it was not possible for users to adjust pedestrain programming. Because of this interaction, the developers are in the process of modifying their software to incorporate a gap-acceptance criterion for pedestrians (similar to the vehicular gap-acceptance criteria). This modification has been demonstrated via their on-line webinars, but has yet to be released commercially.

5 CONCLUSIONS

Despite its poor crash record - especially given the numbers of pedestrians involved, the certainty that these numbers will grow with increased motorisation and, evidence from developed nations indicating that more systematic investigations allied with modified techniques have resulted in significant reductions in crash numbers, road safety investigations in South Africa have continued largely along the traditional lines of aggregating crash attributes, reactive investigation and retro-fitting of locations with a greater than average number of incidents.

Some alternative road safety assessment techniques used internationally, could be adopted in South Africa, but they rely on large amounts of local data or specialist investigative units/professionals, which is probably why they have not been widely adopted in South Africa.

The use of microscopic simulation models to assess the safety risk of road infrastructure via surrogate measures of potential road user conflicts on the other hand, can be carried out with limited datasets, or experimental data and by many transportation professionals.

Post-processors of vehicle trajectory outputs from simulations to identify possible risk via surrogates such as: Time-To-Collision, Post-Encroachment Time, differences in car following speeds, have been used for some time now and are quite widely accepted. However, their use is (rightly) focussed on intersections and not really on measures that can reduce speeds or volumes which have a proven record in reducing collisions. Furthermore, they do not consider the safety of pedestrians. This study therefore, undertook to review if micro-simulation models could further address safety risk by using these aspects by looking at infrastructure that helps reduce speed and volume and, through the use of Paramics' collision viewer - the identification of possible vehicle-pedestrian conflicts.

The criteria used to gauge the ability of the model to assist in safety investigations were: whether results from the simulation model can be used to discriminate between different infrastructure measures in terms of surrogate safety (in this case speed and volume) and whether it can simulate vehicle-pedestrian conflicts which correlate with real-world scenarios. The results indicate that the former condition can reasonably be met, but that the second condition cannot be fully met as the pedestrian simulation results were only partially representative of observed behaviour for the shared surface type modelled. This latter critical review is now the subject of further software development by the vendors of the software. A recent (May 2012) update release claims to have a modified pedestrian behaviour sub-routine and this may well address the issues raised herein.

With the continuing upward trend in computing power, modelling techniques and increasing availability of detailed data, such as: behavioural criteria through vehicle tracking and video surveillance, it seems likely that more safety studies will be carried out using a more inclusive approach based on the simulation and capture of road user behaviour rather than on the unpredictable and restrictive crash events. These approaches also circumvent the need to wait for crash statistics to investigate known hazardous locations, allow assessments of hypothetical designs and/or control alternatives and, are applicable to facilities where other traditional, volume-based crash-prediction models or safety audits have not been undertaken.

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