CALIBRATION AND VALIDATION OF A MICRO-SIMULATION MODEL FOR A LOCAL ARTERIAL IN CAPE TOWN

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ABSTRACT

Traffic simulation models have been widely used to study traffic operations and systems impacts because simulation is safer, less expensive and faster than field implementation and testing. Their use has also increased dramatically in recent years due to their flexibility and ability to visualise simulations. Whilst the models are useful to the profession, they must be calibrated and validated before they can be used to provide realistic results. However, the transportation profession has not yet established any formally accepted or consistent guidelines for the calibration of these models. In practice, many model based studies are conducted under default parameter values, limited field observations or best-guessed values. This is mainly due to the difficulties in collecting field data for these variables, the complexity of evaluating key parameters and the ranges of their values due to their interaction and the lack of a readily available procedure for model calibration.

This paper provides a summary of some of the published methods of calibration to provide a contextual background to the identification of the key parameters and the calibration of a microscopic simulation model of a local arterial in Cape Town.

1. INTRODUCTION

The use of traffic simulation models as a method to study traffic operations and traffic system impacts has increased dramatically among traffic engineers and transportation planners during recent years because of the challenges of urban in-migration, city densification and the need to use scarce resources as efficiently as possible. Simulation software is nowadays more detailed and flexible, better-documented and, generally, easier and more intuitive to use. It is suggested that traffic simulation programs provide clear advantages over more traditional traffic analysis tools in that they can provide comprehensive results for an entire study area and on-line visualisation that is often valuable as a preliminary form of face-validation (Milam & Choa, 2000).

The majority of traffic simulation tools have been developed specifically for traffic performance analysis where the primary focus is related to capacity. This is reasonable since capacity is the most common concern of the traffic engineering practice (Akcelik & Besley, 2001). More recently, there has been an interest in obtaining alternative types of traffic system impact, particularly traffic safety and environmental issues as well as, the consideration of multi-modal users of systems.

From a modelling perspective, a significantly higher level of detail is required for accurate forecasting, particularly, in relation to the relatively simple behavioural sub-models that describe car-following, gap acceptance and lane changing. Higher levels of modelling fidelity also require the collection of suitably detailed empirical data and demand greater stringency in the processes of model calibration and validation. Ultimately, this makes simulation modelling aimed at a broader level of assessment far more difficult and resource demanding than that aimed at capacity analysis.

Model calibration and validation refers to the process of assuring that a model reproduces real-world traffic conditions reasonably well. 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.

The following sections present a review of contemporaneous methods of achieving calibration and validation of various models and procedures that can be undertaken to determine best estimates for key model inputs (parameter setting) to replicate field observations (i.e. calibration), as well as. A summary of an exercise into the sensitivity of the parameter set included in a commonly used micro-simulation package and the calibration of a local arterial in Cape Town is also presented.

2. CALIBRATION PROCESS

2.1 Overview

The basic principle of most simulation models is to create a representation of the road network, in which drivers 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 other vehicles in the network. Agent-based pedestrian models extend this principle further by applying similar goals via (different) rules for pedestrians.

Building a model begins with the scope of the study and its area followed by a number of key requirements, such as geometry, volumes etc. In addition, some characteristics which help define the working model prior to calibration need to collected or defined. Parameters related to road user behaviour and vehicle characteristics are difficult to collect from the field; consequently, the user needs to assess these values.

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).

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% (FHWA, 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. Should this be the case, there is no need to continue with the procedure presented in Figure 1. Usually it is not the case and the simplified procedure illustrated in Figure 1 would be followed to ensure an acceptable match between field observations and model output.

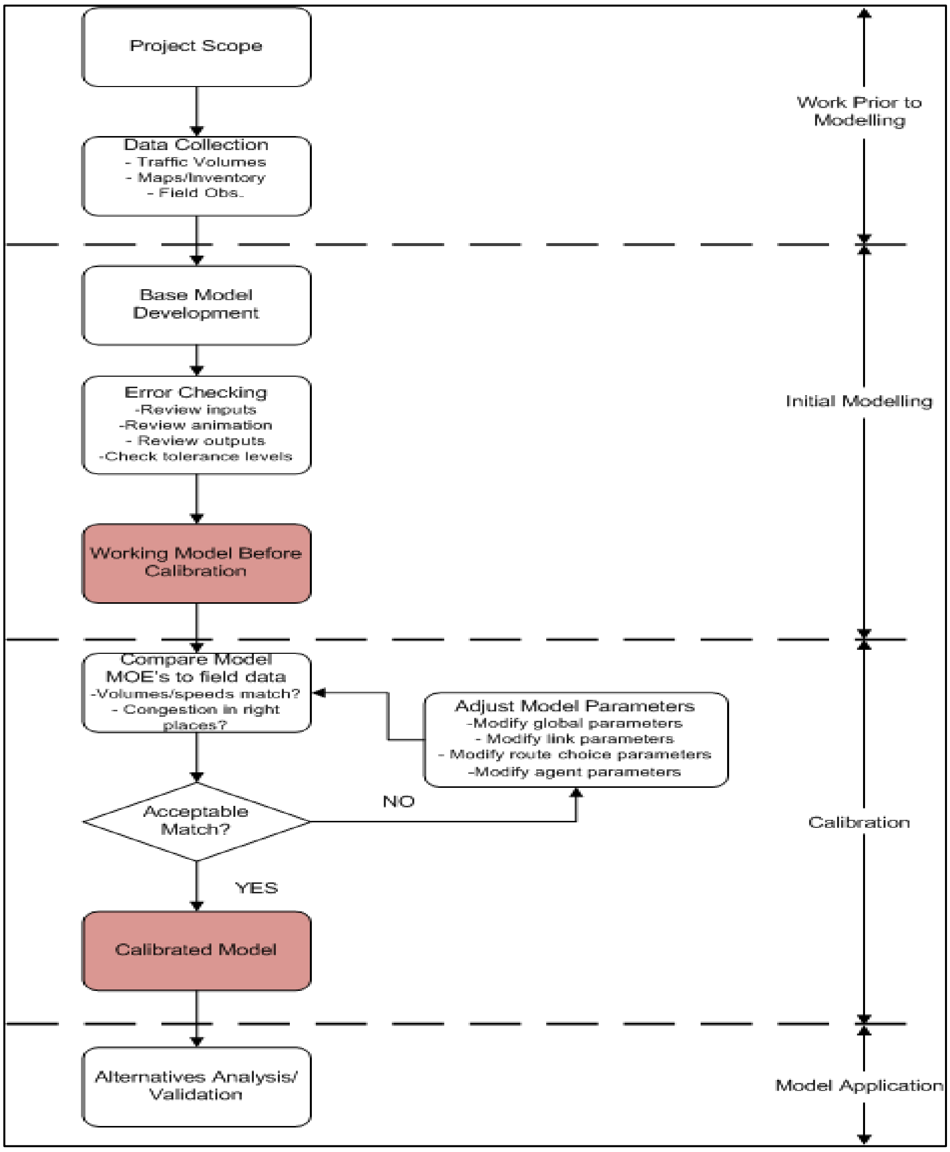

Figure 1: Typical Micro-simulation Task Sequence
Source: Adapted from Minnesota Department of Transport, 2008

2.2 Parameter Setting

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

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) and can be applied to vehicle only and vehicle and pedestrian mixed environments (although some terminology may not be applicable or needs modification):

I. 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.
II. 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.
III. System performance calibration- Finally the overall model estimates of the system performance (travel times and queues) are compared to observed and fine-tuned to match.

Each step is then calibrated using acceptable criteria with a single set of model parameter values and outputs form runs with different random number seeds.

The definition of some parameters incorporated in microscopic models along with their typical range of values, based on multiple studies around the world, is shown in Table 1. These are compared and contrasted to parameter types and values provided/obtained in the section following.

Table 1: Parameters commonly included in microscopic simulation models

Parameter	Type	Notes	Typical value
Desired speed	Behavioural and political	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
Desired headway	Behavioural	May be expressed in units of time or distance	1.5–2.5s; 5.96s for truck; 6.5m
Reaction time (s)	Physiological	May not be explicitly represented (may be inherent in the simulation interval)	0.57-3.0
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)
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)
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
Stimulus required to induce use of the reduced gap	Behavioural	Time spent waiting for acceptable gap or number of rejected gaps	Various
Minimum gap (s)	Behavioural		1.0
Rules for mandatory lane change	Behavioural and political	May simply reflect traffic regulations but may vary depending on enforcement policy	Various
How far ahead the driver anticipates the need to change lanes	Behavioural and political	The behavioural element may be constrained by sight lines, etc.	1 to 2 links or 500m
Minimum acceptable gap when changing lanes	Behavioural	As in gap-acceptance model	As gap acceptance model

Source: based on Bonsall et al, 2005

2.3 Calibration Criteria

Calibration data, as already intimated, can consist of measures of capacity and system performance such as travel time, speed, delays and queues. Given the number of parameters and their interaction, it is clear that the calibration exercise can be a multi-faceted and complex exercise especially if more than one criterion is applied. There are, therefore, several examples in the literature which focus 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 2.

Table 2: Single Criterion parameter calibration studies

Study	Type of Optimization	Model	Network	Measures of Performance	Results	Note
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%(RMSPE)	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: Doung, 2011

Table 3: 'Multi-criteria' parameter calibration

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)	NGSA 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, 2011

The literature also provides several studies, which suggest that the single criteria approach which ensures the accuracy in one attribute (e.g. travel time or speed) does not ensure accuracy in another (e.g. acceleration profile or headway). This has led to the development of several multi-criteria approaches to resolving the calibration issue. 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). 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 3.

2.4 Calibration Targets

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 can be correlated to that of others on a network-wide or corridor-wide basis (depending on which is adjusted). This is the case for almost any size and complexity of network, so the analyst can easily get trapped in an endless process of fixing one problem only to discover a new one pops up elsewhere. Calibration therefore needs to be a multi-faceted and iterative process (Dowling et al, 2004). 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 out 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. 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 is provided in Table 4.

Table 4: 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[1] 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%	
Visual Audits	> 85% of cases
Individual Link speeds	
Acceptable speed-flow relationship	
Bottlenecks	
Acceptable Queuing	To analyst's satisfaction

Source: Wisconsin Department of Transport, 2002

2.5 Visualisation

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.

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[1] 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.

3. CASE STUDY

The case study was conducted using a stretch of local arterial road in Cape Town. It consists of a one kilometre stretch of 2/3 lane main corridor and various side roads, mainly residential, but allowing some alternative routes as well as a mix of pedestrian and vehicular traffic. Morning peak hour vehicular and pedestrian flows were manually obtained for the main corridor as well as intersection signal timings. Travel times and speeds were obtained via GPS enabled devices from multiple trips. Data obtained from the City Council indicate that the road has been the scene of many crashes, with a large proportion of pedestrian involvement. It is therefore the scene of a good deal of transport friction and presents an interesting vehicle and pedestrian interaction calibration exercise that could be carried out using one or some of the methods outlined above.

3.1 Choice of Simulation Software

A review of previous studies indicated that there are relatively few studies which compare all available transport related microsimualtion software. The most comprehensive of these was the SMARTEST project commissioned by the European Commision 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 (Bloomberg et al., 2003) a comparison to the Highway Capacity Manual, Yang and Ozbay (Yang & Ozbay, 2011) on safety analysis and Papdimitriou et al (Papadimitriou 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 and its agent-based ability to model pedestrians Paramics was selected for this study.

3.2 Parameter Evaluation

Paramics contains over 50 adjustable/ user defined parameters. A number of these are switches between one type and another or on/off values such as: a random number generator type, seed number, turning penalty visibility and a number that can be confirmed from field surveys. These variables were set at particular values which corresponded to the project and were left un-amended throughout the calibration exercise as suggested in the base model development procedure above. The remaining parameters were reduced to the key parameters shown in Table 5 by examining their effect on major outputs such as volume and travel time for a range of acceptable values (see Figure 2).

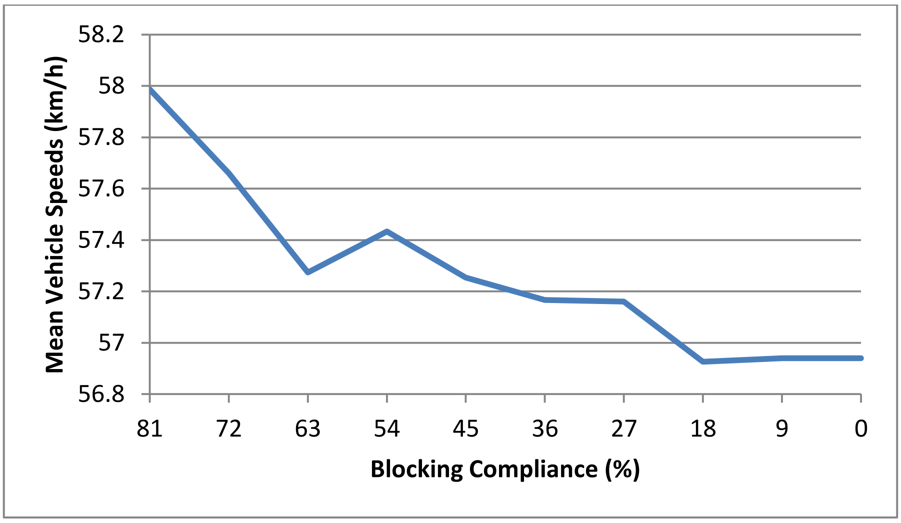

Figure 2: Effect of Pedestrian Blocking Compliance on Mean Vehicle Speed

Despite these reductions, it can be seen (Table 5) that the number of parameters, their respective ranges of values and the combination of parameters that can be used for calibration is still significant. Moreover, some parameters affect the simulation on a ‘global’ basis and some on a ‘local’ link basis and many of the parameters are continuous values rather than discrete (Park and Schneeberger, 2005). For global calibration it was apparent that mean target headway and pedestrian walking speeds directly affected capacity and as this study’s focus is essentially one corridor, these parameters were used as adjustable ones whilst keeping others constant.

Table 5: Major Variable Parameters in Paramics

Parameter	**Default Value**	**Feasible Range**	**Effect**
Mean Target Headway	1s	0.35-5s	Car following distances/ aggression
Mean Driver Reaction Time	1s	0.5-3s	Car following/lane changing/awareness
Minimum Gap	2m	1-3m	Queue Lengths
Feedback Period	5min	1-10min	Assignment
Compliance Levels	100%	0-100%	Pedestrian behaviour and thus vehicles at crossings
Acceleration	2.5m/s^2	1-8m/s^2	Driver reaction time
Deceleration	4.5m/s^2	1-8m/s^2	Driver reaction time
Speed Memory	3	1-75	No. of timesteps/driver reaction time
Signpost Range	250m	1-300m	Driver behaviour
Link Headway factor	1	0.5-2s	Driver behaviour – link specific
Link Reaction Factor	1	0.5-2s	Driver behaviour – link specific
Category Headway Factor	1	0.5-2s	Driver behaviour – link category specific
Agent Speed Fluxing	On/off (1.3m/s± 0.25m/s)	0-4m/s	Agent walking speeds/ vehicle speeds

Source: Quadstone Paramics (Quadstone Paramics, 2011), various.

3.3 Calibration Exercise

As is common in other simulation packages, Paramics uses a random number generator to provide a stochastically generated simulation pattern in terms of vehicle and pedestrian loading and path. Aggregated output from many runs will, therefore, have a certain distribution of minimum and maximum values. Statistically, the number of repetitions required to ensure that all possible cases are simulated can be determined by the following equation:

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

*W*here: *C = 1−Confidence Level (f*or example, for a 90% confidence level, *C* = 0.1); $t_{(1-\propto/2),N-1}$ 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 (FHWA, 2004).

In this study, where travel time or speed is pertinent, a relatively high confidence limit can be used. For a 95% confidence limit and confidence interval of 2, eight repetitions are calculated to be the minimum number required.

Outputs from the software that could be used for comparison with collected field results include: queues, speeds, travel times and volumes.

Acceptability criteria were assessed by using a box plot of outputs for travel time and comparison of link volumes using the GEH statistic. For this calibration exercise, it was found that a small combination of parameters - Mean Target Headway (i.e. the target gap and not the actual gap), Matrix Turning Level and Base Speed Deviation for pedestrians of default ±0.5m/s (due to mid-block and non-compliant intersection crossing)- provided outputs in travel times that were within the band of observed values (See **Error! Reference source not found.**3) and GEH values of less than 5 for link and pedestrian volumes.

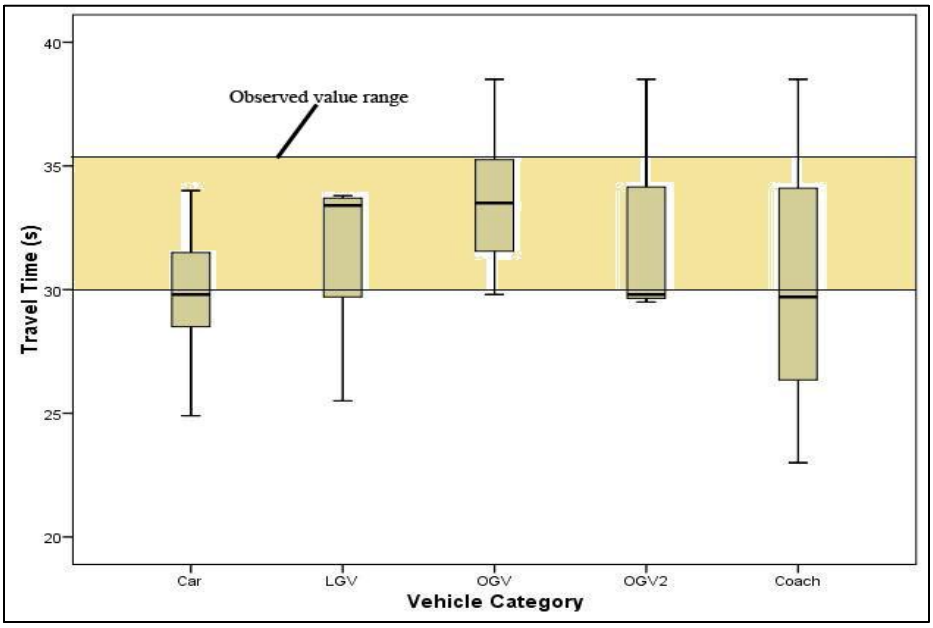

Figure 3: Comparison of Simulated Travel Time to Field Values

In comparison to Table 1, the value of 0.5sec for target headway is low but is thought to reflect the some of the more aggressive driving styles in South Africa. Previous studies for the N2 highway found values of 0.5s and 0.35s for Mean Target Headway (MTH) and Mean Driver Reaction Time (MDRT) respectively to be appropriate for calibration (Vanderschuren, 2006). A similar study in the US found these values needed to be adjusted to 0.625 and 0.45 respectively as shown in Table 5 (Chu, 2004).

Table 5: Comparison of Published and Observed Values for MTH and MDRT

Study	From Table 1	Cape Town Freeway	US Freeway	This Study
Headway (MTH)	1.5-2.5 sec	0.5sec	0.625 sec	0.5 sec
Driver Reaction Time (MDRT)	0.57-3 sec	0.35 sec	0.45 sec	1 sec

For the pedestrians, Base Speed Deviation values were set at default as they were similar to average surveyed values for walking speeds and allowed to vary by 0.5m/s. These values are comparable to a video based study at railway station concourses in Durban and Cape Town which found similar pedestrian speeds - 0.97 to 1.61m/s for males and 0.72 to 1.19m/s for females - although this study was more gender based and not related to road traffic (Hermant, 2010).

3.4 Validation Process

Validation of the calibrated model was carried out with untried data to ensure that the calibrated model works with this set of data and, therefore, it can be used for different cases (not locations). Again, multiple runs were conducted with different random seed numbers and the calibrated parameter set. The simulation outputs corresponded with the performance measure collected from field data within a 90-95% confidence interval.

4. SYNTHESIS

This paper has identified the emerging importance of micro-simulation models in transportation as well as related fields and that calibration and validation of these models is an important process in ensuring that modelled outputs are realistic and meaningful.

Models are generally developed using data from particular (usually developed world) situations and, it is suggested in the literature that they may even contain informed guesswork for some parameter values. Of the current commercially available micro-simulation packages, none have been developed in Southern Africa. Calibration for all local conditions is, therefore, an important step.

Models contain many adjustable parameters; the relevant parameters for each software package vary for different calibration categories. Parameters that define these categories for each package were also found to be considerably different as well as the values applied to them. The Paramics package, for instance, contains around 50 different variables. Given this number of variables, the variety of terms and effects of the variables between packages and the complexity of adjusting parameter sets to match field data, it is not surprising that there is a lack of established or formally accepted guidelines for calibration.

A commonly accepted method whereby model performance is accepted for single criterion is by setting confidence level targets, using x-y plots by or histograms. Usually confidence levels vary between 90-95% as the number of repetitions and complexity of the model would be too great and would not be justifiable for higher values. Other methods call for multiple criteria analysis.

A review of published details on the pros and cons, characteristics and uses of various transport related microsimulation packages showed that there is no one particular package that is the best overall. The choice of package depends on the function required. In this instance, where a mixed traffic environment needed to be modelled, Paramics was selected because of it capabilities in regard to modelling pedestrians as well as its flexibility in providing user programmable units which allow modification of some of its algorithms.

A case study of a local highway in Cape Town helped to establish the key parameters for the Paramics suite by modifying values of each parameter within an acceptable range.

Values of parameters derived from this exercise were used to calibrate the model using travel time and volume as the acceptability criteria. As the case study was essentially a corridor with some minor diversion routes, a global calibration of the main corridor was carried out. This was directly affected by the parameters for target headway and pedestrian walking speeds. The value for target headway (0.5s) which provided acceptable results was found to be quite different to some studies but similar to others. An investigation of output values for loops placed on the corridor showed that despite this setting the average gap simulated was greater than one second for all cases. There is no similar comparison for pedestrian values used in a mixed traffic environment. However, similar ranges of walking speeds were obtained for a local study on station concourses using another microsimulation package.

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References

Akcelik, R. and M. Besley (2001), Micro-simulation and analytical models for modelling urban traffic. In Micro-simulation Conference on advanced Modelling Techniques and Quality of Service in Highway Capacity Analysis. California, USA., 2001.

Bloomberg, L., M. Swenson, and B. Haldors (2003), Comparison of Simulation Models and the Highway Capacity Manual. In 82nd Meeting of the Transportation Research Board. Washington D.C., 2003.

Bonsall, P., R. Lui and W. Young (2005), Modelling safety-related driving behaviour – impact of parameter values, Transportation Research, Part A, Issue 39, Pages 425-444

Chu, L., L. Liy, J. Oh, and W. Recker, (2004), A Calibration Procedure for Microscopic Traffic Simulation. In Transport Research Board Annual Meeing., 2004.

Doung, D., 2011. Calibration and validation of VISSIM microscopic traffic simulation model parameters using Pareto Archived Dynamically Dimensioned Search. Thesis. Waterloo, Ontario.

Dowling, R., A. Skabardonis, J. Halkias and G.A.McHale. (2004), Guidelines for Calibration of Microsimulation Models. Journal of the Transportation Research Board , Pages 1-10.

Federal Highway Administration (FHWA, 2004), Guidelines for Applying Micro-simulation Modeling Software. Federal Highway Administration.

Hermant, L., M. De Gersigny and R. Ahuja, (2010), “Innovative Methods for Assessment of Pedestrian Space Requirements for Railway Stations”. 12th WCTR, July 11-15, 2010 – Lisbon, Portugal.

Milam, R.T. and F. Choa (2000), Recommended Guidelines for the Calibration and Validation of Traffic Simulation Models. Roseville, CA, USA: Fehr and Peers Associates Inc.

Minnesota Department of Transport, 2008. Advanced Corsim training Manual, Minnesota Department of Transport, SHE No. A-MNDOT0318.00, January 2008, US.

Park, B.B. and J.D. Schneeberger (2005), Microscopic Simulation Model Calibration and Validation. Case Study of VISSIM Simulation Model for a Coordinated Actuated Signal System. Transportation Research Record 1856, Paper no. 03-2531.

Quadstone Paramics (2011), [Online] Quadstone Paramics [Accessed November 2011].

SMARTEST, 1997. *Review of Micro-Simualtion Models*. Project Deliverable D3. European Commission.

Sykes, P. (2010), Traffic Simulation with Paramics. In J. Barcelo, ed. Fundamentals of Traffic Simulation. Barcelona: Springer. pp.131-72.

Toledo, T., M.E. Ben-Akiva, D. Darda, M. Jha, and H. Koutopolous (2004), Calibration of Microscopic Simulation Models with Aggregate Data. Transportation Research Record. Volume 1876, Issue 1 Pages 10-19.

Vanderschuren, M.J.W.A (2006), Intelligent Transport Systems in South Africa, Impact assessment through microscopic simulation in the South African context, TRAIL Thesis Series T2006/4, ISBN number: 9055840777, August 2006 (book).

Wisconsin Department of Transport (2002), Freeway System Operational Assessment. Technical Report I-33 Paramics Calibration & Validation Guidelines (Draft). Milwaukee.

Yang, H. & Ozbay, K., 2011. Calibration of Micro-simulation Models to Account for Safety and Operation Factors for Traffic Conflict Risk Analysis. In *3rd International Conference on Road Safety and Simulation*. Indianapolis , 2011.