AIMSUN MICRO-SIMULATION – A PRACTICAL APPLICATION: MICRO-SIMULATION OF THE N1 FREEWAY

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ABSTRACT

The objective of this paper is to discuss the successful application of Micro-simulation in South Africa by way of modeling one of the most congested freeways in the country - the N1 Ben Schoeman Highway. The paper deals with the tedious task of calibration of the model and introduces the topic of calibration for gradient, an often over-looked aspect in micro-simulation models. This involved the manual calibration of the model parameters (the three assigned speed-change parameters being maximum acceleration rate and its normal and maximum deceleration rates) resulting in the improvement of the models sensitivity to the effect of gradient. Once a reliable, calibrated base year model was developed, future year interchange designs and freeway improvements were tested using the design year traffic loading. The paper subsequently highlights the benefits gained from micro-simulation that would not necessarily have been achieved using conventional analysis tools. One of these was that it presented a reliable tool for testing auxiliary lanes, that is, the length and number of lanes required to facilitate the flow of traffic accessing and exiting the freeway at interchanges.

The paper also touches on practical suggestions on making micro-simulation modeling a productive and viable option in traffic engineering. The latter is discussed to introduce the possibility of using optimization techniques in the calibration process in order to improve the efficiency of the modeling methodology and improve the accuracy of results. This would involve moving away from manual calibration, which is a highly tedious process in micro-simulation due to the number and complexity of model parameters, to a more automated procedure, saving both time and money.

1. INTRODUCTION

The development of an advanced simulation tool was seen as an important step in a complete and thorough assessment of one of the most congested freeway sections in the Gauteng area. The micro-simulation model of the freeway and associated arterials would be used to evaluate the existing road network and to test new interchange designs that could adequately facilitate the flow of traffic on and off the freeway.

To produce a micro-simulation model that was faithful to the traffic congestion experienced on this notorious freeway, traffic patterns and driver behavior had to be understood and accurately replicated. A simulator with credibility in modeling the complicated driver behavior associated with lane changing, gap acceptance, weaving and merging traffic was also critical. For this, the AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) software suite, a proven simulator that has sufficient parameters available to control the lane changing and gap generation and acceptance behavior important to modeling freeway traffic flow, was used. Added to this, a robust

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calibration procedure was necessary to faithfully produce existing conditions.

Traffic patterns and driver/vehicle behavior that generated bottlenecks were observed from the freeway traffic flow. It was noted that bottlenecks occur due to:

- Weaving, where large volumes of traffic exit or enter the freeway
- a lane drop, where the number of vehicles arriving is greater than the capacity of the reduced cross-section
- complex network geometry resulting in a drop in vehicle speed
- where the capacity of the ramp terminal is exceeded, resulting in queue spillbacks onto the slow lane of the freeway.

If the freeway is operating at or close to capacity, as is the case with this section of the N1 freeway, any one of the above could result in severe congestion in a short space of time.

The study area consists of a freeway corridor and ramps with 4 major arterials and signalized intersections, modeled to within a kilometer on either side of the freeway, shown in Figure 1 below. The major arterials modeled are, Rivonia Road, William Nicol Drive, Malibongwe Drive and Beyers Naude Drive.

Figure 1 Micro-simulation network of freeway and arterials

The paper goes on to describe, in some detail, the calibration procedure of the above network and ways of improving micro-simulation modeling to make it a more viable and reputable option in our industry.

2. MODEL CALIBRATION

Calibration is the process whereby parameters in the model are adjusted to accurately reproduce local traffic conditions and driver behavior. Calibration of the model is critical as it provides some degree of assurance that the model will accurately predict traffic performance for future scenarios.

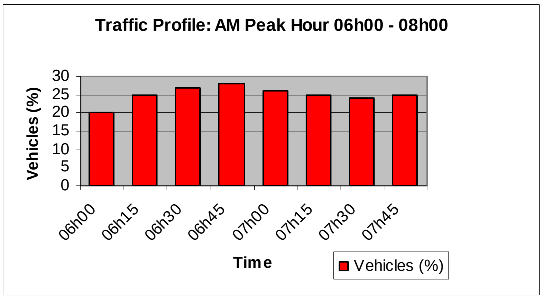
It is critical that proper calibration of parameters, particularly those that strongly influence the performance of the model, and the model outputs, be undertaken, rather than using the default values. Currently, calibration is an iterative process in which the model parameters are adjusted by the engineer until the results accurately represent field conditions. However, given the sophistication and complexity of micro-simulation models, these parameters have become quite numerous and the range of combinations of parameters too exhausting to contemplate. This results in a rather ad-hoc calibration process using a combination of both trial and error and engineering judgement and experience. 'This makes calibration a time-consuming and inefficient process, and as a result it is usually not performed or treated only superficially in most practical applications.' *Hourdakis, Michalopoulos and Kottomannil.*

Considering the above statements, one can imagine that considerable effort was required to manually calibrate the model to some degree of accuracy.

During calibration, one of the major problems experienced was reproducing known bottlenecks that were the cause of major congestion in the system. It was later realised that the lack of congestion was due, in part, to the demand matrices being too low. The demand matrices were developed from turn count information, and, since these were the actual traffic volumes that got through the junction, they did not account for the volume of traffic that was not processed at the end of the time period – that would usually produce congested conditions.

In order to overcome this, firstly the time period was extended to two hours in the morning and afternoon peak hours to represent the gradual build up of congestion and account for peak hour spreading, and secondly, the matrix was spliced into 15 minute time intervals and a traffic profile applied, as shown in Figure 2 below. The non-uniform release rate allowed for a more realistic simulation, particularly the queue discharge at intersections, which resulted in a more accurate build up of traffic congestion.

Through trial and error, model parameters were adjusted with the objective function being to minimise the difference between the modeled and observed volumes, and secondly to replicate the system-wide behavior by assessing queue formation on the network. The calibrated parameters that are presented below should be seen as a guideline only, as substantial research into driver behavior under local conditions, is still required.



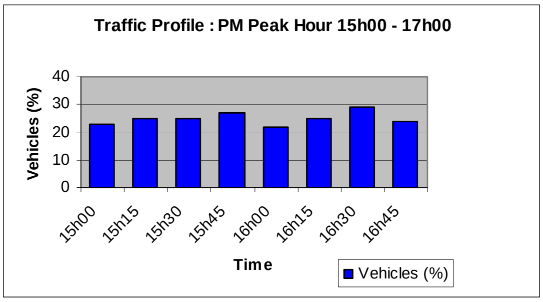


Figure 2 Traffic profile for morning and afternoon peak period

2.1 Calibration Procedure

The first phase in the calibration procedure began with the adjustment of the more general global parameters such as drivers reaction time, reaction time at stop, queue leaving speed etc. Once these parameters were adjusted to produce a good fit between observed and modeled data, and then began to have little further influence on the model outputs, local model parameters were adjusted. These were the freeway section gradients and certain lane changing parameters.

2.2 Calibration of Global Model Parameters

These parameters govern the three basic vehicle behavior models (car following, lane changing and gap acceptance models) and affect the performance of the entire network.

Drivers Reaction time and *Reaction Time at Stop* are two user specified driver behavior parameters that strongly influence the performance and capacity of the network. The default value for **drivers reaction time** (0.75) and **reaction time at stop** (1.35) have been calibrated under UK conditions and, and as was the case with US driving conditions as well, do not well represent typical performance conditions for Gauteng freeways. These values need to be reduced as South African drivers also tend to accept smaller gaps and have quicker reaction times. There is very little to no research for measured values of reaction times for drivers on South African roads. Improved model performance was attained with values of 0.68 for drivers reaction time and 1.00 for reaction time at stop.

Queuing up and *Queue leaving speed* parameters has some influence on the lane changing model. The higher the queue leaving speed, the longer the vehicle is considered to still be at a standstill. A vehicle driving in Zone 3 (the shortest distance to the next turning point whereby vehicles are forced to reach their desired turning lanes, coming to a standstill if necessary) of a section, shown in Figure 3, is not willing to wait for a gap for longer than the Maximum Give Way Time at a standstill, and the condition of standstill is governed by these parameters (AIMSUN NG Users Manual). Thus, the longer the vehicle is considered to be at a standstill, the longer it will wait for a gap in the traffic stream (rather than forfeiting any chance of a forced gap and continuing on the wrong lane to become a lost vehicle in the model).

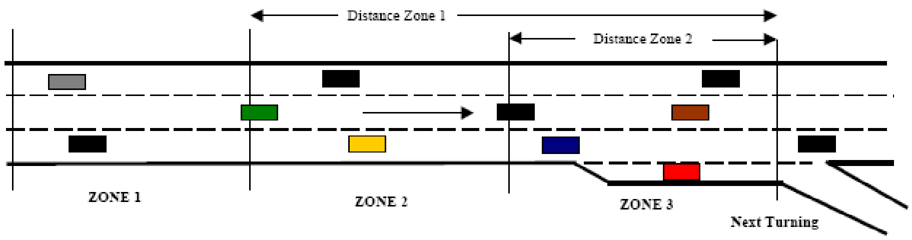


Figure 3 Lane Changing Zones (AIMSUN NG Users Guide)

Look Ahead is the maximum number of turnings ahead that vehicles consider when choosing which lane to travel in. The default is 2 which was increased to 3 since drivers familiar with congested routes tend to get into their correct lane much earlier in their journey to avoid having to force a gap closer to their exit point. This allows for correct queue formation and lane usage under congested conditions. Table 1 below shows the parameter values, default and adjusted, that were used to replicate field conditions.

Table 1 Calibrated Model Parameters

Model Parameter	Default Value	Calibrated Value
Drivers Reaction Time	0.75	0.68
Reaction Time at Stop (secs)	1.35	1.00
Car Following Model		
Max Speed Difference (km/hr)	50	40
Max Speed Difference on ramp (km/hr)	70	40
Lane Changing Model		
Percent Overtake (%)	90	99
Percent Recover (%)	95	100
Queuing up Speed (m/s)	1	1
Queue leaving Speed (m/s)	4	8
Look Ahead Model		
Maximum number of turnings	2	3

The parameters listed above have a significant influence on the performance of the vehicles in the network, resulting in more forceful driver behaviour, earlier acceptance of gaps, quicker start-up times etc. This type of aggressive behaviour was confirmed by Vanderschuren (2007) in her calibration of the Paramics Micro-simulation model to South African conditions.

2.3 Calibration of Local Parameters

These parameters are defined at the section level and applied locally to vehicles while they are driving along a section. These include speed limits for vehicles travelling through a section, section gradients and Distance Zone 1 and Distance Zone 2. The latter was particularly important in governing the lane change behavior along sections of the freeway.

2.4 Calibration for gradient

The network comprises several significant (length and steepness) gradients along certain sections of the freeway. Gradients were therefore entered into the model, as mentioned under local parameters above. The model, however, did not reflect the actual behavior of vehicles, particularly heavy vehicles on the steep gradients. To improve the model sensitivity to the effect of gradients on vehicle behavior, especially trucks on steep grades (eg.William Nicol off-ramp westbound), the vehicle attribute parameters were calibrated to reflect observed network conditions. The parameters that were calibrated are shown in Table 2 below.

Table 2 Calibrated acceleration and deceleration parameters

Parameters		Default Values	Calibrated Values
Car			
Max. Acceleration	Min	2.6	2.3
	Max	3.4	3.2
Max. Deceleration	Min	5	4.4
	Max	7	6.4
Truck			
Max. Acceleration	Min	0.6	0.5
	Max	1.8	1.6
Max. Deceleration	Min	4	3.4
	Max	6	5

After calibration of the above parameters, the influence of the slope on braking capability and reduction in acceleration was able to be reproduced by the model. At the William Nicol off-ramp (westbound) heavy vehicles visibly slow down on the steep gradient, obstructing vehicles wishing to get in lane for the off-ramp and thus slowing down the freeway traffic considerably. There was also pronounced platooning of vehicles around the slow moving trucks, thus generating the observed bottleneck on this section of the freeway.

The effect of the calibrated parameters on the simulation at the William Nicol off-ramp is shown in Figure 4 below.

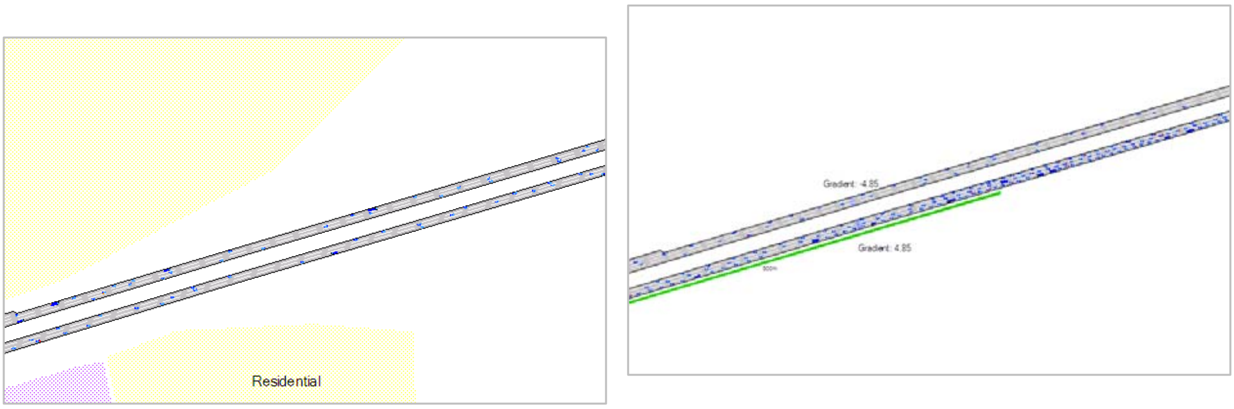


Figure 4 Effect of gradient on lane density and lane changing

2.5 Calibration Results

Volume-based calibration was carried out for the above study as it was the less complicated option. To add more weight to the accuracy of the model, the calibration process should have been progressed further by minimising the goodness-of-fit measurement for the freeway speed parameter. Some attempts were made at this, however thorough research needs to be carried out with respect to speed-flow and density relationships and their representation in micorsimulation models. The following results are an indication of the effectiveness of the calibration.

2.5.1 *Goodness-of-fit measurements*

A widely used measure of effectiveness is the Root Mean Squared Percent Error (RMSP) that gives an estimate of the degree of fit between the modeled and actual traffic flows. RMSP is defined as:

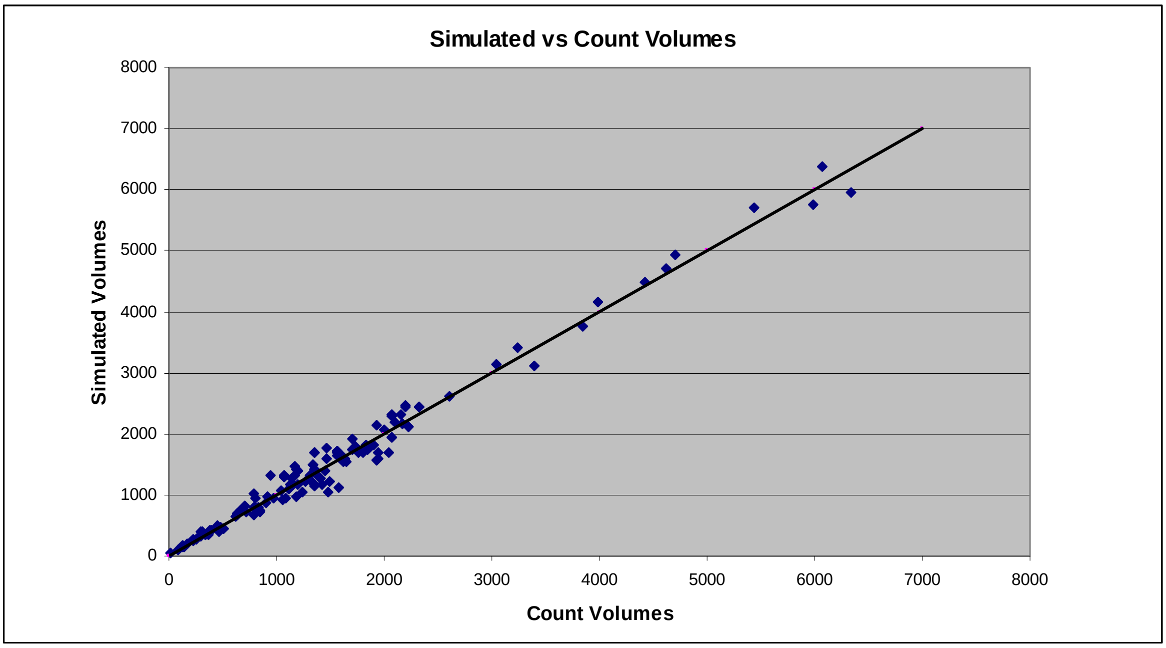
$$\text{RMSP} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i - y_i}{y_i}\right)^2} \qquad (1)$$

where

x_i is the simulated traffic measurement value at time i
y_i is the actual traffic measurement value at time i

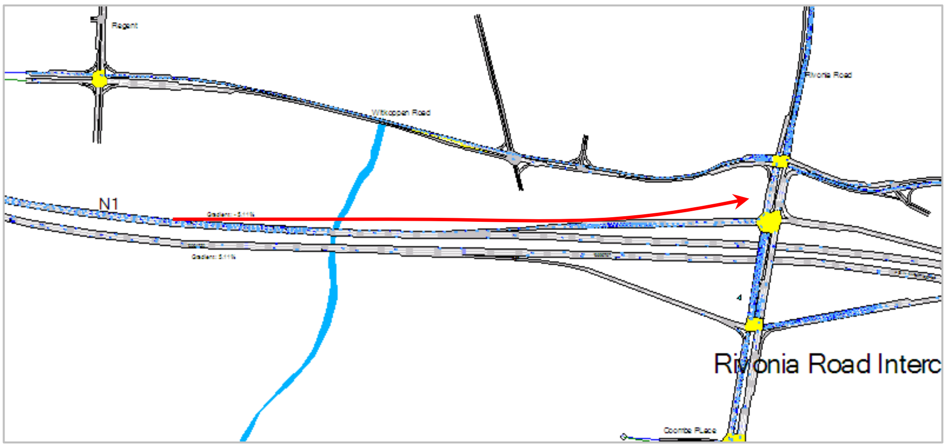
For the morning peak hour results, the RMSP was calculated at 15.3%, the range for freeways, major arterials and minor arterials being between 7% and 15%. Graph 1 shows the simulated volumes and the traffic counts.

Some models, like AIMSUN, use a user-defined maximum waiting time while a vehicle is attempting to change lane, after which it gives up and continues in the wrong direction, becoming a 'lost vehicle' (TSS, 2002). While it is a failure in the modeling procedure, the number of 'lost vehicles' is an indication of simulation success and in particular, of the lane changing, car following and gap acceptance models. The percentage of lost vehicles in the morning peak hour simulation was 0.04% of the total number of vehicles simulated.



Graph 1 Correlation between Simulated Volumes and Traffic counts

2.5.2 Queue Formation



The model was able to accurately replicate known congestion points on the network. The screenshot below shows the slowing down effect of vehicles trying to exit the freeway at Rivonia Road Interchange during the morning peak hour.

Figure 5 Slowing down effect of eastbound traffic exiting the freeway at Rivonia Road Interchange, morning peak hour

3. USE OF THE MODEL

The Study Area was first analysed using various analytic tools. aaSIDRA was used for basic intersection capacity analysis, TRANSYT was used for signal co-ordination and throughput analysis and HTM (Highway Traffic Model, Van As, 2006) modeling was carried out to test performance and capacity of freeway sections. The N1 study area is, however, a fairly complex urban road system experiencing severe congestion and other traffic issues that could not be adequately represented using the above traditional tools.

Microscopic simulation of traffic is gaining greater acceptance and wider use in the industry, particularly for its benefits in modeling highly congested areas and solving problems that cannot be solved by analytical methods alone. For this project, it allowed the evaluation of the road network operating as a complex system and the determination of the optimum solution for different network and traffic loading scenarios.

The future design year network was determined using the analytical tools described above, together with significant traffic experience from the design team. This design was then coded into the model and simulated using a 2020 design year traffic loading. The following is a brief account of the design year analyses using the micro-simulation model:

3.1 Future Year Network

The upgrading of the N1 section of freeway, with due consideration to land, geometric and structural constraints, resulted in an additional lane in each direction, and a lane gain between Rivonia Interchange and Buccleuch in both directions. The capacity improvements to the interchanges and arterials were then restricted in terms of their delivery capacity to the freeway, to prevent over-saturation of the freeway and a recurrence of the current congested conditions.

Although the interchanges and intersections were designed using aaSIDRA, the significant geometric changes to three of the interchanges and their operational ability were not conclusively analysed. The micro-simulation was thus invaluable in, firstly, observing the operation of each interchange from a traffic perspective, and secondly, communicating these designs to design engineers and officials. The designs were also fine tuned using the micro-simulation model and any ‘blockages’ due to inadequate network design were observed and the necessary improvements made.

Figure 6 Micro-simulation Rivonia Road Intercahnge

3.2 Auxiliary Lane Testing

One of the shortcomings of the design year network, that the micro-simulation revealed, was insufficient ramp length and auxiliary lanes to accommodate the forecast merge/diverge traffic volumes. The model was then used to determine the optimal characteristics of auxiliary lanes such that:

- On the one hand, merge/diverge ramp flows do not impede freeway flows i.e. an indirect analysis of the freeway merging capacity
- On the other, to ensure sufficient ramp capacity is provided such that cross-roads do not "grid-lock".

Results for the William Nicol Interchange are shown in Table 3 overleaf.

Although these were the only objectives of the modeling exercise for the project, it should be stated that the model can be used in a more extensive manner; from testing traffic management plans such as HOV lanes and ramp metering to assessing ITS programs.

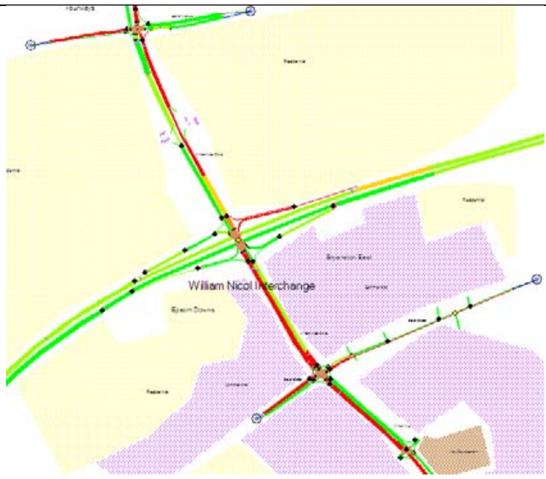
4. GUIDELINES FOR MICRO-SIMULATION MODELING

The following are recommended guidelines for applying micro-simulation software in transportation analyses:

General Guidelines:

1) A properly defined scope of works to ensure that sufficient time and resources are available to perform the analysis within the time allocated.
2) Good quality data, which is critical for good Micro-simulation results.
3) Good calibration to local traffic conditions (local traffic knowledge is invaluable)
4) This being said, calibration effort should also be based on the nature of the model's use
5) Use Micro-simulation where and when it is appropriate and can adequately address the issues at hand.

Table 3 Sample Results - William Nicol Interchange Morning Peak Hour, Eastbound direction

N1 Freeway	Forecast Volumes	Modeled Volumes	Queued on the arterial	Interchange Simulation
Simulation 1: On-ramp with 300m auxlilliary lane				
On-ramp Traffic	2335	1637	**2628**	
Freeway Traffic	6400	6147	-	
Simulation 2: Onramp with 2 auxilliary lanes, 300m outer lane, 700m inner lane				
On-ramp Traffic	2335	2171	**560**	
Freeway Traffic	6400	6559		

Technical Guidelines:

6) Follow a systematic calibration procedure
7) Collect sufficient data to enable faithful convergence of model parameters
8) Include delay and queue length surveys, and unequal lane utilisation as part of the data collection exercise in order to accurately generate bottlenecks (if a congestion model is being developed)
9) Speed contour maps could be used to easily identify/visualise bottlenecks in the system
10) When modeling congestion, model the estimated demand and not actual traffic flows as reflected in the traffic count information

5. MOVING TOWARDS AN AUTOMATED CALIBRATION APPROACH

In the calibration methodology applied in this project, several parameters such as driver reaction time, maximum acceleration and deceleration rates etc. were calibrated based on experience and engineering judgement. Numerous iterations were carried out; manually adjusting various combinations of these parameters to improve the performance of the system. This requires considerable time and effort, indicating a need to automate the iterative process of manually adjusting parameters. This is generally achieved through an optimisation technique which searches for an optimum set of model parameters through efficient search methods. In order to solve the problem, calibrating a set of model parameters until an objective function is minimised is usually the method applied. The following objective function, presented by Hourdakis, Michalopoulos and Kottommannil, TRB, 2003 whereby the objective function to be minimised was defined as the sum of squared errors of the mainline freeway station volumes, subject to bounds on the simulator parameters; ideally suits the problem at hand. Mathematically, the optimisation problem was stated as:

$$\text{Minimise } F = \sum_{j=1}^{st}\sum_{i=1}^{m}(v_{si}^{j} - v_{ai}^{j})^2 \qquad (2)$$

Subject to

$$L_{xp} < x_p < u_{xp} \text{ , p = 1, 2, n…}$$

where F is the objective function to be minimised

v_{si}^{j}	is the simulated traffic measurement of station j during time interval i
v_{ai}^{j}	is the actual traffic measurement of station j during the time interval i
L_{xp}	is the lower limit of simulator parameter xp
U_{xp}	is the upper limit of simulator parameter xp
n	is the number of simulator parameters to be optimised
st	is the number of detector stations on the freeway section
m	is the number of time intervals

In order to implement the above process, the optimisation technique is attached to the program via a subroutine that allows the transfer of data between the two programs. For AIMSUN users, the authors have used the Lindo API software that acts as an interface with AIMSUN via external scripting. The software deals with simulation-based optimisation problems and if applied to models will significantly reduce the calibration effort. This small though complex network required approximately 2 and a half months to calibrate, with an optimisation technique attached to the program, it could be a matter of hours before convergence is reached, and more accurately than was achieved for the project.

A simple yet effective means of calibration would ensure that engineers produce models of integrity that can be reliably used to predict the performance of a road network or traffic management plan.

6. CONCLUDING REMARKS

A key focus of this paper is the results that can be achieved with micro-simulation, given that some effort is put into calibrating the parameters that strongly govern model performance and outputs. It was undertaken under time and budget constraints as dictated by the project, and, should more research be conducted towards providing a set of calibrated parameters for South African conditions, micro-simulation modeling should improve its reputation. It can thus be regarded as the valuable tool that it is for assisting in road network design and performance testing. The model eventually aided significantly in the refinement of interchange designs and in the identification of bottlenecks generated through design inadequacies. To reduce the effort and ad-hoc nature of current model calibration, a widespread, automated calibration procedure, through the use of optimisation techniques, is imminent. The Lindo API optimisation software has been developed to act as an interface with AIMSUN and should improve the calibration procedure significantly.

7. ACKNOWLEDGEMENTS

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