MICRO-SIMULATION MODELLING OF ITS MEASURES ON THE BEN SCHOEMAN HIGHWAY

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ABSTRACT

The last couple of decades have brought about a paradigm shift in the way professionals view land transport. The original line of thought was to predict (Traffic flow) and provide (Infrastructure). The concern now is more about managing our existing road networks and infrastructure, but also ensuring that the effects of the newly constructed roads are appropriately forecasted.

Intelligent Transport systems (ITS) are one of the measures applied to improve traffic conditions. It appears that the use of microscopic simulation models is needed to estimate the effects of ITS measures

This study investigates the applicability of the micro-simulation software Paramics in the South African context by modelling the Ben Schoeman Highway between Pretoria and Johannesburg. ITS measures that have been investigated are:

- Bus and High Occupancy Vehicle (HOV) lanes,
- Variable Speed Limits (VSL) using variable Message Signs (VMS), and
- Ramp metering.

1. INTRODUCTION

Congestion is a daily reality in most South African cities. There has been a massive increase in car use for work trips. At the national level, the percentage of people using cars went up from 30% to 45% between 1997 and 2004. According to the National Household Travel Survey 2003, the figure for Gauteng is even worse (55%).

South African metropolitan areas show values for the average motorised trip length ranging from 15 up to 22 km. These values are much larger than those of cities in Europe and the USA, even for cities with comparable population densities (Vanderschuren, 2006). For several reasons, current public transport services do not provide an alternative for car traffic.

This paper presents the results of an assessment study for a selection of ITS measures using the microscopic simulation model Paramics. Based on a literature scan it was concluded that HOV lanes, the application of Variable Message Signs (VMS) to limit speeds and ramp metering are the most promising ITS measures for South Africa

(Vanderschuren, 2006). Two corridors have been investigated: the Ben Schoeman Highway (BSH) in Gauteng and the N2 near Cape Town. This paper will only report on the results for the BSH.

2. DRIVING BEHAVIOUR PARAMETER SETTINGS

Literature suggests that driving behaviour of South Africans might be quite different from that of Europeans and Americans. In a traffic simulation study, it is essential that the simulation model replicates real behaviour of drivers (Bonsall et al, 2005). Parameters in simulation models should, therefore, preferably be calibrated for each different setting. In the assessment study the microscopic simulation model Paramics is used. The model has four relevant parameters: mean target headway, mean reaction time, aggression and awareness. The latter two do not have values but are types of distribution, describing the variation in behaviour among the population of drivers.

The mean target headway (MTH) is the global target time for each vehicle, in seconds, between a vehicle and a following vehicle. The mean reaction time (MRT) for each driver is also measured in seconds, and it is associated to the lag in time between the change in speed of a leading car and the reaction of the following vehicle to the change. Default Paramics settings are 1.0 second for both MTH and MRT, and a normal distribution for both aggression and awareness. The seed specifies the value used by the random number generator in a simulation; therefore if the same seed value is used for identical networks then the generated results would be the same. More than 50 different settings, including different seed numbers, were investigated during the calibration process. A selection of the findings is provided in Table 1.

To identify the final settings for the BSH, a headway analysis was carried out (Table 1). The headways for followers in the model are slightly shorter than the headways of actual followers measured on the BSH. The modelled variance in follower headways is slightly larger than those measured on the BSH. The differences between the different parameter settings (runs: OD8A-OD10C) are minimal. Based on the headway peak analysis, it was concluded that target headway of 0.55 seconds, a reaction time of 0.35 seconds, a normal distribution for aggression and a squared distribution for awareness provides modelling results very similar to the actual measurements. In the next chapter these settings are referred to as the base case.

It can be concluded that the modelling results follow the actual measurements very well, especially for the first two hours (Figure 1). Thereafter, the modelling results alternate quite a bit. Unfortunately, this is typical for microscopic simulation results in congested conditions. The results were, therefore, accepted.

Table 1 Analysis of follower's headways (<3s) for the BSH

INPUT							Output						
RUN	SEED	OD-MATRIX	TARGET HEADWAY	REACTION TIME	AGGRESSION	AWARENESS	VOLUME	AVERAGE HEADWAY (seconds) Lane 1	AVERAGE HEADWAY (seconds) Lane 2	AVERAGE HEADWAY (seconds) Lane 3	HEADWAY FOLLOWER (<3s)	VARIANCE HEADWAY FOLLOWER (<3s)	HEADWAY PEAK
Actual		2001 2002					16 916 17 437	28.6 30.7	35.3 33.6	36.1 35.7	1.62	0.36	1.2-1.8
Default		100%	1.0	1.0	N	N	15 572	33.2	36.6	30.3			
OD8A OD8B OD8C	1111 2222 3333	100%	0.50	0.35	N	Sq	18 128 17 940 18 418	2.95 2.96 2.92	2.51 2.49 2.46	2.50 2.59 2.62	1.37 1.40 1.40	0.51 0.52 0.52	0.4-0.8 0.4-0.8 0.4-1.0
OD9A OD9B OD9C	1111 2222 3333	100%	0.55	0.35	N	Sq	17 673 18 015 18 086	2.95 2.90 2.94	2.57 2.49 2.48	2.68 2.64 2.63	1.39 1.36 1.38	0.50 0.50 0.51	0.4-1.0 0.4-1.0 0.4-1.0
OD10A OD10B OD10C	1111 2222 3333	100%	0.60	0.35	N	Sq	19 800 18 081 18 353	2.93 2.91 2.88	2.54 2.49 2.46	2.59 2.60 2.59	1.35 1.38 1.38	0.49 0.49 0.49	0.6-1.0 0.4-1.0 0.4-1.0

Note: The grey background indicates that the results were not accepted based on that parameter

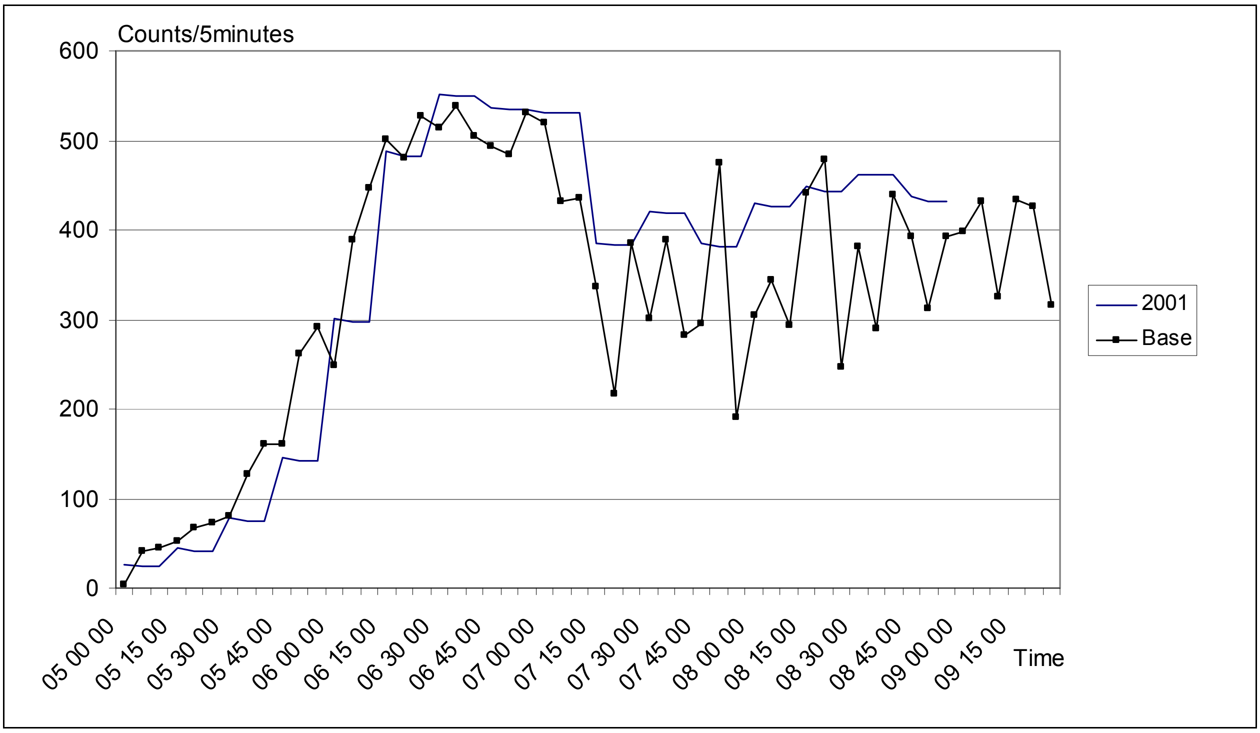

Figure 1 Comparison of actual and modelled volumes over time for the BSH

Source: Vanderschuren, 2006

3. DESCRIPTION OF THE CORRIDOR

The research corridor of the BSH, between the Brakfontein and Buccleugh interchange in the direction from Tshwane to Johannesburg (Figure 2), consists of three lanes. The corridor is 25.5 km long and has seven interchanges. The weaving areas are generally short. The BSH has three considerable inclines followed by comparable declines. The maximum measured volume is 6600 vehicles per hour, of which on average five percent are heavy vehicles.

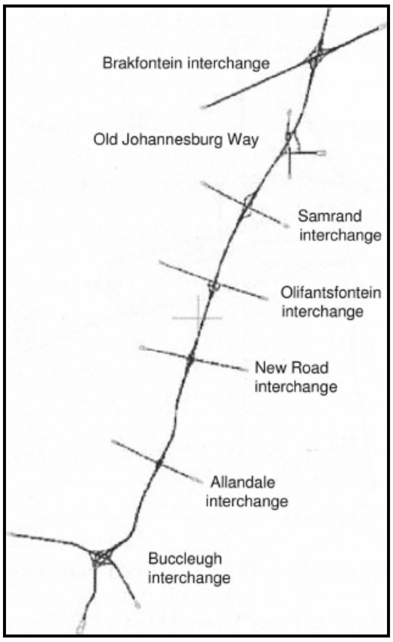

Figure 2 Ben Schoeman Highway
Source: Vanderschuren, 2006

4. THE APPLICATION OF BUS/HOV LANES

Early implementations of HOV lanes showed travel time benefits of between 8 and 25% (Dahlgren, 1998 and Johnston et al, 1996), although travel time for non-HOV vehicles can increase by up to 200%. Roux and Bester (2002) investigated an HOV lane in the Cape Town region. The implementation of an HOV lane does not look as promising. Although a substantial decrease in travel time (76%) and an incredible increase in average speeds (+319) were measured, the throughput (40%) of the highway decreased substantially. Many vehicles apparently were not able to enter the highway.

On the BSH one of the existing lanes will be converted into a bus/HOV lane, the other two lanes would be used by private vehicles. Traffic is informed timeously that it has to divert to the slow and middle lane. This creates a bottleneck. Buses and HOVs are supposed to use the third (fast) lane. In all scenarios the buses can use the dedicated lane. The HOVs that are allowed vary in the scenarios: vehicles with more than three people, or more than two people or more than one person. A final scenario with a shift of five percent from Single Occupancy Vehicles (SOV) to HOV is included. In this scenario it is assumed that two drivers carpool. Due to the shift, there is a 2.5% decrease in vehicles that will be assigned to the network.

4.1 Travel speed and safety aspects

The impact on travel speeds for the BSH (Figure 3) is different from the results of Roux and Bester (2002). The increase in speed in the latter study is due to the fact that 40% of the traffic is not able to enter the highway, and speeds are only calculated for the highway section of the trip.

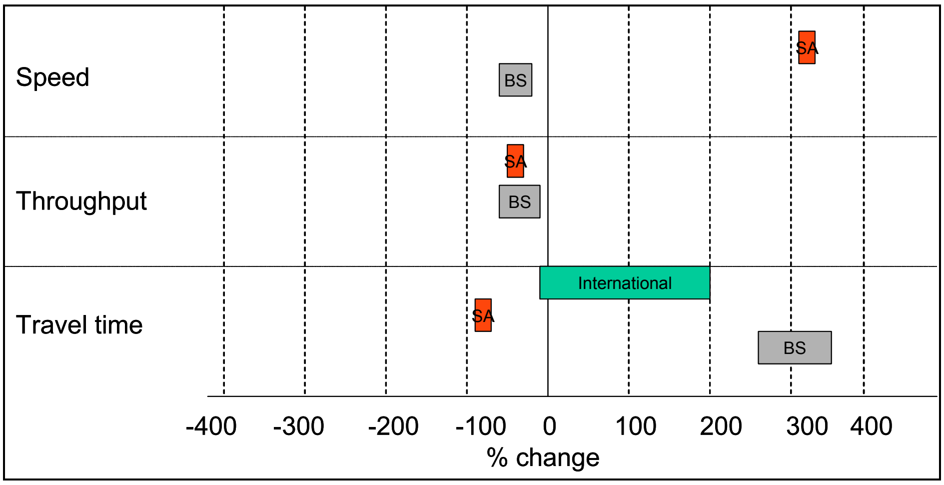

Figure 3 Reported and estimated effects of HOV lanes

The decrease in speed found for the BSH (Figure 3) is an indication that there might be a safety improvement. To verify this, Time-To-Collision (TTC), as well as headways are measured and calculated. A TTC-value of less than three seconds is considered a potential safety problem. Moreover, followers that drive 20 km/h faster than the leading vehicle are considered a threat. Table 2 provides an indication of the number of potential conflicts in percentages.

Table 2 Vehicles with small TTC-values for HOV scenarios on the BSH (%)

	Actual data	Base case	HOV >1 person
TTC < 3 sec and ΔSpeed ≥ 20 km/h	12.6	9.3	4.1
TTC < 1 sec and ΔSpeed ≥ 20 km/h	2.1	2.8	0.1

Source: Vanderschuren, 2006

Another safety indicator is the time headway. Literature indicates that headways shorter than one second are dangerous. From the headway distributions obtained from the study for all scenarios, it is clear that the HOV scenarios decrease the number of short headways and, therefore, the safety risk. The reduction in lanes for the private vehicles implies that the number of overtaking opportunities diminishes significantly. Short headways are often measured before overtaking.

4.2 Throughput analysis

The throughput on the BSH, as well as in the study by Roux and Bester (2002), decreases due to the HOV lane. Based on the analysis, it can be concluded that the HOV lane on the BSH creates a severe bottleneck. The traffic volumes drop by almost 50% due to the dedicated lane. Implementation of a HOV lane on the BSH in the way it is suggested in this study is, therefore, not recommended.

4.3 Travel time analysis

International literature focuses on travel time (Figure 3). A travel time improvement up to 25% has been measured for public transport. The increase in travel time for private cars, on the other hand, has been substantial (up to 200%). The results for the BSH are similar. The bottleneck created by the HOV lane is so severe, that travel times for public transport/HOV vehicles as well as Single Occupancy Vehicles (SOV) increase with some 300%. This increase is as a result of vehicles spending a lot of time queuing before they reach the HOV lane.

5. HOMOGENISING TRAFFIC FLOW VIA SPEED LIMITS

Homogenising via Variable Speed Limits (VSL) does not always result in more homogenised traffic flows on a highway system (Stemerding et al, 1999). They model a maximum speed limit of 90 km/h and notice that total throughput decreases by two percent; whereas more traffic is using the secondary road network. Moreover, in this study the number of stops increases, which is negative from a road safety aspect. Bonsall et al (2005) investigated speed limit compliance on highways. It was estimated that the throughput generally increases with between 2.9% and 5.7%. Nevertheless, the throughput during off peak, if the speed limit is reduced by 10 km/h, will drop by 24.2%. In the Netherlands and the USA many homogenising systems are put in place, as the impacts appear to be large. The SWOV estimates for the Netherlands a reduction in accidents of around 20% (www.swov.nl). In the USA injury accident reductions of between 20% and 29% have been measured (www.benefitcost.its.dot.gov).

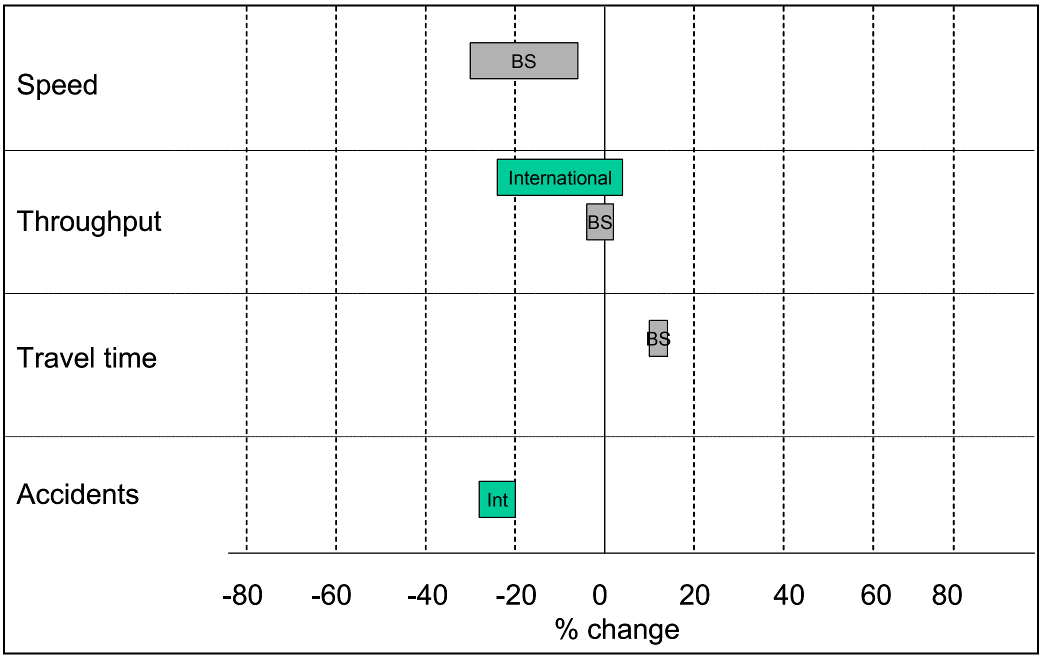

Figure 4 Reported and estimated effects of Variable Speed Limits

Vanderschuren (2006) has tested several algorithms to lower the speed. It appeared that differences in results are minimal. This paper, therefore, focuses on the most promising algorithm: the VMS showing a maximum speed of 80 km/h if flow is above 1500 vehicles per hour per lane, and 60 km/h if flow is above 1800 vehicles per hour per lane. Moreover, as differences are so small, it was decided to compare the homogenising traffic flow attempt via VMS with a scenario where the maximum speed limit is set to 80 km/h. In this scenario the ITS measures assume 100% enforcement. Figure 4 summarises the findings. It should also be taken into account that the speed limit information needs to be provided to the motorist at 800-1000m intervals, which in turn has cost implications.

5.1 Travel speed and safety aspects

On the BSH highway the VSL scenarios yielded results as expected: there is a drop in average speed (Table 3).

Table 3 Average speed for VSL scenarios (km/h)

Scenario	BSH
Base case	106
VMS	99
Fixed 80 km/h	77

Source: Vanderschuren, 2006

5.2 Throughput analysis

From Figure 4 it can be seen that the change in volume for the BSH is minimal. Generally, a decrease in volume of up to about 3.5% is witnessed.

5.3 Travel time analysis

Travel time analysis for the BSH shows that the travel times for the VSL scenarios are slightly longer than the base scenario. The travel time patterns in time are the same as for the base case. By the end of the peak period, travel times are almost identical to the base case.

6. RAMP METERING

The objective of ramp metering is to reduce disturbances and shockwaves on a highway. Many studies have shown that proper ramp metering results in a better overall traffic flow during periods of traffic congestion although results vary (Stemerding et al, 1999, Westra et al, 2002, Goudappel Coffeng, 1997 and 1998 PIARC, 2004 and Mkhize and Thomas, 2005).

The selected ramp metering settings for the BSH corridor are quite conservative. If the upstream loops on the highway are occupied for 25% of the time or more, the traffic light on the on-ramp will show red for seven percent of the time. In the scenario ramp metering has been introduced on all on-ramps in the corridors, although under certain conditions ramp metering (congested sections) is not the best solution. Ideally different scenarios should be investigated where ramp metering is applied at particular interchanges. Some practitioners also dispute the use of micro-simulation to analyse ramp metering effects.

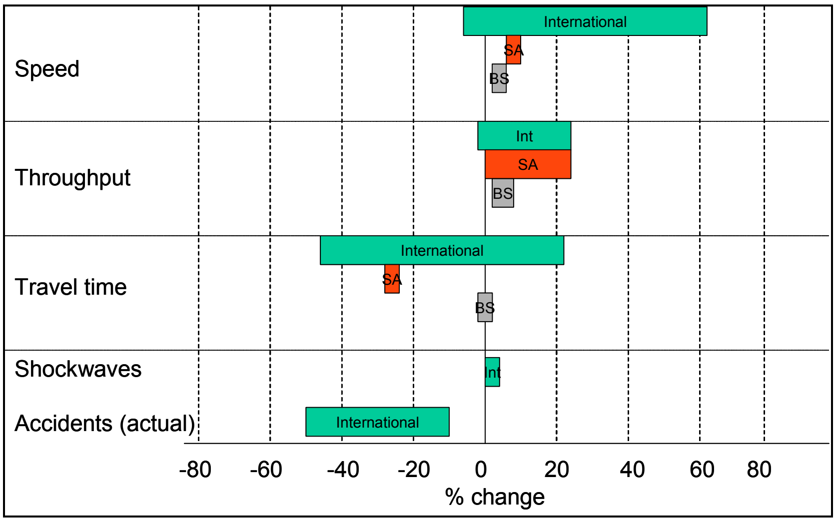

Figure 5 Reported and estimated effects of Ramp Metering

6.1 Travel speed and safety aspects

The estimated impacts of ramp metering for travel speed are rather moderate compared to international studies (Figure 5). Travel speed increases slightly on the BSH due to somewhat improved flow conditions. Safety is not always reciprocal to travel speed. The homogenising impact of ramp metering might improve the safety aspect despite an increase in travel speed. An analysis of the TTC-values revealed that there is a significant reduction in safety risk on the BSH (Figure 6).

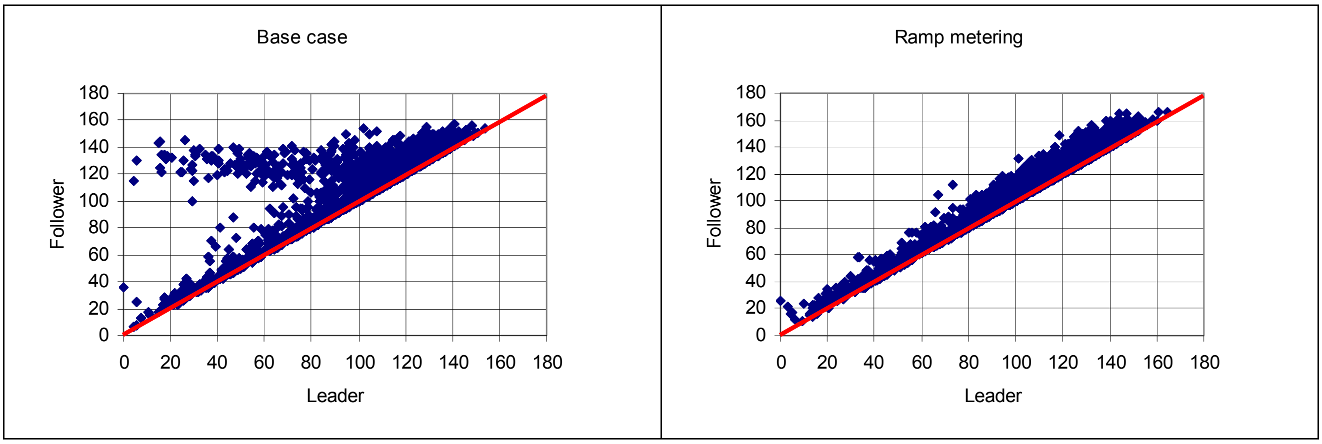

Figure 6 Comparison of leading/following vehicle speed with a TTC < one second of ramp metering scenarios for the BSH
Source: Vanderschuren, 2006

6.2 Throughput analysis

In general, ramp metering provides a better utilisation of the road. This is confirmed in international as well as South African studies (Figure 5), and is also found in the BSH corridor. During the peak period, the average throughput increases by 2.2%, whereas the increase during peak hour is 8.5%. It has to be noted that the secondary roads linking to the highway were not considered and could be negatively affected by the ramp metering measure.

6.3 Travel time analysis

No consistent findings with regards to travel time can be found in literature. In general, it looks as if travel time on the highway improves, although delays on the on ramps can be severe. On the BSH corridor, being most promising, a more detailed analysis of travel times was carried out.

For both, trips from Tshwane to Johannesburg and the shorter trips from Midrand to Johannesburg (with a traffic controller on the ramp), the model calculations reveal similar travel times for the base case and the ramp metering scenario. It is concluded that ramp metering on BSH does not have a significant positive or negative effect on travel times for traffic on the highway, as well as traffic on the on ramps.

7. CONCLUSIONS

A literature survey of impact assessment studies of ITS measures reveals wide ranges of results. It is, therefore, not possible to adopt ‘rules of thumbs’ with regards to impacts of ITS measures. In this paper an ex ante evaluation study has been performed with respect to the introduction of HOV lanes, Variable Speed Limits and ramp metering on the Ben Schoeman Highway between Tshwane and Johannesburg. The results of the study fit into the wide bandwidth of results of international and South African studies.

In general, ITS measures are beneficial and contribute to sustainable development. However, an a-priori statement about the potential effects of ITS measures is risky. It is recommended to perform a thorough ex ante evaluation study before any ITS measure is implemented in a particular context.

This paper summarises part of the results of a comprehensive assessment study of ITS measures in South Africa using a microscopic traffic simulation model (Vanderschuren, 2006). The lessons learned with regards to HOV lanes are that, for the introduction of an HOV lane, an additional appropriately enforced lane needs to be created on the highway to ensure the measure to be successful. Safety improvements of HOV lanes, if any, can be attributed to a reduction of overtaking opportunities for non-HOV vehicles. Variable Speed Limits provide a substantial safety improvement. However, for the BSH the impacts on throughput and travel time are negative. With regards to ramp metering, it is concluded that the effects of this measure heavily depends on the characteristics of the corridor. The results for the BSH are positive. It is concluded that, only when the majority of the traffic volume is already on the highway at the entrance of the corridor, which is the case on the BSH, this measure will lead to an improvement.

Calibrated parameter settings were used in the assessment study. It is interesting to note that an assessment study of the ITS measures, with default parameter settings, provided significantly different results. This finding might partly explain the wide bandwidth of effects of ITS measures of model studies in literature, as most studies use default values for behavioural parameters. It also addresses the need for model calibration.

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