Assessment of ITS measures for South Africa

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Abstract

South African government, public and private organisations are investigating the potential benefits of the application of Intelligent Transport Systems (ITS) in South Africa. This paper describes the results of an impact assessment for two South African Highway corridors: the Ben Schoeman Highway in Gauteng and the N2 near Cape Town. The ex ante evaluation study has been performed using the microscopic traffic simulation model Paramics. Since driving behaviour on South African roads is very different from driving behaviour in Europe or the US, the model had to be calibrated using actual data. Based on a scan of international literature, it was concluded that bus/High Occupancy Vehicle (HOV) lanes, the application of Variable Message Signs (VMS) to limit speeds and ramp metering are the most promising ITS measures for South Africa. The results of the scenario analyses for these ITS measures are discussed and compared with findings in the literature.

Introduction

Choking congestion is a daily reality in most South African cities. Traffic volumes are growing at an average rate of seven percent a year. 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 cities, like Johannesburg, Cape Town, Buffalo City (previously East London), eThekwini (Durban), Mangaung (Bloemfontein), Maunduzi (Pietermaritzburg), Nelson Mandela Metropole (Port Elisabeth) and Tshwane (Pretoria) 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). It is obvious that the land-use patterns created in the apartheid era have a substantial impact on present (car) travel demand (Vanderschuren et al, 2003). For several reasons, current public transport services do not provide an alternative for car traffic.

South Africa does not have the financial means to supply the road infrastructure needed to accommodate the growing number of vehicles. Moreover, all over the world the awareness is growing that the traditional predict-and-provide approach in transport policy is not sustainable and will lead to unacceptable congestion and pollution levels. The implementation of ITS measures is seen as a challenging option to accommodate car traffic on existing road infrastructure in a more sustainable way.

Up to now, research with regards to the impacts of ITS in South Africa has been limited. The raising interest and investment in the field calls for a closer look and investigation of its potential benefits for South Africa. 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.

Driving behaviour parameter settings

Literature suggests that driving behaviour of South Africans might be quite different from that of Europeans and Americans. However, no comprehensive study has been conducted yet. In a comparative study of general behavioural differences between various cultures/countries Hofstede (1991) shows that South Africans score high for masculinism and individualism, and average for uncertainty avoidance. He also concludes that masculinism and uncertainty avoidance are dominant indicators for 'aggressive' driving behaviour.

South Africa has a triple heritage, from African society, Europe and Asia. It is, therefore, tricky to compare the South African average score with other countries. In another study (Trompenaars et al, 1998) eight cultural groups within South Africa were analysed. In this study it was concluded that behavioural differences between these groups are large. It indicates that differences in driving behaviour in South Africa are probably larger than in Europe and the USA. In a recent study (Sukhai, 2006) it was found that South Africans are the most aggressive drivers among ten researched countries.

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. Default settings of Paramics are 1.0 second for both mean target headway (MTH) and mean reaction time (MRT), and the normal distribution for both aggression and awareness.

The model has been calibrated for each of the two corridors (Vanderschuren, 2006). Over 50 different settings were tested and analysed using actual data. The final settings (base case) are summarised in table 1.

Table 1 Summary of the base case settings

Parameter	BSH	N2
Mean Target Headway	0.55	0.55
Mean Reaction Time	0.35	0.35
Aggression	N	Sq
Awareness	Sq	Sq

Source: Vanderschuren, 2006

The results of the calibration confirm the findings in literature. The relatively low values for MTH and MRT indicate that driving behaviour is indeed very aggressive, and squared distribution for awareness (BSH and N2) and aggression (N2) indicates the diversity of the drivers on South Africa's roads.

Description of cases

The research corridor of the BSH, between the Brakfontein and Buccleugh interchange in the direction form Tshwane to Johannesburg, consists of three lanes. The corridor is 25.5 kilometres long and has seven interchanges. The weaving areas are generally short, as is the norm in South Africa. 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.

The second case is the N2 corridor near Cape Town from International Airport to Hospital Bend, a stretch of 9.8 kilometres. On and off ramps are short and close to each other. The corridor is considered flat terrain, except for the last 2.2 km where the road slopes up 55m near Table Mountain. The first 1.1 km of the corridor has two lanes, thereafter it increases to three lanes. The maximum measured volume is 5400 vehicles per hour on the three lanes section. Some seven percent are heavy vehicles.

For both corridors the impacts of the three ITS measures are estimated using the simulation model with the parameter settings derived from the calibration (see table 1). The modelled ITS measures are: HOV lanes, Variable Message Signs to limit speeds, and ramp metering. Several scenarios were run and compared with the base case. For each measure travel speed, traffic throughput, travel time and some safety indicators were assessed and compared with both international and South African studies.

The application of bus/HOV lanes

Early implementations of HOV lanes showed travel time benefits of 25% (Johnston et al, 1996), although travel time for non-HOV vehicles can increase up to 200%. A travel time reduction of up to eight percent is estimated in modelling studies (Dahlgren, 1998). Dahlgren indicates that adding an HOV lane to a three lane highway is more effective than adding a general purpose lane, only if the initial maximum delay is in the order of 35 minutes or more and the proportion of HOV vehicles is some 20%. Moreover, even with a substantial freeway travel time benefit, the number of people that are motivated to shift, will be limited – between one and four percent – due to the inconveniences and longer off-highway travel time associated with HOV.

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. For private vehicles the road will change from three into two lanes. Traffic is informed timeously that it has to divert to the slow and middle lane. This obviously 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. With the current service level of public transport, it is unlikely that car owners will shift to public transport. Due to the shift, there is a 2.5% decrease in vehicles that will be assigned to the network.

Travel speed and safety aspects

The impact on travel speeds for the two corridors are quite similar (figure 1), although quite 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 part of the trip.

The decrease in speed for both corridors is a first 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.

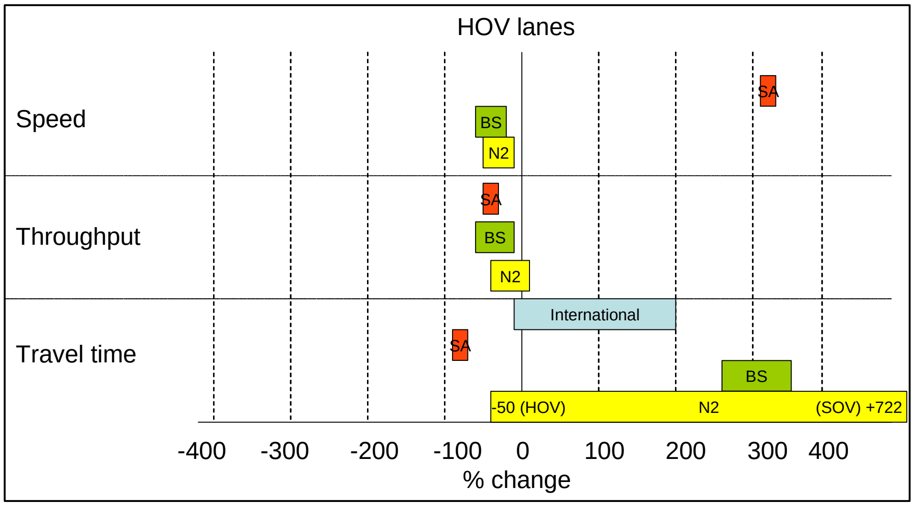

Figure 1 Reported and estimated effects of HOV lanes

Comparing the base case with actual data for the BSH shows, that the base case underestimates the number of vehicles with a TTC of less than three seconds and a speed difference of at least 20 km/h, and slightly overestimates the number of vehicles with a TTC of less than one second and a speed difference of at least 20 km/h.

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

Comparing the BSH base scenario with the other scenarios (Vanderschuren, 2006), it turns out that the scenario with the HOV lane utilised by vehicles with more than one passenger, performs best. The number of potential conflicts is expected to be least in this scenario.

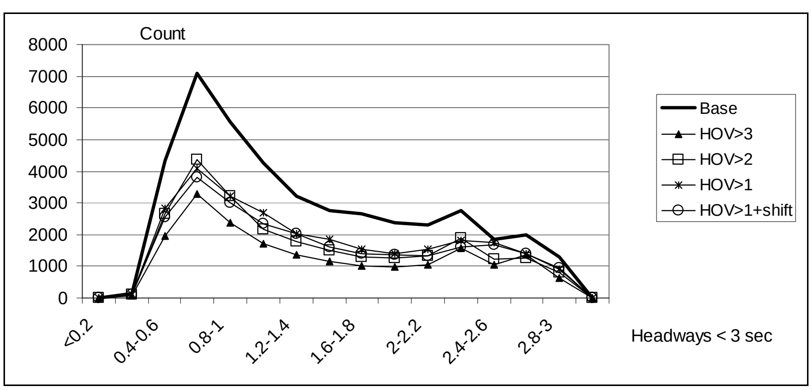

Figure 2 Headway distributions of HOV scenarios for the BSH

Source: Vanderschuren, 2006

Another safety indicator is the time headway. The view on what a safe headway is varies between 0.9 seconds and four seconds. Literature indicates that headways shorter than one second are dangerous. Figure 2 provides an overview of the headway distributions for the BSH 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.

Throughput analysis

The throughput on both corridors, as well as in the study by Roux and Bester (2002), decreases due to the HOV lane (figure 1). Traffic volumes on the BSH are close to capacity. A slight disturbance can create major problems. 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.

The reduction of traffic volumes on the N2 is less severe (29%). Analysis for the peak hour on the N2 shows a loss in throughput of between six and 26%.The fact that the N2 changes from two lanes into three lanes when the bus/HOV lane starts, prevents the creation of the severe bottleneck that is witnessed on the BSH. Nevertheless, the reduction in throughput leads to severe congestion in the suburbs, as vehicles can not enter the highway.

Travel time analysis

International literature focuses on travel time (figure 1). 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 two modelled networks were similar. As indicated, on the BSH one of the existing lanes was converted into a bus/HOV lane. 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%. On the N2 the travel time for SOV increases with over 700% while HOV vehicles experience a decrease in travel time with up to 30%. Figure 3 provides an overview of the travel time comparison between the base case and two different HOV scenarios for the N2.

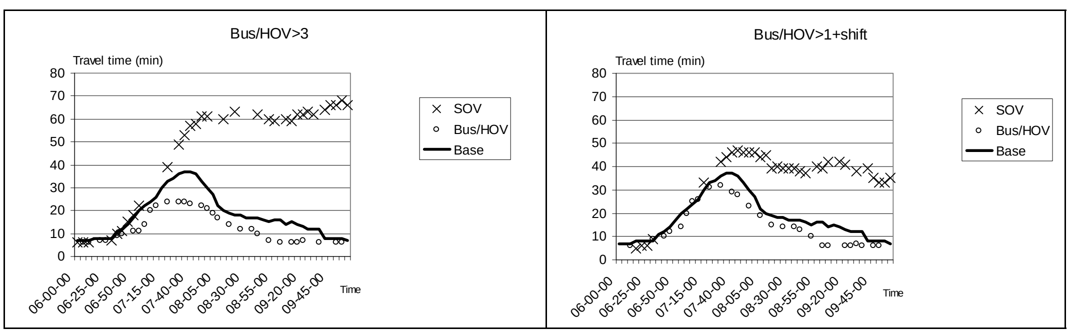

Figure 3 Travel time comparison between SOVs and HOVs for the N2

Source: Vanderschuren, 2006

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. Also 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 because the impacts appear to be large. Measured speed reduction in the Netherlands is between five and 14 km/h. The percentage of drivers speeding is reduced by between 25% and 31%. 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).

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.

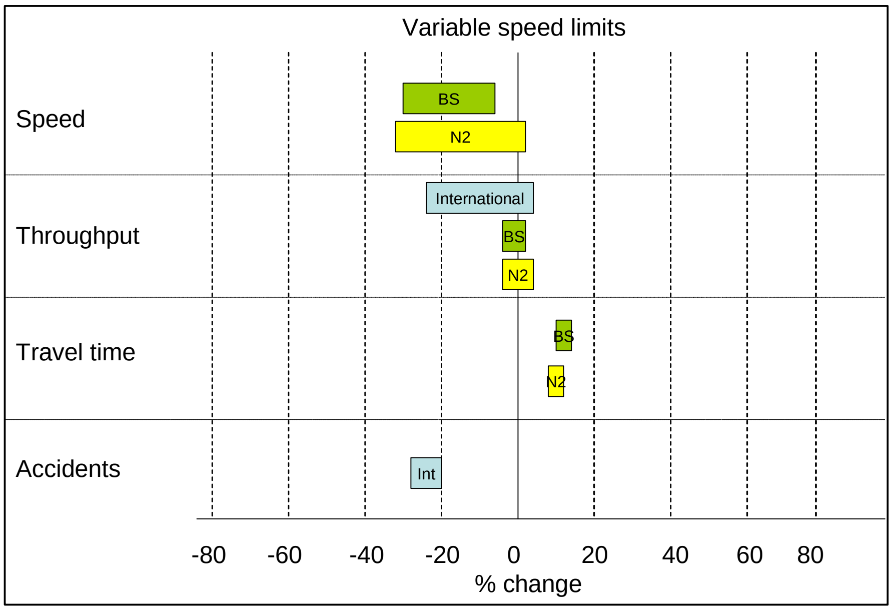

Figure 4 Reported and estimated effects of Variable Speed Limits

Travel speed and safety aspects

On the BSH highway the VSL scenarios yielded results as expected: there is a drop in average speed. The N2, on the other hand, shows a slight increase in average speed for the VMS scenario. Due to the higher gain in peak-hour flow for the N2 and the increase in speed for the VMS scenario, it was decided to focus the safety analysis on the N2.

Table 3 Vehicles with small TTC-values for VSL scenarios on the N2 (%)

	Base case	VMS	Fixed 80 km/h
TTC < 3 sec and ΔSpeed $\geq$ 20 km/h	3.7	10.7	5.2
TTC < 1 sec and ΔSpeed $\geq$ 20 km/h	0.2	1.2	1.0

Source: Vanderschuren, 2006

The analysis of short TTCs and high speed differences shows that the homogenising scenarios have a higher accident risk than the base case (table 3). The fixed 80 km/h scenario appears to be safer than the VMS scenario. This is an unexpected result and a more detailed analysis of individual vehicle data is needed.

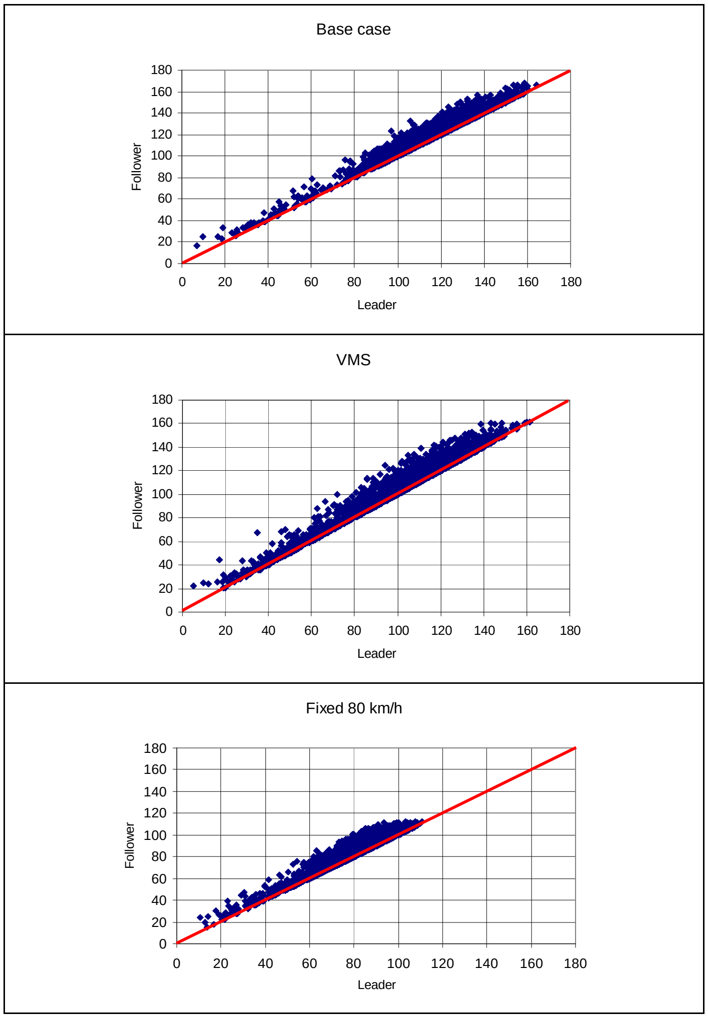

Figure 5 ***Comparison of leading/following vehicle speed with a TTC < one second of homogenising scenarios for the N2***
Source: Vanderschuren, 2006

No headway measurements are available for the N2. Figure 5, therefore, only includes the base case and the two homogenising scenarios.

The VMS scenario shows no significant difference compared to the base case scenario. Large speeds keep appearing, which indicates that the VMS is active only part of the time. Comparing the fixed 80 km/h scenario (which effectively is the same as a VSL scenario where the VMS is active 100% of the time), with the base case scenario for the N2, a substantial improvement is witnessed. The fixed 80 km/h scenario appears to be much safer than the other scenarios. All speeds of followers with a TTC of less than one second are less than 120 km/h, compared to 160 km/h for the base case and the VMS scenario.

Throughput analysis

From figure 4 it can be seen that the change in volume for the BSH, as well as the N2 is minimal. Generally, a decrease in volume of up to about 3.5% is witnessed. Nevertheless, analysing the results in more detail it appears that the efficiency is slightly better during the peak hour when implementing a VMS on the BSH, as well as the N2 (up to 1.9%).

Travel time analysis
Travel time analysis for both the BSH, as well as the N2, shows that the travel times for the VSL scenarios are slightly longer than the base scenario (figure 4). Other than the HOV scenarios, 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.

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. In a European study by Stemerding (Stemerding et al, 1999) the conclusion for ramp metering was that the throughput does not change (neither on the highway nor on the secondary roads) and the speed increases slightly (eight percent overall). The findings of another ramp metering study (Westra et al, 2002) indicate that ramp metering can have both a positive and negative impact on travel time. Overall travel time increases by two percent in the morning peak. Studies from Goudappel Coffeng (1997 and 1998) reveal that travel time reductions by ramp metering strongly depend on network characteristics, volumes and flow patterns: travel time reductions vary from six to 48% and in one study an increase in throughput of eight percent was achieved.. All in all the estimated effects of ramp metering are very promising.

Ramp metering studies in the US (PIARC, 2004) have measured the following benefits:

- An increase in motorway (highway) capacity between 17% and 25%,
- An increase in speed between 16% and 62%,
- A reduction of accidents between 24% and 50%, and a reduction of injury accidents by 71%.

In eThekweni the impacts of a freeway management system were assessed (Mkhize and Thomas, 2005). The integrated system included incident management and ramp metering. The estimates show a decrease in speed (44%-45%) as well as a decrease in travel time (27%-32%).

The selected ramp metering settings for the BSH and N2 corridors 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.

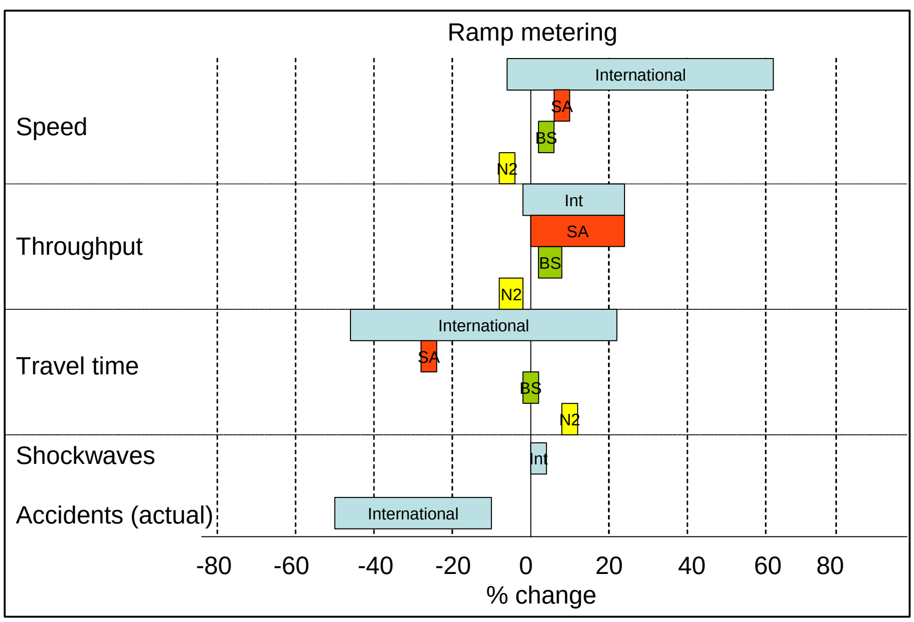

Figure 6 ***Reported and estimated effects of Ramp Metering***

Travel speed and safety aspects

The estimated impacts of ramp metering for travel speed in both corridors are rather moderate compared to international studies (figure 6). Travel speed increases slightly on the BSH due to somewhat improved flow conditions. For the N2, ramp metering has an opposite impact for travel speed. This result is outside the range found in international studies. In general, traffic flow becomes more homogenised by ramp metering. This appears not to be the case for the N2.

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 7). It appears that ramp metering stabilises traffic flows. The leader/follower analysis for the N2 does not indicate a significant difference, although the width of the band of data points seems slightly wider.

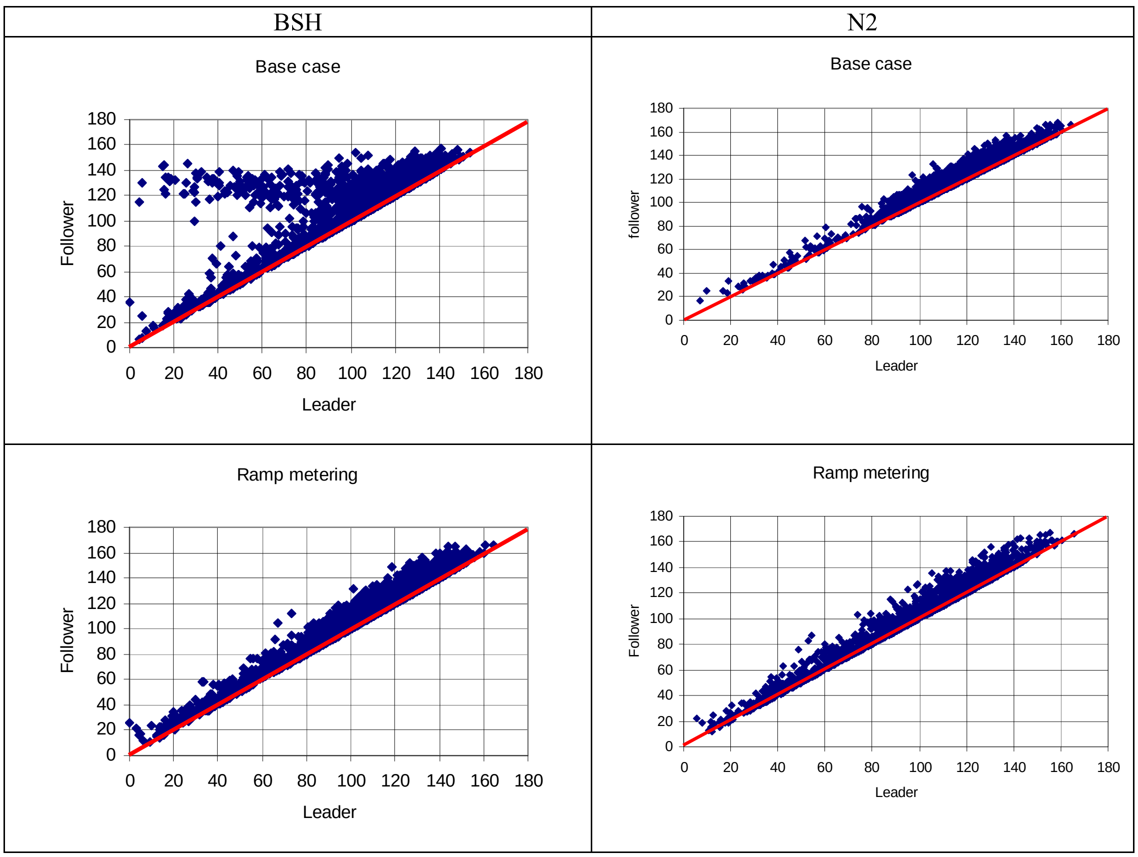

Figure 7 ***Comparison of leading/following vehicle speed with a TTC < one second of ramp metering scenarios for the BSH, as well as the N2***

Source: Vanderschuren, 2006

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 6), 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%.

The results for the N2 are again opposite: a decrease in peak period throughput of 2.5% and even 8.5% in the peak hour. Attempts to increase the throughput by changing red times at on ramps and/or eliminating traffic controllers on some of the on ramps, did not sufficiently improved the throughput.

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 (figure 8).

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.

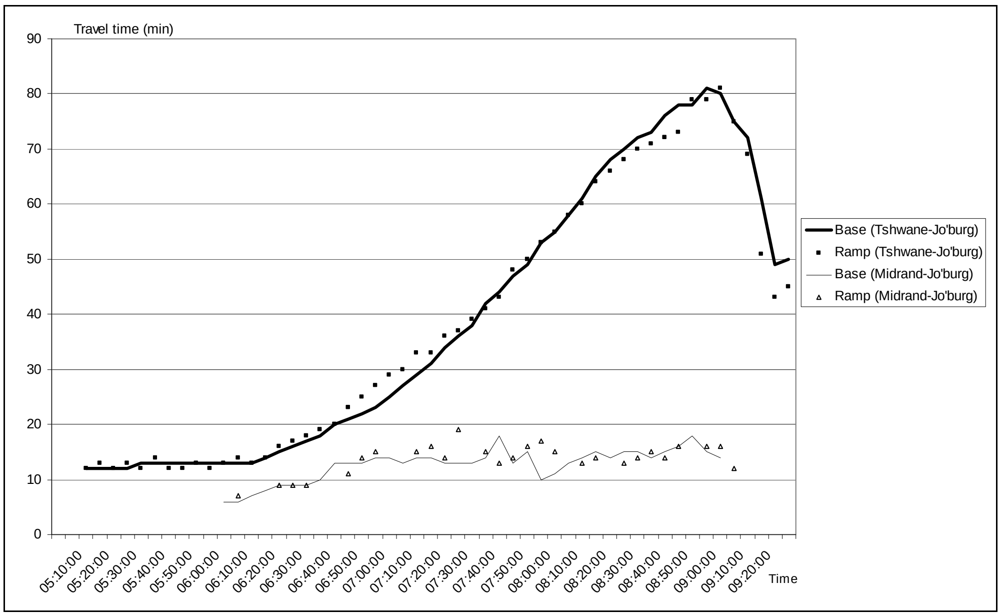

Figure 8 ***Travel time over time of ramp metering scenarios for the BSH from Tshwane, as well as Midrand to Johannesburg***
Source: Vanderschuren, 2006

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. The study deals with two major corridors in South Africa: the Ben Schoeman Highway between Tshwane and Johannesburg and the N2 near Cape Town. 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. The two case studies point in the same direction for South Africa, despite clear differences in transport systems and travel behaviour compared with developed countries. 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. There are many factors determining the effectiveness and efficiency of ITS measures, such as: network characteristics and geometry, traffic patterns and flow levels, and driving behaviour. The study in this paper contributes to this general finding.

This paper summarises 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 lane needs to be created on the highway to ensure the measure to be successful. An HOV lane is a transport policy measure that favours specific categories of travellers. A proper implementation of this measure implies that these travellers will benefit whilst the traffic condition for others will worsen. 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 two South African corridors 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 Ben Schoeman Highway corridor are positive, whereas ramp metering for the N2 near Cape Town has adverse impacts for various settings. The study indicates that, only when the majority of the traffic volume is already on the highway at the entrance of the corridor, this measure will lead to an improvement.

Driving behaviour on South African highways turned out to be quite different from European and American behaviour. Instead of using default parameter settings, it was decided to calibrate the traffic simulation model Paramics, which has been used for the assessment study, using real data from each of the corridors. The calibration of the model confirms findings in the literature that driving behaviour in South Africa is very aggressive.

The 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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