

THE USE OF DRACULA MICRO SIMULATION MODELLING IN THE EVALUATION OF PUBLIC TRANSPORT PRIORITY MEASURES ON THE SOWETO TO PARKTOWN CORRIDOR

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ABSTRACT

The City of Johannesburg (CoJ) Integrated Transport Plan (ITP) recommends the implementation of a Strategic Public Transport Network (SPTN), comprising of 325 km of grid-based corridors along mobility spines, linking the main residential and economic nodes. The implementation of the first phase of the primary north-south corridor, linking Soweto to Sandton, Rivonia and Sunninghill, is currently underway. The traffic and transportation component of the study includes the investigation of potential public transport priority measures to improve travel time, and the provision of improved facilities for public transport users at stops and strategic transfer points. DRACULA micro simulation modeling was used to quantify the impact of various proposed public transport priority measures on travel time and delay in the corridor. The paper presents the traffic study approach and discusses the modeling results.

1. INTRODUCTION

The City of Johannesburg (CoJ) has commenced implementation of its Strategic Public Transport Network (SPTN). The SPTN aims to develop a focused, higher frequency public transport grid, linking residential areas and major economic nodes. Public transport infrastructure decisions and expenditure will be clearly focused on these corridors, including provision of public transport priority measures, public passenger interchange facilities at the main intersection points on the network, park and ride facilities, provision of public transport signage, passenger information displays, shelters, street furniture, and dedicated stops with improved safety and security activity including excellent lighting and closed circuit television surveillance.

The main north-south corridor linking Soweto directly to the northern destinations of Rosebank, Sandton, Rivonia and Sunninghill via Parktown, indicated in **Figure 1**, is being implemented first. Phase 1, the subject of this study, includes the southern section from Soweto to Parktown. A traffic study was commissioned to assess corridor demand, determine the location of transfer points and stops, determine infrastructure requirements at these points, and to assess operation of the route in order to develop appropriate traffic engineering and geometric solutions to provide priority to public transport.

This paper presents the traffic study approach, the development of a DRACULA micro simulation model to test the proposed public transport priority measures' effectiveness in reducing public transport journey times while minimising the impact on other road users, at the same time providing a solution that is affordable to the City of Johannesburg.

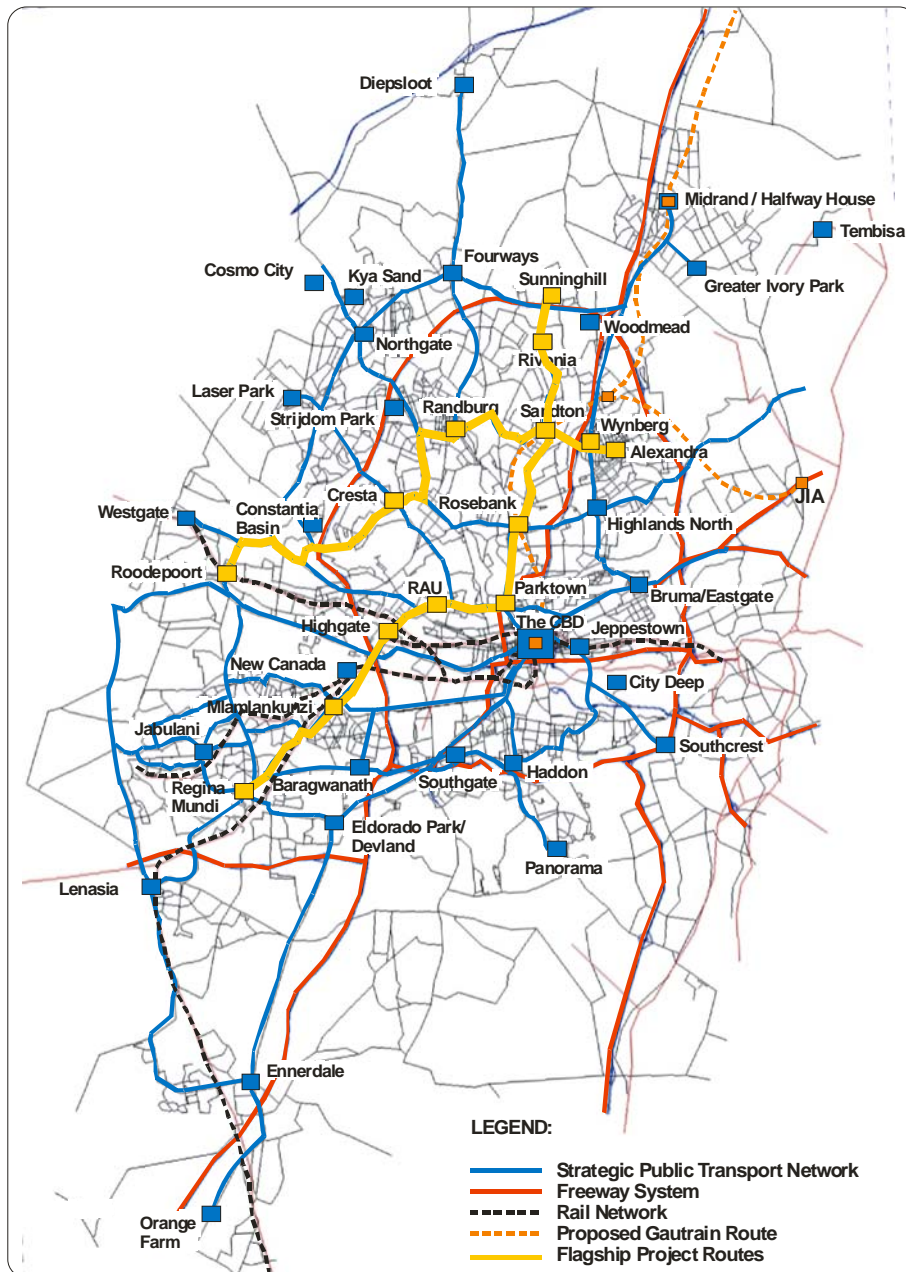


Figure 1: Strategic Public Transport Network

2. THE SOWETO TO PARKTOWN CORRIDOR

The corridor is approximately 22 km long, and follows the following arterials: Old Potch Road, Klipspruit Valley Road, Main Road, New Canada Road, Fuel Road, Perth Road, Kingsway, Stanley Road and Empire Road, terminating at the Parktown transfer point at the intersection with Victoria Road, where it will link up with the next phase to the north, along Rivonia Road. The corridor crosses 77 intersections, of which 39 are currently signalised. The majority of the route consist of dual carriageway or four lane undivided roads, but localised sections of the route have two lanes only and sections along Kingsway and Empire Road have more lanes. It is characterised by severe congestion during the peak period, particularly in the northern section (from Perth Road northwards) where car use is significantly higher. The average off-peak travel time northbound and southbound is 34 minutes, increasing to 52 minutes in the morning peak period (northbound), and 40 minutes southbound in the afternoon peak period.

Bus volumes are currently relatively low, ranging between 0.9% and 1.6% of total traffic. In the southern section, taxis make up a significant percentage of total traffic (between 38% and 42%), but reduce rapidly after Main Road (between 6.6% and 6.9%). However, converting vehicle trips to person trips, it is estimated that between 85% and 90% of trips are on public transport in the southern section, and in the northern section between 55% and 65%, somewhat less as a result of much higher car use, but still a significant percentage of all trips. The importance of providing public transport priority along this specific corridor is clear.

It was estimated that approximately 28 000 public transport trips are likely to take place on the corridor in the 3-hour peak period, with bus volumes of up to 140 vehicles and taxi volumes of up to 690 on the busiest sections in the peak hour as per the City's bus rationalisation plan and operating licensing strategy.

3. TRAFFIC STUDY APPROACH

The traffic study focussed on the development of a micro-simulation model of the corridor, primarily because conventional assignment packages cannot model the range of public transport priority measures considered. DRACULA was selected because it could interface with the City's existing EMME/2 model and SATURN models and has a sound track record. SATURN (Simulation and Assignment of Traffic to Urban Road Networks) was initially developed at the Institute for Transport Studies, University of Leeds since 1981. With over 300 users worldwide in some 30 countries over all six continents it has been thoroughly tested and applied. The dynamic network micro-simulation model DRACULA (Dynamic Route Assignment Combining User Learning and micro-simulation) has been developed at University of Leeds since 1993. Further developments to the software were made specifically for this project by the Developers in Leeds to better model unique local conditions (such as minibuss taxi operation).

The use of SIDRA for capacity analysis was considered but based on international case studies it was felt that this approach would not take into account the interaction of priority measures on the corridor as a whole, as this would only provide results on individual intersection performance. A SATURN assignment model was first developed to obtain traffic flows in the corridor, for input into the DRACULA micro-simulation model.

Key assumptions agreed with the City before embarking on the study included:

- As far as possible, proposed public transport priority measures should not reduce the current level of service of private vehicles, while an attractive viable alternative to private transport does not yet exist. Therefore existing capacity would not initially be converted to exclusive bus and taxi use.
- Where additional capacity is added, this will be reserved for public transport use only. However added capacity should be adequate for future public transport services, but need not be sufficient to maintain the current level of service of private vehicles up to the design year. In other words, private motorists should not initially be disadvantaged, but additional capacity will not cater for future private traffic volumes. Therefore, as private vehicle growth continues to increase, so will congestion and resultant delay to private vehicles, in effect providing an incentive to change to public transport.
- All public transport priority measures should also work in the interim, while the proposed SPTN services may not yet be operational as envisaged in the ITP.

In conventional modelling assignments, a few alternative scenarios are usually selected prior to the commencement of the study, and these are then modelled to determine the

differences in performance of the Alternative tested and the Base Year. However the sheer size of the model (77 intersections) and the infinite number of combinations in the type of public transport priority measures applicable and the locations where they could be applied made it impossible to select a few pre-determined alternative scenarios and model these one at a time.

The approach was therefore to incrementally and iteratively develop an improved public transport priority network. The development of this scenario started with the identification of the most severe bottlenecks, and testing the effectiveness of alternative solutions by observing the animation and analysing the modelled 'before' and 'after' corridor travel times. If the proposal was deemed to be effective, the next most severe bottleneck was dealt with. If not, (increasing delays or causing excessive disruption) further alternatives were tested. After addressing the most severe bottlenecks, the development continued by assessing other identified delay points, generally proceeding from south to north. However, if a change in the south was observed to increase delays on a section further north, these were first addressed before proceeding to the next intersection.

Although the measures proposed were modelled on a 'trial and error' basis, a qualitative analysis of the proposed measure was carried out prior to testing the proposal using the existing traffic patterns and turning movement volumes to determine the applicability and or likely impact. In some instances, a quick SIDRA run was used to first determine whether a proposed change would significantly reduce capacity.

4. DATA COLLECTION

The existing intersection layouts have been obtained from the aerial photography, while signal timing information was obtained from the Johannesburg Roads Agency, in both instances supplemented by information gathered on site. Car observer surveys were carried out during the morning-, afternoon- and off-peak, using a GPS receiver to record trip logs from which average travel times to specific intersections are then extracted. This information was used to identify existing bottlenecks where efforts to provide public transport priority measures should be focussed. In addition, the information was also used to calibrate the base year DRACULA model. Traffic counts were carried out during May 2004 at 29 locations while recent historic counts were sourced for a further 7 intersections.

To assess existing and future public transport demand, information in the ITP on historic mode share was studied, use was made of the 2002 Gautrans Household Survey's origin-destination data, the traffic volumes were analysed and existing bus and taxi routes coinciding with the route or crossing it were assessed using information in the CoJ's EMME/2 transportation model. Future bus and taxi volumes were determined from the City's Bus Rationalisation Plan and Operating Licensing Strategy.

The location of bus and major taxi stops was recorded during site visits, supplemented by information on the aerial photographs. Meetings were also held with Bus Operators to determine the stopping location of buses and transfer patterns of passengers on the route.

Two private vehicle growth scenarios were modelled: medium (annual growth in private vehicle trips of 2.5% per annum over 10 years), and higher growth (4% p.a).

5. DEVELOPMENT OF SATURN AND DRACULA MODELS

5.1 Overview of SATURN and DRACULA

SATURN is primarily a traffic assignment model. There are two general inputs:

- the network, which specifies the physical structure of the roads upon which trips take place (supply inputs) and
- the trip matrix which specifies the number of trips from each zone to each other zone in the study area during the time period modelled (demand inputs).

Both the matrix and network are input to a “route choice” model which allocates trips to “routes” through the network, as a result of which total flow along links in the network may be summed and the output can then be used as input into the DRACULA model.

DRACULA is a micro-simulation of the movement of vehicles through the network (pre-specified, using SATURN output). Drivers follow their pre-determined routes and en-route encounter signals, queues and interact with other vehicles on the road. Vehicles move in real-time and their space-time trajectories are determined by car-following and lane-changing models and network controls such as signals. The model includes an animated graphical display of vehicle movements in the network. To our knowledge, this was the first time DRACULA was used in South Africa. Micro simulation models have been in use in South Africa for some time but it is believed that very limited work has been done in modelling public transport in any detail.

5.2 Model Validation and Calibration

Network validation consists of checking of the coded network data. Site inspections were carried out periodically and the aerial photography was used extensively to verify that all intersection data in the current network has been realistically coded.

The matrix was developed iteratively using SATME/2, SATURN's matrix estimation module. As the model's intended use is to generate flows for use as input into the DRACULA model, which simulates behaviour of junctions, it is important that the modelled flows are correct. In the absence of an origin-destination matrix for the corridor, it was not possible to use this as the basis for the matrix estimation, and it is therefore possible (and likely) that some of the flows are made up of the wrong i-j movements (i.e. too many vehicles from a certain origin and not enough from another and vice versa).

However, as the model represents a corridor, and not a network, by design it will not re-assign trips to alternative routes, and the correct i-j movements, which is important when re-assignment is considered in a network model, are therefore not that relevant. In addition, the primary focus of the model is public transport, which is coded separately from the private vehicle trip matrix. For this reason, it is possible to manually adjust the matrix to present flows that are very near to the counts.

Traffic Flow Validation was carried out using the least squares regression equations and their associated R-squared (R^2) statistic and by plotting scatterplots comparing modelled to observed flows. The base year model's $R^2 = 0.97$, which is an extremely good fit (a perfect fit would give an R^2 of 1.0). The good fit is partially due to the manual adjustment of flows (in the matrix) to purposefully match the counted volumes, as discussed above.

The *GEH statistic* compares the absolute and relative difference between modelled flow ($V1$) and observed flow ($V2$), and is defined as the square root of the product of the

absolute difference, $V_2 - V_1$, and the relative difference, $(V_2 - V_1) / V_{BAR}$ where the “average flow” $V_{BAR} = 0.5 * (V_1 + V_2)$:

$$GEH = \sqrt{(V_2 - V_1)^2 / (0.5(V_1 + V_2))} \quad (1)$$

This statistic is used because of the inability of either the absolute difference or the relative difference to cope over a wide range of flows. For example an absolute difference of 100 pcu/h may be considered a big difference if the flows are of the order of 100 pcu/h, but would be unimportant for flows of the order of several thousand pcu/h. Equally a 10% error in 100 pcu/h would not be important, whereas a 10% error in, say, 3000 pcu/h might mean the difference between building an extra lane or not. The GEH parameter is less sensitive to such problems since an error of 20 in 100 would be roughly as bad as an error of 90 in 2,000, and both would have a GEH statistic of, roughly, 2. As a rule of thumb in comparing assigned volumes with observed volumes a GEH parameter of 5 or less would indicate an acceptable fit, while links with GEH parameters greater than 10 would probably require closer attention.

In the absence of South African guidelines, the UK Department of Transport validation guidelines, indicated in **Table 1**, were used.

Table 1: UK Department of Transport Validation Guidelines

More than 85% of flows to satisfy the following:		Validation Achieved:
For Counts:	Modelled flows within:	
< 700 vph	100 vph	93%
> 700 but < 2700 vph	15%	95%
>2700 vph	400 vph	100%
GEH statistic < 5		80%

Although 20% of counts have a GEH statistic greater than 5, only 4% are greater than 10. These have been considered individually and are not deemed to detract from the overall accuracy of the model, which has an average GEH of 2.9, indicating a good network wide validation.

Observed and modelled cumulative travel times were also plotted and compared to estimate how well the model is estimating travel time (as opposed to pure flows). The modelled travel times passed the UK Department of Transport criteria (times within 15% or one minute if higher) and indicated a good fit.

A graphical animation of the vehicles’ movements is also shown in parallel with the simulation, giving a direct view of the traffic condition on the network. In addition to the validation of modelled flows and travel times, this shows graphically whether the traffic behaves as observed in the field.

As the base year model is deemed to behave largely as observed, it was concluded that the model reflected reality sufficiently for the purpose it was developed for and the final base year AM network was therefore copied and modified to reflect the proposed network changes to test future scenarios.

5.3 Alternative Scenarios Modelled

Four Scenarios were modelled, numbered 0 to 4 in **Table 2**. For each Scenario, three sub-scenarios were tested, namely current-, medium growth- and high growth private vehicle volumes, the latter two numbered X.1 and X.2

Table 2: Matrix of Alternative Scenarios Modelled

			Network		
Traffic	Public Transport Service Design	Private Traffic	Base Year	Full Public Transport Priority	Base Year +Signal Upgrades Only
		Existing Services	Current	0	1
Medium Growth			0.1	1.1	
High Growth			0.2	1.2	
Future SPTN Services		Current		2	3
		Medium Growth		2.1	3.1
		High Growth		2.2	3.2

- **Scenario 0** is the Base Year Model (do nothing Scenario), and models the existing network and the existing public transport services.
- **Scenario 1** models the existing services on the future improved public transport priority network. This is modelled to ensure that the proposals also work in the interim while the ITP's SPTN services are not yet operational.
- **Scenario 2** models the future SPTN services on the future improved public transport priority network (the 10 year design horizon)
- **Scenario 3** was modelled to determine how the corridor might operate in future should the SPTN services be implemented but no upgrades to infrastructure are done (for example as a result of no funds being available). Do minimum upgrades such as signalisation of key intersections and optimisation of traffic signals was however carried out, similar to what was done in the improved network.

6. DRACULA MODEL RESULTS

The effectiveness of various public transport priority measures and the impact of public transport priority measures on the operation of the corridor (including the effect on non-public transport traffic), were quantified through:

- Observation of the simulation animation
- Analysis of the corridor travel time (average and per vehicle type)
- Analysis of overall network performance measures.

Observation of the simulation animation provides an instant answer to the effectiveness of any proposed measure, for instance if a queue bypass lane is modelled, the simulation will indicate private vehicles blocking back past the beginning of the lane if it is too short.

By comparing the modelled corridor travel times with and without the proposed solutions, the effectiveness in reducing corridor travel time could be determined. In many cases, proposals reduced local delay where they were implemented, but because of the increased capacity, the bottleneck merely shifted to downstream intersections, resulting in even bigger delays.

As a measure of network performance, the simulation outputs network, link and route specific measures such as average travel time, speed, queue length, fuel consumption and pollutant emission. An increase in network travel time (in vehicle hours), while corridor travel time reduced, would indicate that delays to traffic crossing the corridor has been increased.

The following trends were identified from the results:

1. In the base year (status quo), the travel time of bus and taxi is longer than that of car, as would be expected with the additional time spent stopping to load and off-load passengers (dwell time)
2. Comparing Scenarios 0.1 and 0.2 to Scenario 1, overall travel time increases roughly at the same rate as the increase in private traffic. For the medium and high growth Scenarios, travel time northbound increases to 73 minutes and 81 minutes respectively (currently 54 minutes). Bus and taxi travel times remain higher than car travel times.
3. In Scenario 1, which models upgrades to the network to provide public transport priority, without any changes to the existing traffic, an overall reduction in corridor travel time of 22% is achieved (41 minutes). Bus and taxi travel time savings, at 24% and 29% respectively, are more than that of cars, indicating that the proposed public transport priority measures would be effective. Bus and taxi travel time is not less than that of cars in this Scenario, but it should be kept in mind that cars will initially also benefit from the improved capacity created by the road upgrading. Bus and taxi travel time further also includes dwell time, and the fact that their travel time is still similar to that of car despite this indicates a significant improvement.
4. In Scenario 1.1, which models the upgraded corridor with medium private vehicle growth, the effect of increasing congestion can be seen. In this scenario, private vehicle travel time is the same as what it is currently, but Bus and Taxi travel time (49 and 46 minutes respectively) is still much better than what it is currently (and public transport is now faster than car travel).
5. The trend in the results of Scenario 1.2 (the same as Scenario 1.1 but with high private vehicle growth instead of medium growth) is similar to that of Scenario 1.1. The travel time by car is however slightly higher (60 minutes), while bus and taxi travel times are also somewhat higher (55 and 52 minutes) but is still less than what it is currently.
6. Scenario 2 models the upgraded corridor, but instead of the existing public transport services, the future SPTN services are modelled. In this scenario, all modes also experience an improvement in travel times but this is less significant than that of Scenario 1. The reason is that much higher public transport volumes now operate on the corridor. For instance, if the ITP's public transport volumes are used, the section between Main Reef and Main/University Road will experience an increase of more than 500 additional public transport vehicles in the peak hour, mainly taxis.
7. Scenario 2.1 models the same conditions as Scenario 2 except at a future date – with medium private car growth. Travel time of bus and taxi (52 and 51 minutes) are still some 9% and 11% better respectively than what it is currently, while car travel time has increased slightly (55 minutes).
8. In Scenario 2.2, which is a continuation of Scenario 2 but with high growth instead of medium growth in private car volumes, the travel times are now worse than what it is currently for all vehicle types. For cars, it is significantly more (21%), while bus and taxi travel times are more or less back to where they are now (-1% and +1% respectively). This is an indication that the priority measures, as modelled, are reaching their capacity. Priority measures would likely need to be extended (by adding additional capacity, which could take the form of converting existing capacity to exclusive public transport use) or alternatively by reducing the number of public transport vehicles (using bigger vehicles).

9. Scenario 3 was modelled to determine how the corridor would cope with the new travel patterns proposed by the ITP if no investment in new infrastructure is made, for instance due to a lack of funding. With the current private vehicle traffic, car travel time increases by 8% while bus and taxi travel time increases by 20% and 14% respectively. Clearly the higher number of public transport vehicles (see trend 6 and 8 above for reasons) will increase congestion impacting on all road users but it is public transport that will lose the most.
10. Scenario 3.1 and 3.2 is a continuation of Scenario 3 but added more private vehicles to the corridor (medium and high growth respectively). In these scenarios, the modelled corridor travel time increases to 116 minutes and 124 minutes respectively, in the order of two hours of travel time or more than double what it is currently. It is unlikely that this scenario will materialise as modelled. In practice, congestion will become so untenable that motorists will find alternative routes with shorter travel times and or peak spreading will take place. However the conclusion that travel times will increase drastically should current trends in traffic growth continue, while no investment is made in infrastructure, remains.
11. From the cumulative travel time results a number of problem areas have been identified from the scenarios where no or minimal improvements were made to the corridor. All of the above problem areas have improved in both Scenarios 1 and 2 as a result of the proposed improvements to the corridor. In Scenarios 1.1, 1.2, 2.1 and 2.2 however the problem in the northern highly congested section emerge again as a result of spare capacity having been outgrown by the growth in traffic. However as a result of the public transport priority measures in place, the problem does not affect public transport as much but instead increases car travel time (now higher than bus or taxi travel time).
12. The network performance indicators shows that the improvements in travel time on the corridor did not come at the expense of the traffic not travelling on the corridor (travelling perpendicular to the corridor). The overall network speed improved in both Scenarios 1 and 2.

7. CONCLUSIONS

The development of the model took much longer than originally anticipated due to its complexity and sheer size. As it is a micro simulation model, it follows that the data requirements are naturally more intensive than a conventional assignment model and because of the greater number of variables the accuracy of such models tends to be questioned.

However, it is believed that

- Micro simulation was the right approach
- DRACULA has proven suitable and where necessary customised changes were made by the developers specifically for this project
- Much of the development work was done to ensure that the model was calibrated and validated to a high degree and adequately for the purpose it was developed for

The main advantages of Micro-simulation can be summarised as follows:

- Because a whole corridor approach was taken, proposed upgrades were not considered in isolation. Any changes in one place on the corridor is bound to have an impact upstream or downstream which may not have been taken into account otherwise

- It is believed that a minimum cost scenario to adequately cater for the forecasted traffic has been developed, as the modelled improvements seem to reach capacity at the end of the design period.
- Now that the development of the model is complete, it is a fairly simple matter to test further scenarios, for instance the performance of the corridor should high volume taxi services, which contributes to congestion in the corridor, be replaced by bus services which will require less vehicles.
- The graphic animation makes it easy to visualise the impact of proposed changes and can also be used as a communication tool with less technical audiences as it is easy to understand.
- It is believed that the approach followed can be used on subsequent implementation phases, with minimal change. Valuable lessons have been learned during this phase which can be applied to the next stage and that should save both time and cost. However the development of a model of this magnitude does take time and it is therefore important to allow adequate time for this activity in the planning phases.

The results of the model confirm the following:

- The proposed upgrades result in a marked improvement in public transport travel time in the corridor, without negatively impacting on other users. This improvement applies to all road users initially but as private traffic increases, the travel time of car users increase steadily and in future will exceed that of public transport, providing an incentive to switch to public transport
- The proposals accommodate current public transport operations as well as future public transport operations and the fact that the priority measures seem to reach their capacity with the higher growth rates in traffic volumes confirms that it is likely to be the minimum upgrades required.
- The proposed SPTN public transport operations is unlikely to achieve the ITP's objectives of providing an attractive alternative for car use if the recommended investment in infrastructure is not made. A commitment to provide funding for this purpose is paramount if the project is to succeed.

The City's vision of creating a permanent, legible and recognizable public transport system is ambitious and comes with significant challenges. Not only will the City need to obtain sufficient funds for infrastructure to implement the proposed public transport priority measures, but it also have to drive the advancement of the softer issues, most notably the alignment of public transport services with that envisaged in the ITP. The challenge for 2010 is to maintain the drive, and the urgency of the City to implement the first part of the flagship phase demonstrates commitment to make the vision a reality.

8. REFERENCES

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