

AN INVESTIGATION INTO THE PERFORMANCE OF FULL BRT AND PARTIAL BUS PRIORITY STRATEGIES AT INTERSECTIONS BY MICRO-SIMULATION MODELLING IN A SOUTH AFRICAN CONTEXT

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ABSTRACT

Rapid urbanisation is a global problem affecting most developing countries. Current statistics indicate that South Africa's urban population is set to double by 2030. Urban infrastructure expansion generally lags behind this exponential growth, especially in African countries. This reality calls for smart responses, implying that current resources need to be used more efficiently, catering for the needs of the ever increasing urban population. Smart Transport is an innovative response to the urgent mobility and accessibility needs of urban inhabitants. One such strategy is Bus Rapid Transit (BRT) System.

Research into High Level of Service Bus (HLSB) systems, such as BRT has shown that they can successfully improve urban mobility, while simultaneously reducing congestion, energy consumption vehicular emissions and increase transit efficiencies. However, the relatively high capital and operating costs of full specification BRT are prohibitive to many local authorities.

In the long term, BRT has been selected as the preferred model for mass urban transit by the South African government. To optimise service delivery, an opportunity exists to identify alternative ways to implement HLSB. Hence, the following fundamental question is investigated this paper: *Is it possible to reap the benefits of a full specification BRT system at a lower cost by tactical implementation of Bus Priority Schemes at strategic locations along transit routes?* Through the application of micro-simulation software, a number of suitable transit priority schemes are modelled for a proposed transit corridor in Cape Town. Preliminary outputs indicate that applying transit priority, such as Bus Signal Priority can produce Level of Services (LOS), which are comparable to full specification BRT Systems.

Introduction

Public transportation is undergoing a process of transformation in most of South African major cities and urban centers. This transformation is a move towards improving the quality of public transport (PT) supply. The public transport modes currently operate in an environment of increasing urban demand for mobility, limited financial resources and need for economic growth and accessibility to opportunity.

South Africa's urban areas faced with the effects of rapid urbanisation, inadequate municipal infra-structure and the historical legacy of racially segregated urban planning of the apartheid era. However, the government has recognised the urgency of this dire situation as shown in the recent legislation .i.e. the NLTA of 2009 and Public Transport Strategy 2007-2020 which currently inform the provision of public transport in South Africa.

According to the provisions of the (PTS 2007-2020), Integrated Rapid Public Transport Networks (IRPTN) will form the basis of the "new wave" of public transport. Furthermore, Bus Rapid Transit (BRT) which is type of enhanced services; are to form the basis these networks. These provisions reflect the design objectives of model full specification BRT systems in Curitiba, Brazil and particularly Bogota, Colombia. According to the BRT Guide (2007); BRT is defined as a high quality bus based transport system that uses segregated right-of way infra-structure ,strong branding ,frequent and rapid operations to deliver fast, comfortable and cost-effective urban mobility(Wright & Hook, 2007).

In response to these developmental challenges and bringing municipalities in alignment with legislative requirement, Municipal Authorities (MAs) such as the City of Cape Town (CoCT) have initiated the public transport projects to address to these adequacies. The phased roll-out of full specification Bus Rapid Transit (BRT) systems in Johannesburg, Cape Town, Durban, Rustenburg and Tshwane represents active steps the government's vision of public transport in to create liveable cities and improve mobility.

Full specification BRT systems are relatively more expensive than other manifestations of Bus with High Level of Service (BHLS).In addition to local socio-economic context, network density .i.e. station spacing; literature indicates that the level of segregation and priority achieved are one of the key drivers of the total cost of such systems. Bus Rapid Transit (BRT) is defined as a high quality bus based transit system delivers, fast, comfortable and cost effective urban mobility by using segregated right of way (RoW) infra-structure. As Figure 1.1 illustrates the fact that most expensive component of a full specification BRT is its physical segregation or RoW infra-structure .i.e. road works and civil relating to BRT RoW command as much as 51 % of project costs.

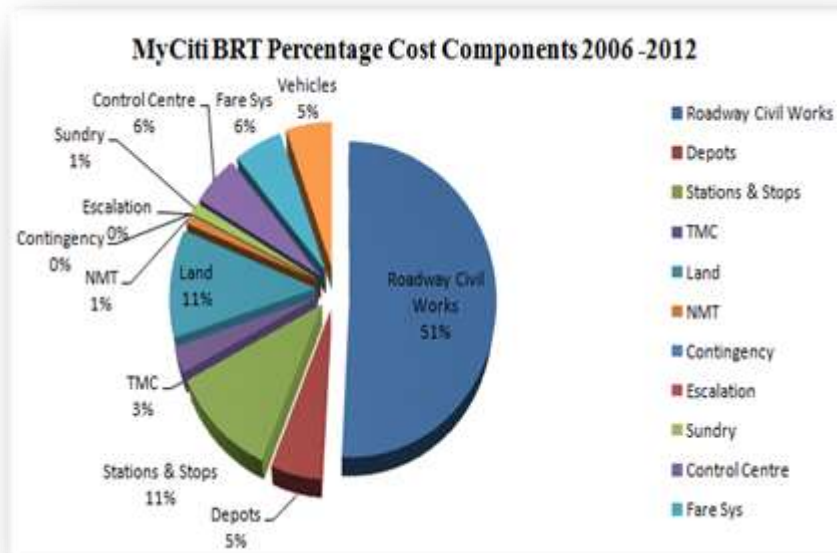


Figure 2-1 Cost Components of Typical South African BRT System

It is clear from Figure 1.1, that an opportunity exists to find alternative ways of extracting the service level benefits of building strong priority measures such as dedicated bus lanes (DBLs) that typify full spec BRT systems at lower cost. This despite the documented fact the BRT is cheaper than other mass public transit modes such as rail or metro; it has been shown that most MAs in South Africa and developing countries cannot actually sustain BRT operations and construction without state subsidy.

There exists alternative set of methods to improve the *speed, reliability* and *capacity* of bus services through partial priority measures. An example of the most commonly used partial bus priority schemes is Bus Signal Priority mechanisms and related traffic engineering methods which are less reliant on relatively costly dedicated bus RoW or lanes. These traffic interventions to improve the LOS of PT modes present a less expensive and faster time horizons of implementations.

The harsh reality remains that the majority of South Africans do not have access to a private vehicle and depend mostly on the Mini-Bus Taxi (MBT) for their transport needs. There are other PT modes such as trains and buses but they exhibit the fundamental flaws of delays, poor facilities, unreliable services which are endemic to public transport modes in South Africa. This gives further impetus to addressing this socio-economic imbalance in a cost effective manner.

This paper will use micro-simulation to evaluate objectively the difference in performance between full bus rapid transit priority measures and partial priority measures. Furthermore, it will seek to quantify the impacts on non-priority traffic and the time and benefits of each type of scheme. To this effect it seeks to answer the basic question: *Is it possible to extract the traffic related LOS (operating speed and travel time) improvements offered by strong bus priority measure like full specification BRT by implementing partial priority schemes at strategic location along PT corridors?*

Literature Review

There is a considerable amount of literature in the field of transit priority measures and traffic micro-simulation. Though most of this literature ; emerges from international sources and contexts .i.e. the benefits and LOS improvement related to implementing different degrees of public transit priority in South Africa has not been well quantified in the public domain or documented in widely accessible academic publications.

A review of literature reveals mainly two main schools of thought with regard to increasing bus transit reliability and capacity. The first being the advocates of full specification BRT systems which typically include public transport(PT) priority schemes such as dedicated bus lanes(DBL) along bus routes ; the ITDP and the World Resources Institute(WRI) through its EMBARQ program ,who are among the established promoters of this model(Hidalgo & Carrigan 2010)(Lloyd Wright : Walter Hook 2007).The second school of thought suggest an alternative approach to improving bus performance .Recent research has shown that the implementation alternative PT priority schemes like Bus Signal Priority(BSP) on their own can achieve similar or greater reductions in bus delay and travel times especially at intersections(Barker et al., 2003)(Skabardonis & Christofa 2011)(Kim et al. 2012).(Dion, Rakha, Asce, & Zhang, 2004).In recent presentation Salvucci(2014) of MIT states the following:

“More traditional bus services, and modestly improved bus services, continue to be essential in corridors with narrow street widths, and modest existing land use densities. These are usually essential to any goal of offering access to the entire metropolitan area, and should not be designated as “BRT Lite” and “Not True BRT”

These contradictory findings raises questions about the necessity of implementing full specification BRT in South Africa while it may be possible to extract similar benefits by employing partial bus priority measures at strategic locations along the BRT corridors. Since BSP and related measures that deviate from the dedicated bus lane (DBL) BRT model of PT priority; they are relatively cheaper and flexible they have the ability to substantially reduce capital and operational expense of municipal authorities (MAs) on BRT projects.

In order to predict to the expected performance of Intelligent Transport Systems (ITS) and physical upgrades on urban arterials, a number methods can used. As an example, Hensher (2008) makes a comparison between alternative transit priority mechanisms entirely on a financial basis. Additionally, a broad range of evaluation approaches are were noted in literature from numerical, financial and computer based simulation (Hensher & Golob, 2008).The method selected is dependant firstly on the public transport system parameters of interest and available data. In this academic study case micro-simulation because allows the vehicle-to-vehicle and vehicle-to-infrastructure interaction to be captured accurately. This means that changes in driver behaviour and vehicle performance in relation to modifications in road geometry and signal operations can be modelled and recorded.

A number of extensive studies in the North and Latin America and Western Europe ;relating to operational performance of BRT,TSP and more novel approaches to bus priority such as intermittent bus lanes published from as early as the 1970s (Evans and Skiles 1970).As Dion *et al*(2004) report the benefits transit priority is substantial with but location specific. This means that generally prescribed parameters like operating bus speed, delay and travel times have been shown to be improved by Transit Priority but these effects have to be evaluated carefully .i.e. the location's context and impact on other forms of traffic.

Based on the above, there is a need to quantify and explore the benefits of the alternative public transit schemes on South Africa urban transport corridors , which are characterised by limited road reserves .i.e. corridor wide road widening is not feasible. This means decision-makers and stakeholders can be more aware of the generally expected operational improvements that each alternative offers under South African conditions. Thus, this will allow for locally appropriate or adjusted public transport improvements rather than a “one size fits all” .i.e. highly prescriptive approaches such the Bus Rapid Transit Guide (2007).

- **Methodology**

The micro-simulation of traffic modelling was used to simulate the interaction of public transit modes and general traffic along the case study corridors. A commercial software package called Quadstone PARAMICS® was used to execute this step of the investigation. The primary objective of the process was to implement a working base model which could then be modified to simulate possible priority schemes

1.1 Key Steps of Study

Below are the main steps followed to develop the traffic model and generate the results that were consequently analysed.

1. Data Collection and Area Reconnaissance: four types of data were collected these are the intersection traffic counts ,traffic signal timings ,peak travel speed and travel times along corridors. Due to limitations in resources traffic signal times and counts were only conducted at 3 critical locations. The locations and technology used to collect the specific data type are summarised in the Table below:

Location(Intersections)	Data Type	Technology
Klipfontein + Jan Smut Road	Traffic Count Signal Timings	Manual Counts Video Camera
Lansdowne + Jan Smuts Road	Signal Timings	Video Camera
Duinesfontein + Lansdowne Road	Signal Timings	Video Camera

The video data obtained was further analysed to determine the exact phase allocation for movement more accurately. Furthermore, a set of loop counts was obtained from the Traffic Management Centre located in Goodwood, Cape Town. The loop counts consisted of data from 2007, 2010 and 2012 for some different road segments .i.e. erratic due to faulty or vandalised loops. The average travel speeds and travel time times were determined by driving along the corridor during the peak interval 7h00 to 9h00 on two different days (Tuesday and Thursday) of the same week.

- 2. Road Network Coding:** This step was executed with the use of Google Maps .A scaled background image was generated using *Google Earth*; this was to ensure that the distances used by the simulation calculations were correct. Based on the test measurements the mapped features was correct to within 1m .The network model features relevant to the investigation were drawn using the Designer Module of Paramics .i.e. selected links ,traffic signals and bus stops.
- 3. Input of Data into Model:** the collected data such as signal timings were input directly used the signal control module of the software. However, the traffic counts and loop data were used to create an O-D matrix that reflected the real world situation. Given, that no known micro-simulation study this detail has been done on the corridor, there was no external point of reference apart from iterative validation with available data.
- 4. Simulation Model Testing:** In this stage, the model was tested by running it used the default setting .i.e. no randomisation implemented the (default seed #6) was used. The aim of this step was ensure that the network components and behaviour was realistic and identify serious errors such as unconnected links and blocked intersections(signal timings all set to red).A few errors were identified and rectified
- 5. Network Audit and Calibrations:** parameters such as vehicle mixes (modal splits) were adjusted to reflect the latest available data from the CoCT. Further, runs were completed to refine the O-D matrix especially with regard to link volumes and mean speed. The validation process was based primarily on the loop data and field observations of link speeds which had provided modal split and volume for a given segments along Klipfontein and Lansdowne Roads. It was the relatively more reliable and hence the O-D matrix was adjusted until the model outputs flows were within an average of 20% deviation from the observed data (loop counts). Calibration is often the same as validation process. A strict calibration is not possible because of difference in level of detail in available information(Wu, Brackstone, & McDonald, 2003). The validation was done by comparing the road segments under consideration with corresponding loop section count.

1.2 Micro-simulation Modelling

The evaluation of literature and consultation with transport professionals helped the author propose five key scenarios including a baseline scenario partly based on 2012/13 traffic data.

The results were generated from the five (5) main scenarios .The processor module of PARAMICS was used to allow for multiple runs to be executed in faster time. A set of 50 runs were carried out per scenario and each scenario was from a randomly generated seeds .i.e. to simulate the intrinsic variability in inter-day traffic flows .These results were then averaged from all 50 runs per scenario and then prepared for analysis. As Figure 3-1 illustrates the traffic operations and infra-structure in the study area were modelled input accurately.



Figure 2-2 a screenshot of an intersection geometry as coded into the model

The main real world components of the transport system that were inputs and simulated are the: Traffic conditions, Geometric considerations, Transit Operations and Signal Operations. The traffic conditions observed such as vehicles flows were focused on the peak period 7h00 and 8h00 with an allowance for a 5 minute warm-up period. The transit operations were modelled at 10 minute frequency and an assumption of all stop service which is reasonable based on information obtained from Golden Arrow Bus Services (GABS) along the Klipfontein Road corridor.

1.3 Background

The study area selected is located in the Cape Town Metropolitan Area. The main reasons it was selected are listed below:

- The *two main arterials* being investigated currently experience high levels of congestion .i.e. some sections are jammed during peak hour. This situation was a common place in many of South Africa's urban areas but dynamics of operating enhanced or ordinary bus services under such conditions have not fully understood.
- The Klipfontein and Lansdowne Road Corridors are earmarked for to be an integral part of the continued expansion of the CoCT's IRPTN, as Fig 3-2 below shows they fall under proposed *Phase 2* of implementation. At time of publication, the CoCT was initiating Phase 1B after which Phase 2 is expected to follow.



Figure 2-3 the Different Phases of MyCiti (Cape Town's IRPTN) Implementation

It is noted that the study area is been subject to a number interventions to improve performance of public transport modes particularly exiting bus services. These measures include marking of bus lanes. However, observations during site visits to area by the author revealed that most of measures were visibly ineffective, as motorist do not comply with them.

- The area has relatively high travel demand given the settlement patterns and prevailing level of service observed.
- There is limited space in most corridor sections for widening of roads to accommodate conventional full specification BRT (especially median lane placement) and to build extra lanes.

The Table 1 "Summary of Study Area Statistics" below gives a summary of the some important characteristics of the study area:

Table 1 Summary of Study Area Statistics

Feature / Characteristic	Quantity / Size
Geographical Footprint	24.1 km ²
Population Density	1500 -1700 p/km ²
Road Length	Klipfontein : 9.2 km Lansdowne :7.3 km
Observed Mean Bus Stop spacing	714 m
Number of Main Signalled Intersections	Klipfontein : 11 Lansdowne : 5

The Figure 3-3 below shows a map of the study area and coordinates as extracted from Google maps.

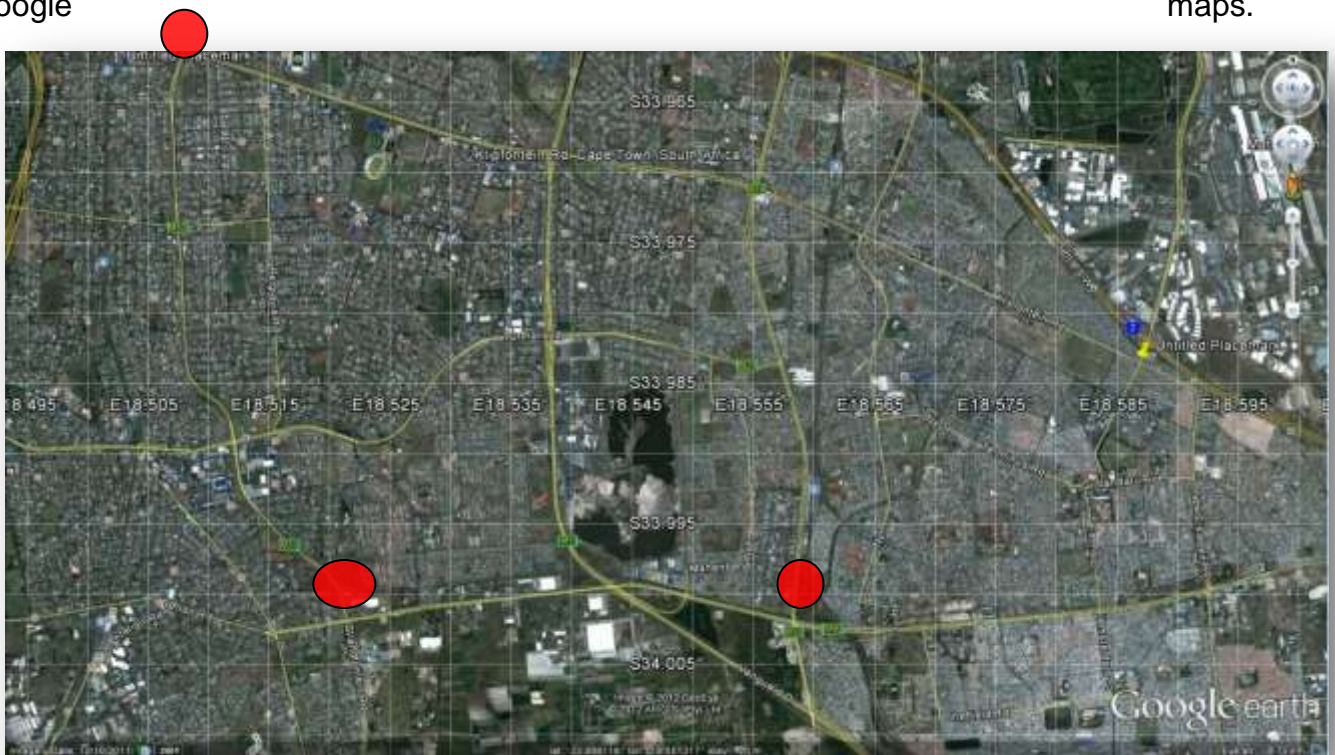


Figure 2-4 A picture of the Study Area highlighting (light yellow) the roads included in the model network and locations of data collection exercises (red) (Google Maps, 2013)

The above map indicates a relatively high dwelling density which substantially increases westwards especially after the E18.555° Longitude (refer to Fig 3-1). This trend is due to the informal settlements and low income townships that the area is composed while the more formal areas have lower density. The Figure 3-4 shows that road network in aerial photo (Figure 3-3 above) as coded into Paramics and scaled to ensure realistic distance related data and travel times.



Figure 2-5 A screenshot of the study area road network as coded into the Paramics Model.

Simulation Results and Analysis

The results of the microsimulation are presented in this section and grouped according to the aforementioned five (5) modelled scenarios. In All the modelled scenarios made the assumption of a mean 60-second dwell time, bus/PT lane, with turn delays, a 10 minute frequency and typical signal timing (except the one bus queue jumper (BQJ) and two BSP scenarios). Furthermore a warm-up period of five minutes was allowed for hence a simulation run-time of 60 minutes was used (excluding the first 5 mins) to mimic the 7h00 – 8h00 AM traffic peak.

1.4 Scenario Analysis

Figure 4-1 the Baseline scenario reflects the current conditions on the corridor particularly .i.e. the general traffic mean speed is reduces exponentially as the traffic volumes increases in the network from reaching a up to 35 km/hr and it remained relatively stable at 7 km/hr(+/- 2km/hr deviation) for the last 30 minutes of the simulation periods. The graph also show the drastic effect of traffic congestion on bus operations in that the general traffic mean speed forms an upper boundary for bus speeds .i.e. bus speeds average 5 km/hr and decline to 3 km/hr during the last 30 minute interval but do not exceed the speed the congested mixed traffic is travelling at .

Figure 2-1 Baseline Scenario Bus Vs General Traffic Speeds

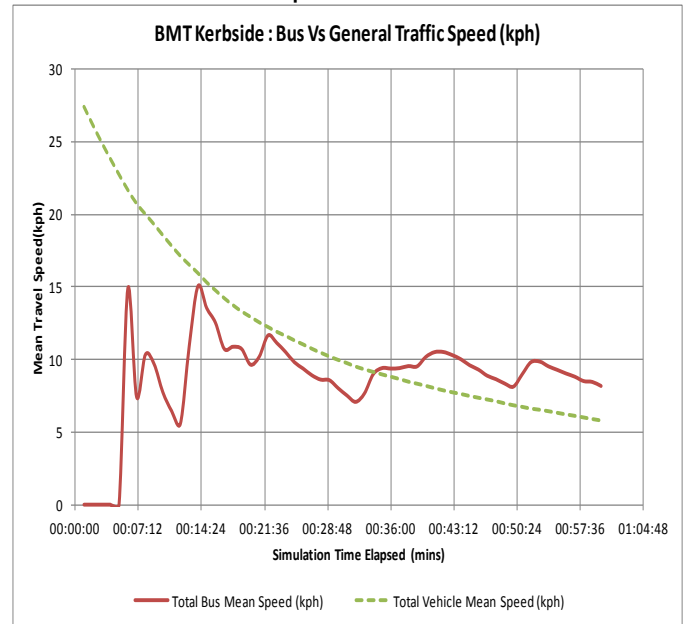
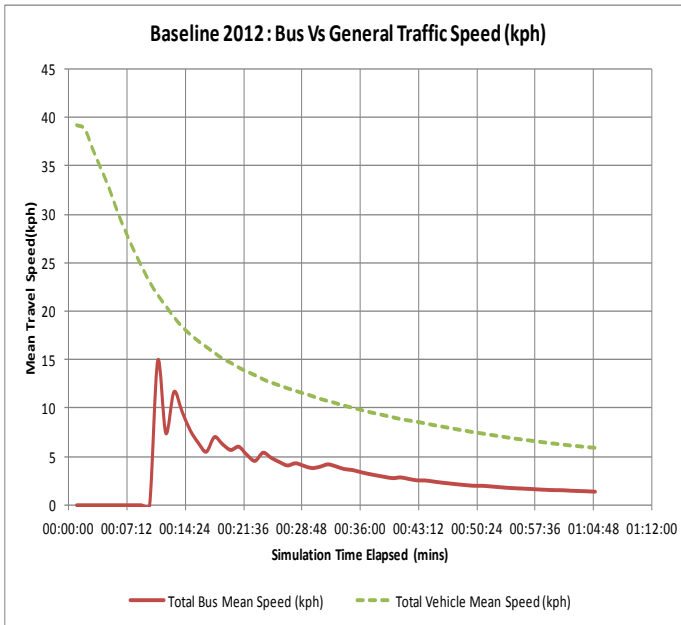


Figure 2-2 BMT Lane Scenario Bus Vs General Traffic Mean Speeds

The Figure 4-2 shows the results after a simulated BMT lane was implemented on the Klipfontein Corridor, the mean operating speed for buses is substantially improved .i.e. with it maintains of mean velocity of above 12 km/hr for the first 30 minute interval though a slight decline to 10 km/hr is observed as network becomes more congested and with and there is higher level of consistency in speed during the time interval. As seen from Figure 4-1 the general traffic speed also reduces exponentially .However due in this scenario buses speeds exceed that of general traffic and are able to maintain a mean velocity of 11 km/hr(+/- 2km/hr deviation) even as in general traffic speed decrease in the second 30 minute interval of the simulated AM peak hour. This observation indicates that the BMT lanes successfully allay public transport modes from hourly peak congestion by allowing them to maintain a consistent operating speed throughout the peak period.

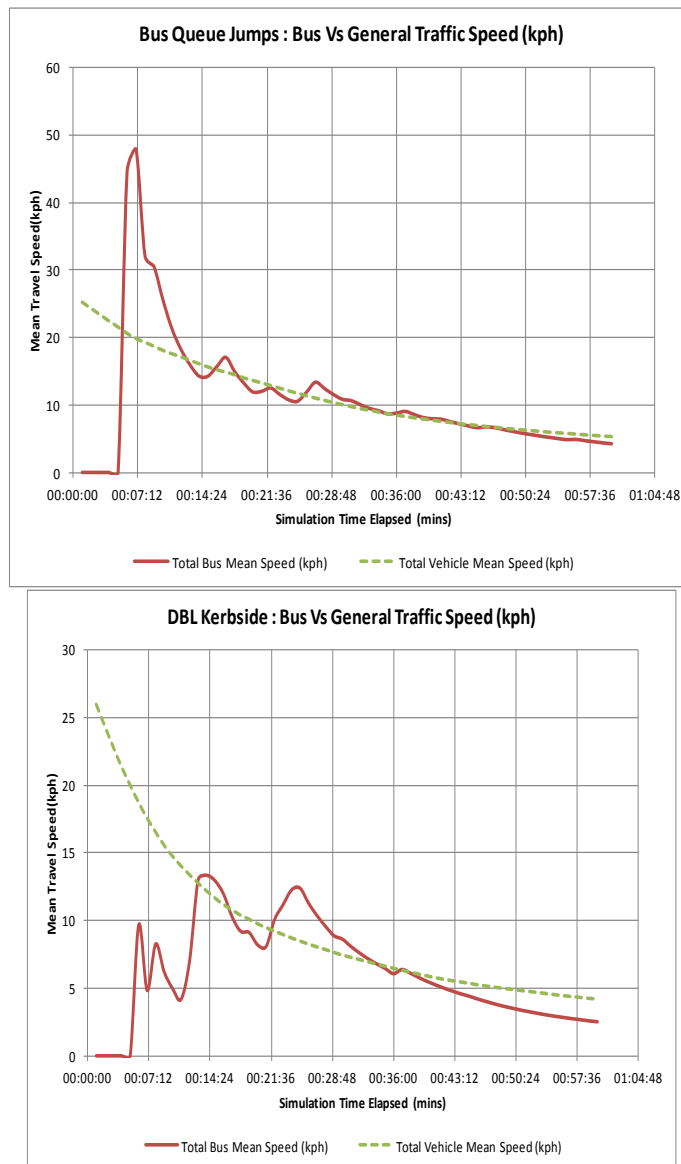


Figure 2-3 BQJ Scenario Bus Vs General Traffic Mean Speeds Figure 2-4 DBL Kerbside Scenario results

In the Figure 4-3 above; geometric changes in the form of bus queue jumps (typical 60 – 100m longs) were implemented at four major intersections along the corridor including Klipfontein-Jan Smuts and Klipfontein-Vanguard Roads. The logic of this priority is based on the observation of long queues (+60metres) at major intersection approaches. However the bus signal priority (BSP) along the queue jumper lanes was only given to buses since the baseline indicates they the most adversely affected transport mode. This was accomplished by setting detector loop size to be 5 m .i.e. can only activated by buses which have typical lengths in excess of 5 meters.

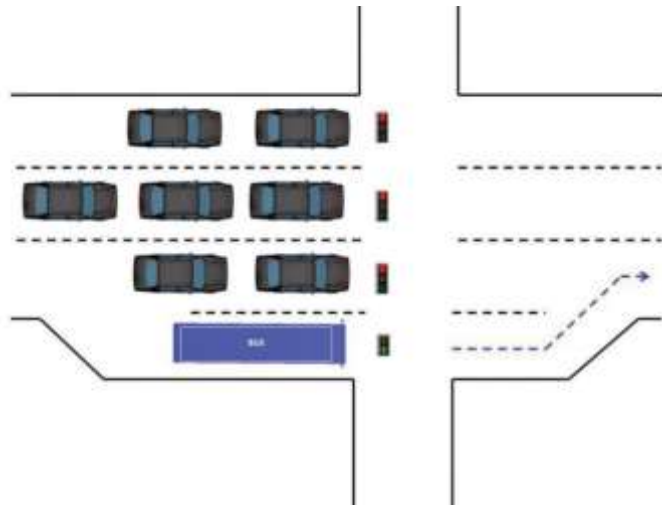


Figure 2-5 Typical Bus Queue Jumper(BQJ) Lane Configuration(Dhruva Lahon, 2011)

The impact of this change is shown that it improves the speed of buses and slightly above that of general traffic. However, both modes mean speeds approach the same equilibrium speed of about 5 km/hr. This is expected due to the cumulative effects of cross-street traffic increases at intersections and congestion along mixed sections of the corridor. i.e. priority is only given at intersection.

The figure 4-4 illustrates the negative effect on general traffic of dedicating a traffic lane to buses. i.e. kerbside DBL (assumed 100% compliance to restriction). The bus speeds continue to show marked improvements consistent with other PT priority scenarios. However, there is greater fluctuation in speed as disruption from turning movements and weaving movement into traffic stream.

The following figure 4-5 show the Dedicated Bus lane with Median placement and Bus signal priority: the results indicate that the buses attained the highest operational speed for under this scenario .i.e. 25 km/hr though this for a short interval but throughout the simulation period it maintain at least 6 km/hr above mean general traffic speed even though it has to make one to two stops per kilometre along the corridor .i.e. average observed bus stop spacing was approximately 714 meters(14 stops on the 10 km segment modelled)

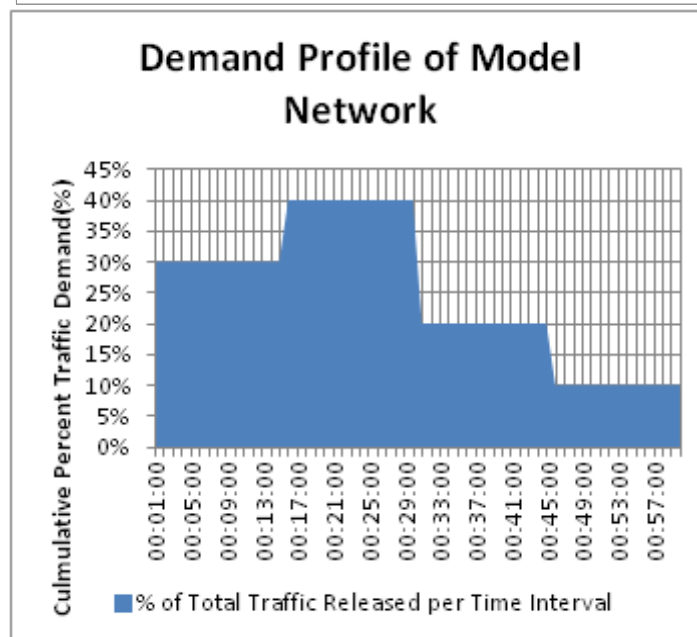
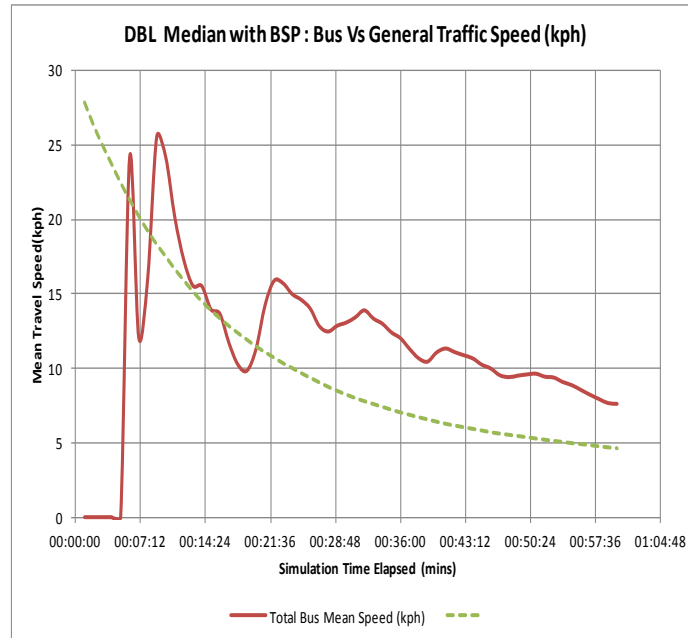


Figure 2-5 DBL Median with BSP Results

Figure 2-6 Peak Hour Demand Profile used in Simulation

Overall the results illustrate that highly congested arterials such as Klipfontein Road can also benefit from alternative bus priority schemes which require less infrastructure and capital such bus queue jumps and bus signal priority. However, the results obtained from simulation need to be further refined in to capture the effect of turning movements, cross traffic phase cycle lengths and bus stop dynamics more accurately. Therefore the results thus far should be viewed conservatively given the very poor traffic conditions .i.e. baseline. However, they provide an indication of the plausible order of magnitude of speed and delay improvement that each modelled priority scheme can attain.

In the case of the DBL scenarios (median and kerbside) ; it was also observed that maximum mean speeds of +20 km/hr achieved for brief periods (5 – 20 mins) during the early part of the simulation are in line with bus operational/commercial speeds best practice as reported in the BRT Standard of 2013(Hook et al., 2013).This implies that further simulation work needs to optimise station dwell times, BSP timings to mitigate the effects of high turning, and cross street traffic volumes or investigate the possibility of re-routing some cross-streets to reduce turning movements across bus lanes to make these consistent throughout the corridor and peak period. The results strongly suggest that these relatively high bus speeds and delay reductions at the cost of negatively impacting the already low peak mean general traffic speeds and movements(+/- 5km/hr).

The focus of this academy study was not to extract exact travel speeds though the outputs (particularly from baseline scenario) are consistent with observed mean peak speeds (+/- 4.0 km/hr) during site visits on the 24th and 25th August 2013.i.e. traffic jam conditions on most segments between 7h30 and 8h00. Conversely it was to obtain the feasible improvements on key bus service performance indicators such as mean speeds (including stop times for boarding and alighting passengers) and travel delay along an urban arterial. This summarised in the Table 2.0 “Summary Table of Net Effect on Mean Speeds per Simulated Scenario” and Table 3.0 “Summary Table of Net Effect on Mean Travel Delay per Simulated Scenario”.

1.5 Summary: Effect of Measures on Public Transport and General Traffic

The values presented in table 2.0 and 3.0 show the net change on respective traffic types namely bus and general traffic. All scenarios were benchmarked against the Baseline 2012 Scenario which represents the Do Nothing case .i.e. improvements in KPIs is shown in green and negative (e.g. reduced mean speed) is shown in red. It can be seen that expectedly the DBL with BSP offers the most benefit in terms of bus speeds and delay; 131 % (increase) and 32% (reduction) respectively but reduces general traffic speed by 11%.

However the results reveal that BMT lanes (80%) and Bus Queue jumps (124%) offer equally substantial improvements in bus speeds over the worst observed peak speeds. Additionally the simulation results show that the aforementioned alternative scenarios can reduce mean bus travel delay by 31% and 27% respectively. This compares well with international studies .i.e. findings of authors such as Lahon(2011) in her microsimulation study of a two 3.2 km urban arterial corridors in the City of Pleasanton(California, USA) ; in which Bus Queue jumps were found to reduce mean bus travel times by 30% especially under higher traffic volumes.

Table 2 Summary Table of Net Effect on Mean Speeds per Simulated Scenario(AM Peak 7h00 -8h00)

Modelled Scenario	Bus /PT Mean Speed(kph)	General Traffic Mean Speed(kph)	Net Change (Vs Base)	
			Bus (%)	Vehicles (%)
Baseline 2012	4.9	11.9		
Bus Mini Bus Taxi Lane(Kerbside)	8.8	12	80%	1%
Bus Queue Jumps	11	11.6	124%	-3%
DBL Kerbside	6.5	9.6	33%	-19%
DBL Median	11.3	10.6	131%	-11%

Table 3 Summary Table of Net Effect on Mean Travel Delay per Simulated Scenario (AM Peak 7h00 -8h00)

Modelled Scenario	Bus /PT Mean Delay(sec)	General Traffic Mean Delay(sec)	Net Change (Vs Base)	
			Bus (%)	Vehicles (%)
Baseline 2012	1295	1295		
Bus Mini Bus Taxi Lane(Kerbside)	890	1266	31%	-2%
Bus Queue Jumps	940	1282	27%	-1%
DBL Kerbside	904	1252	30%	-3%
DBL Median	875	1375	32%	-6%

Another interesting finding is that the BMT Lane and Bus Queue Jumper had the least negative effect of general traffic movement and performance .i.e. the most demonstrative example is the BMT lane scenario which actually increased mean general traffic speed by 1%.This improvement despite removal of general traffic from one lane can be explained by the elimination of mini-bus taxis from general traffic and since they constitute up to 33% of modes share of vehicles .i.e. restricted to outmost/kerbside lanes where their movements where less disruptive to general traffic and increasing its performance parameters.

Conclusion

The analysis of the results has demonstrated that the alternative forms of public transport priority measures reduce travel delay, improve bus speeds and have a less negative effect on general traffic(a key factor when for obtain public support for PT priority schemes).Furthermore ,stricter enforcement of lane restrictions can also help make priority schemes like BMT lanes and bus lanes in general more effective.

Based on these results the implementation of alternative bus priority schemes such as bus queue jumpers at intersections is recommended and BMT lanes along sections at appropriate locations or corridor segments. Hence, before full scale roll-out of full specification bus priority schemes like BRT, it is important that other forms of bus priority are exhaustively evaluated to ensure stakeholders, communities and operators are getting the most cost effective method of bus service improvements.

Recommendations for Further Research

In investigating the operation performance of different priority measures under South Africa conditions, there still remain a number of key aspects of public transport priority schemes that need to be quantified and studied in greater detail. These include the magnitude of benefits that Signal coordination along transit corridors offer, the relation between the total cost saving (including environmental benefit) and different priority schemes. Another area is the development calibration techniques of such models especially in the face of inconsistent data which is common place in most developing and intermediate countries.

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2 Bibliography

- (British Department of Environment Transport Government and Regions). (2001). *KEEPING BUSES MOVING “A GUIDE TO TRAFFIC MANAGEMENT TO ASSIST BUSES IN URBAN AREAS”* (Second.). London: London Stationary Office.
- (Kittleson & Associates), (KFH Group), (Parsons Brincker Quade & Douglas), & Hunter-Zaworski, D. K. (2003). *PART 4 BUS TRANSIT CAPACITY CONTENTS* (pp. 4–1 – 4–110). Washington DC. doi:Report 100
- Eichler, M., & Daganzo, C. F. (2006). Bus lanes with intermittent priority: Strategy formulae and an evaluation. *Transportation Research Part B: Methodological*, 40(9), 731–744. doi:10.1016/j.trb.2005.10.001
- Hidalgo, D., & Carrigan, A. (2010). *Modernizing Public Transportation*. Transport. Washington DC.
- Hounsell, N. B., & Shrestha, E. P. (2004). BUS PRIORITY AT TRAFFIC SIGNALS : INVESTIGATING THE OPTIONS, 287–294.
- Kim, S., Park, M., & Chon, K. S. (2012). Bus signal priority strategies for Multi-directional bus routes. *KSCE Journal of Civil Engineering*, 16(5), 855–861. doi:10.1007/s12205-012-1507-7
- Lee, D. A., Cook, G., Ford, N. P., Freeland, R. L., Gilliam, F. M., Hough, J. A., & Bridge, G. G. (2006). *Synthesis 64: Bus Use of Shoulders*. Washington DC. doi:ISDN : 0-309-09767-3
- Lee, D. A., Watson, C., Hair, V. I. C. E. C., Miller, D. L., Dot, K., Irector, E. X. D., ... Wilson, F. (2007). *Bus Rapid Transit Practitioner’s Guide*. Washington DC. doi:Report 118
- Lloyd Wright : Walter Hook (Ed.). (2007). *Bus Rapid Transit Planning Guide* (third.). Institute for Transport & Development Policy.
- Miller, M. A. (2009). Bus Lanes / Bus Rapid Transit Systems on Highways : Review of the Literature.
- Skabardonis, A., & Christofa, E. (2011). Impact of Transit Signal Priority on Level of Service at Signalized Intersections. *Procedia - Social and Behavioral Sciences*, 16, 612–619. doi:10.1016/j.sbspro.2011.04.481
- Salvucci,F. (2014). “The Flexibility of the Bus in both a Strength and a Weakness in Providing Access in Metropolitan Area.Does BRT Hurt or Help?”.Massechussets Institute of Technology(MIT).
- Waterson, B. J., Rajbhandari, B., & Hounsell, N. B. (2003). Simulating the Impacts of Strong Bus Priority Measures, (December), 642–648.

- Wu, J., Brackstone, M., & McDonald, M. (2003). The validation of a microscopic simulation model: a methodological case study. *Transportation Research Part C: Emerging Technologies*, 11(6), 463–479. doi:10.1016/j.trc.2003.05.001
- Zhu, H. B. (2010). Numerical study of urban traffic flow with dedicated bus lane and intermittent bus lane. *Physica A: Statistical Mechanics and its Applications*, 389(16), 3134–3139. doi:10.1016/j.physa.2010.03.040
- Barker, J. B., Alvarez, D., Barnes, R. L., Garber, C., Greene, S., Irwin, R. H., ... Rosenberg, J. M. (2003). *Bus Rapid Transit Volume 2: Implementation Guidelines* (Vol. 2). Transportation Research Board.
- DHRUVA LAHON. (2011). Modeling Transit Signal Priority and Queue Jumpers for BRT. *Intelligent Transport Engineering*, (December), 21 – 24.
- Dion, F., Rakha, H., Asce, M., & Zhang, Y. (2004). Evaluation of Potential Transit Signal Priority Benefits along a Fixed-Time Signalized Arterial, (June), 294–304.
- Evans, H., and Skiles, G. ?1970?. “Improving public transit through bus preemption of traffic signals.” *Traffic Q.*, 24?4?, 531–543.
- Hensher, D. a., & Golob, T. F. (2008). Bus rapid transit systems: a comparative assessment. *Transportation*, 35(4), 501–518. doi:10.1007/s11116-008-9163-y
- Hook, W., Breithaupt, M., Wright, L., Hidalgo, D., Menckhoff, G., Martins, W. C., ... Rutherford, S. (2013). *THE BRT STANDARD 2013*. New York: Institute for Transport & Development Policy and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Dag-Hammarskjöld-Weg.
- Wright, L., & Hook, W. (2007). *Bus Rapid Transit Planning Guide*. (Lloyd Wright : Walter Hook, Ed.) (third.). Institute for Transport & Development Policy.
- Wu, J., Brackstone, M., & McDonald, M. (2003). The validation of a microscopic simulation model: a methodological case study. *Transportation Research Part C: Emerging Technologies*, 11(6), 463–479. doi:10.1016/j.trc.2003.05.001