THE CASE FOR PRIORITY INFRASTRUCTURE: A QUANTIFICATION OF THE BENEFITS TO MINIBUS TAXIS USING MICROSIMULATION

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ABSTRACT

Public transport priority infrastructure like queue-jumping lanes and queue-bypass lanes have been well researched and proven to be successful in reducing delay and improving the overall efficiency of the public transport system. Despite their proven effectiveness when constructed for buses, these forms of infrastructure have not been tested for paratransit vehicles, particularly in the case of minibus taxis which often face challenges relating to traffic congestion and delays. The purpose of this paper was to ascertain the potential net benefits, specifically in terms of delay reduction, associated with the implementation of priority infrastructure at two intersections along two crucial minibus taxi corridors, considering realistic traffic and design conditions. The microsimulation software VISSIM was used to determine the intersection performance measures which included queue length, Level of Service, and vehicle delay. Both infrastructure interventions were found to provide minibus taxi operators with net delay savings at the intersections of up to 6 s per vehicle for the queue bypass lane and over 8 s per vehicle for the queue-jumping lane. The queue-bypass lane, however, showed more consistent benefits. These savings can be significant when priority infrastructure is implemented at several intersections along a minibus taxi corridor.

1. INTRODUCTION

The current body of research has extensively explored the minibus taxi industry's response to proposed formalisation attempts, particularly in the context of integrating informal taxis with the formal Bus Rapid Transit (BRT) system (Schalekamp & Behrens, 2010, 2013). However, a notable gap exists in the literature when considering the improvement of the minibus taxi industry as an independent mode of public transport, without being coupled with the BRT system. While efforts have been made to improve the industry through initiatives such as training co-operatives and minibus taxi recapitalisation, research does not addresses infrastructure development, specifically the integration of priority infrastructure at intersections. Addressing this gap is important, as focusing on intersections could alleviate traffic congestion for minibus taxi operators and enhance passenger movement, given that intersections often serve as bottleneck points in urban traffic flow.

Studies have demonstrated the effectiveness of queue-jump and queue-bypass lanes as priority infrastructure for buses under suitable conditions (Ryus et al., 2012; Cesme et al., 2014; Nowlin & Fitzpatrick, 1997). These lanes, which involve dedicated roadway geometry, can be combined with dedicated signal phases to provide additional time savings. This research aims to explore the benefits, if any, of applying these interventions to minibus taxis. While some preliminary research has touched on this topic (de Beer & Venter, 2021), it has taken a high-level approach, utilising a cost model in Excel. Consequently, the impact and feasibility of improving minibus taxi operating conditions through the implementation of priority infrastructure at intersections have not been sufficiently investigated.

As a result, it remains unknown whether the adoption of such interventions might be warranted and, if so, under which specific conditions. This study seeks to address this knowledge gap and contribute insights into the potential advantages and circumstances surrounding the implementation of priority infrastructure for minibus taxis at intersections.

2. METHODOLOGY

The methodology consisted of identifying two intersections based on the following criteria:

- The intersection must be located on a main minibus taxi corridor.
- The intersection must be located on a minibus corridor with a low average operating speed.
- The intersection must be geometrically suitable, conforming to the priority infrastructure proposals used in past research.
- The intersection must be located outside the city's CBD.

Data was collected before modelling which included vehicle types, traffic counts through the intersection, vehicle free-flow speeds, acceleration and deceleration rates, and the intersection signal phasing plans. The intersections were modelled in PTV's VISSIM microsimulation software suite which could be calibrated specifically for the observed traffic conditions. Once the intersections were modelled, input data were fed into the models and then calibrated. Two scenarios were included in the modelling procedure: Scenario 1, where the existing conditions were observed and served as the benchmark model, and Scenario 2, where priority infrastructure was added to the intersections in the form of either a queue-jumping lane, a queue-bypass lane or both. A sensitivity analysis was conducted to determine the conditions required for minibus taxi operators and users to receive maximum benefits, or time savings, from the priority infrastructure. Once the models were completed, the output data was collected and analysed. The output data included performance measures such as queue length, LOS, and vehicle delay.

3. OBJECTIVES OF THE PAPER

The main objective of the study was to quantify the potential benefits of priority infrastructure under realistic, typical operating conditions to assess whether a case can be made to warrant future research.

4. SIMULATION MODELLING

4.1 Simulation Modelling of Paratransit Services

To offer preliminary insights into the operational characteristics of minibus taxis at intersections, this section draws upon existing research to enhance the quality of the models proposed in this study. This section outlines the techniques and methods used to model paratransit services in various cities around the world.

4.1.1 Agent-Based Modelling Approaches

Agent-based modeling involves a system of autonomous decision-making entities referred to as agents, where each agent individually assesses its situation and makes decisions based on a predetermined set of rules (Bonabeau, 2002). This modeling approach focuses on individual traveler or vehicle behavior, interactions, and the emergence of traffic patterns.

An example of an agent-based model is demonstrated by Neumann et al. (2015) who developed a “close-to-reality” minibus supply model based on the demand and street network such that it could be used for planning purposes in the future – which includes investigating changes relating to strategies, operations and regulations. The agent-based simulation allowed taxi operators to purchase and sell vehicles as well as to change their routes or drop them completely depending on how profitable each scenario was.

Agent-based models have been employed to model fleet and network evolution, focusing on broader aspects rather than detailed operations under realistic traffic conditions. Given that the simulation in this study was a microsimulation limited to two separate intersections, and not a mesoscopic or macroscopic network analysis, information concerning the performance of the simulated vehicles will be discussed in more detail.

4.1.2 Microsimulation Modelling Approaches

Microsimulation is used to model individual vehicle movements on a second or sub second basis. This is done to assess the performance of the traffic on highways and street systems as well as interactions between regular vehicles and public transport and pedestrians. The method is carried out on a small network and models a specific part of the transport network in great detail and all factors that would influence the performance of the vehicle should be included (U.S. Department of Transportation, 2019).

There are not many studies that have utilised microsimulation to model paratransit vehicle behavior, primarily due to the complexity of the paratransit system and the scarcity of data. Du Preez and Venter (2022) addressed this gap by conducting a preliminary analysis of a shared right-of-way between minibus taxis and Bus Rapid Transit. Their study involved drawing from existing research on taxis and paratransit vehicles while also collecting field data to enhance their model. The performance of vehicles, including taxis, was investigated by Cheng-cheng et al. (2014) in a microsimulation model and the effect of heterogeneous vehicle behaviour on the network was determined. It was found that, although not differing from private vehicles in their physical dimensions, the significant difference between taxis and cars was evident in the driving behaviour: they are seen as aggressive drivers that do not adhere to the standard rules of the road. Although the study was conducted in China, similar effects have been observed in South Africa (de Beer & Venter, 2021). The research conducted by Cheng-cheng et al. (2014) also showed that when taxis lead the queue at an intersection, the time lost due to starting-up was reduced due to the taxis pulling away significantly faster than private vehicles – this then improved the overall capacity of the intersection. Although taxis (in this case minibus taxis) can increase the capacity of an intersection, they can also cause the overall network’s delay to increase (Dumba et al., 2017). This is due to taxis stopping to pick up and drop off passengers as well as erratic lane changes which cause delays for private vehicles. Dumba et al. (2017) found the high instances of lane blockage by minibus taxis in Harare, Zimbabwe to be of greatest significance during the evening peak period (between 16:00

and 18:00) where the intersection was completely blocked by minibus taxis stopping to pick up passengers. This illustrates how minibus taxis behave differently to regular traffic and, as such, should be modelled according to their unique characteristics.

4.2 Using VISSIM to Simulate Intersection Traffic Conditions

VISSIM is a microsimulation and agent-based traffic analysis software package, developed by PTV Group based in Germany. It has been used extensively in the South African context and can be calibrated for local conditions. The software can be used to simulate intersections, public transport networks, and pedestrian interactions. The modeller is able to use VISSIM to simulate unique infrastructure such as dedicated lanes and has full control over the driving rules such as restricting sections of road or allowing certain vehicle types or classes to use a particular road section. The physical road network can be built according to scale, with the route choices being defined. Directional splits of vehicles, defining mode types and characteristics, as well as the distribution of vehicles can be input into the model. In the VISSIM modelled network, vehicles travel using a psycho-physical perception traffic flow model which means that each vehicle's speed, acceleration, deceleration, and following distance is influenced by the vehicles around it. The model runs at up to one tenth of a second time step interval and the model is able to record information of each vehicle (or agent) during every time step which includes speed, acceleration, vehicle position, and driving behaviour. VISSIM was therefore selected as the most appropriate software analysis tool for the purpose of this study.

4.2.1 Calibration and Validation

To ensure that a model can be used with confidence and that it is an accurate representation of a real-world scenario, it must first be calibrated and validated. The data calibration process is iterative and must be repeated until the output data of the model corresponds to the in-field observed data and falls within a predetermined level of accuracy. The statistical methods and techniques used to calibrate and validate simulation models has been documented extensively (Law & David, 1991; Balci, 1998; Kleijnen, 1995). Traffic microsimulation models are most often calibrated using the Geoffrey E. Havers (GEH) statistic (Kabashkin et al., 2018):

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \tag{1}$$

Where:

M : Modelled hourly traffic volume
C : Counted hourly traffic volume

The GEH statistic smaller than 5 is considered a good fit.

Data validation is carried out once the model has been properly calibrated – this is done to confirm that a model's output is consistent with the observed data. To validate a model, the model's output data must be compared with observed data that was not used for calibration purposes.

The input of behavioural driving parameters is a common feature required by all types of microsimulations, regardless of the software being used. The software packages typically come with pre-set values that have to be verified or updated when calibrating the model. Various driving parameters can be required depending on the level of detail being modelled and the software used. Some common parameters include headway, acceleration/deceleration, desired speed, look ahead distance, queuing space, safety distance factors, and route choice.

There are additional data required by VISSIM as main inputs. These variables are location specific and have to be calibrated. These variables include (VDOT, 2020): accurately built intersections, vehicle types, vehicle classes, vehicle compositions, vehicle inputs, reduced speed areas, and conflict areas.

The output data of a model in the form of key performance indicators are used to compare different scenarios with each other.

4.2.2 Performance Measures

To quantify the performance of an intersection, performance measures are required. The traffic network performance is generally measured by queue length, volume/capacity ratios and Level of Service.

5. DATA COLLECTION

The data collected as required by the model includes the vehicle types, traffic counts, free-flow travel speeds, acceleration and deceleration rates, minibus taxi driver discipline, pedestrian information, and intersection signal phasing.

5.1 Vehicles

The dimensions of the light and heavy vehicles were based on the 2011 American Association of State Highway and Transport Officials (AASHTO, 2018) Policy on Geometric Design of Highways and Streets. South Africa uses this international guideline extensively for the design of road geometry. The physical dimensions of the minibus taxi used in the simulations are illustrated in Figure 1.

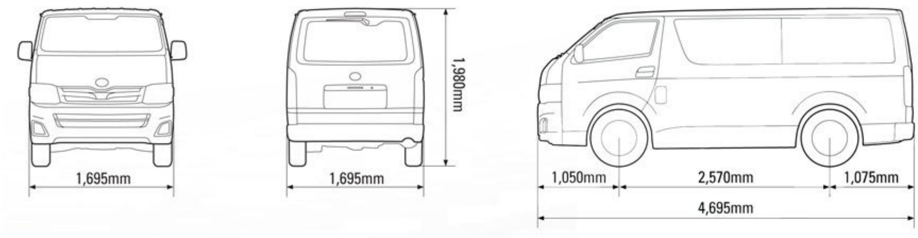

Figure 1: Minibus taxi dimensions (AASHTO, 2018)

5.2 Traffic Counts

A combination of video and manual counting was used to count the vehicles travelling through the intersections in that a camera was used to record the vehicles over a 90-minute period and the vehicles were then subsequently manually counted from the recording. This ensured greater accuracy in making distinctions between vehicle types. Automatic counters, for instance, will not be able to differentiate between a delivery van and a minibus taxi. Traffic counts were performed between 06:30 – 08:00 in the morning and between 16:00 – 17:30 in the afternoon.

5.3 Desired Speeds

The desired travel speeds of various vehicle classes were required as inputs to the simulation models. The desired speed, in VISSIM, is the speed at which a vehicle would travel in an empty road network and not influenced by other vehicles. Figure 2 illustrates the estimated desired travel speeds in km/h for passenger vehicles that were recorded from GPS data. Regarding the other vehicle classes, Du Preez and Venter (2022) measured the desired travel speeds of passenger vehicles, minibus taxis, and heavy vehicles and found the variation in desired speeds when comparing these modes. A 10 km/h faster desired speed was applied to the minibus taxi and a 10 km/h slower desired speed was applied to heavy vehicles.

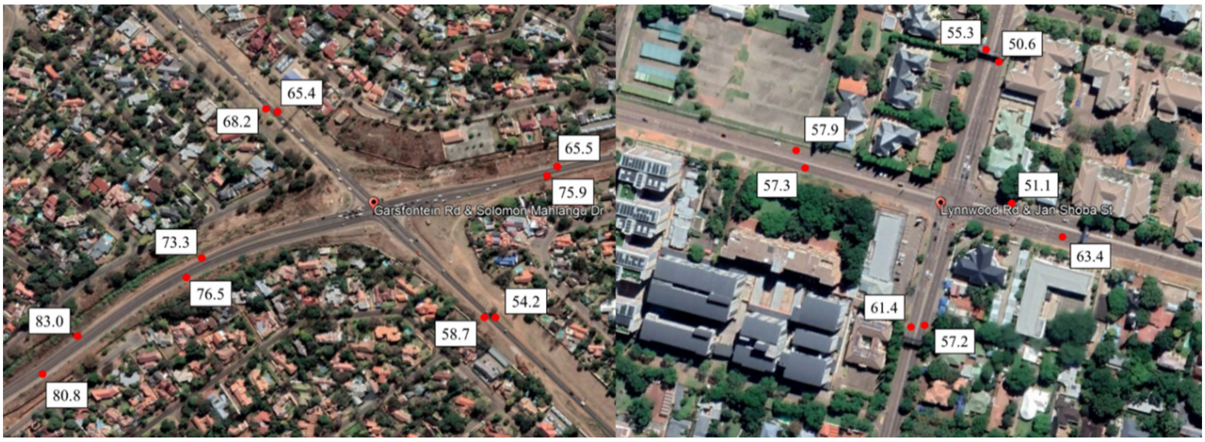

Figure 2: Desired speeds at the Garstfontein/Solomon Mahlangu and Jan Shoba/Lynnwood intersections

5.4 Acceleration and Deceleration

The model had to be calibrated to South African conditions thus the desired acceleration and deceleration for passenger vehicles, heavy vehicles and minibus taxis was calculated by Du Preez and Venter, (2022). An upper bound, a lower bound and average acceleration and deceleration values at different speeds were required by VISSIM. The acceleration and deceleration rates were determined from GPS data, travelling in the vehicles.

5.5 Taxi Driver Discipline

The behaviour of a minibus taxi driver differs from that of a passenger vehicle in terms of the adherence to traffic rules. This behaviour will have an effect on the optimal operation of the priority infrastructure and would require further investigation. These behaviours, however, have been disregarded in this study for the following reasons:

- Geometry: Minibus taxi operators often “create” their own lanes where the road geometry permits by driving in the shoulder lanes. In the case of the selected intersections, such behaviour is unlikely as the drivers will receive their own lanes to to skip the vehicle queues.
- Pick-up and drop-off locations: The intersections selected have limited space for minibus taxis to perform pick-up and drop-off procedures. Although these manoeuvres generally take place during the red phase of the intersection traffic cycle, three intersections were selected that see minimal passenger pick-ups and drop-offs.
- Traffic speeds: Due to the congested traffic, minibus taxis are forced to travel at the same speeds as the surrounding traffic.

After considering these reasons, the driving behaviour and driving rules for minibus taxis have been modelled to be the same as that of regular passenger vehicles.

5.6 Vehicle Following

The following values were used in the vehicle following model:

- The stand-still distance between vehicles: 1.2 m.
- The additive part of the following distance factor: 2.9.
- The multiplicative part of the following distance factor: 2.

These values were determined by measuring the saturation flow rates and stand-still following distance from the video footage.

5.7 Pedestrians

Pedestrians can have a significant impact on the performance of an intersection with jaywalking and vehicle hailing at an intersection. Their influence at the intersections, however, did not fall within the scope of the study.

5.8 Intersection Signal Phasing

The correct signal phasing for each intersection is important to ensure that they operate as close to the real-world scenario as possible. The video footage captured at the two intersections was used to accurately determine the amount of green, amber, red, and all-red time for each phase.

5.9 Microsimulation Models

Using the recorded data, two 2022 base models were modelled in VISSIM. The physical road layouts of the intersections were modelled as accurately as possible by measuring lane widths and lengths from Google Earth. The base models were calibrated and validated and were then used as the baseline against which to compare the models simulating the priority infrastructure forms.

5.9.1 Calibration

Calibration was conducted using the peak-hour flow rate recorded between 06:30 and 08:00. Since only intersections were modeled, and not a network, the calibration process utilised queue lengths and traffic flows. The variation in travel speeds through the intersection was too minimal to significantly contribute to calibration. Observed maximum and average queue lengths, along with hourly volumes, were employed in the calibration process. Actual hourly volume and queue lengths per traffic signal cycle were extracted from video footage obtained during the traffic count. The Geoffrey E. Havers (GEH) statistic, as proposed by Kabashkin et al. (2018), was used for calibration. The model was considered calibrated when all GEH values were below 4.

5.9.2 Validation

Validation was then performed using the 30-minute interval that fell outside of the peak hour. In order to validate the model, the average queue lengths from this period were determined from the video footage and were compared to the outputs of the three models. The results obtained from the validation process yielded GEH values smaller than 4 and the model could therefore be deemed as validated.

6. SCENARIOS

6.1 Base Case

The base models, used to calibrate and validate the simulation models, were used as the two benchmark scenarios. Traffic counts were used to model the traffic volumes to keep these scenarios as close to the observed network as possible. Figure 3 illustrates the Garstfontein/Solomon Mahlangu and Jan Shoba/Lynnwood intersection base cases. The conflict areas are shown in red and green and illustrate which approach is given priority. The reduced speed areas are represented by the yellow rectangles.

Figure 3: Garstfontein/Solomon Mahlangu and Jan Shoba/Lynnwood intersection base models

6.2 Priority Infrastructure

The addition of priority infrastructure, as depicted in Figure 4, assesses the effects of incorporating a queue-jumping lane and a queue-bypass lane at the Garstfontein/Solomon Mahlangu intersection, or a queue-bypass lane at the Jan Shoba/Lynnwood intersection A queue-jumping lane only uses an approaching lane as infrastructure for minibus taxis to use to skip the queue whereas a queue-bypass lane has an approach and a receiving lane. Existing infrastructure was repurposed instead of adding additional lanes to the intersection. The priority infrastructure is indicated by highlighting the lane link. The signal phasing was also adapted by providing an additional priority green phase granting minibus taxis a time advantage to skip the queues at both intersections. The yellow lane links would allow minibus taxis to queue during the red phase whereafter they are given a priority green phase. Regular traffic would be allowed to make left turns during the priority green phase to avoid congestion. During the regular green phase, traffic would operate normally. Partial capacity is removed in both priority infrastructure cases: for the queue-jumping lane minibus taxis use the left-turn lane for their through movements, reducing the number of left-turning vehicles from queueing in this lane. In the case of the queue-bypass lane, regular traffic cannot queue in this lane during the red phase and have to use the adjacent lane.

Figure 4: Garstfontein/Solomon Mahlangu and Jan Shoba/Lynnwood intersection with priority infrastructure

7. RESULTS

Five random seeds were used for each simulation run and the average of the five seeds was used to express the results. Five seeds were deemed sufficient as the simulations were for intersection analyses and not network analyses.

7.1 Base Case

The results generated by the Garstfontein/Solomon Mahlangu and Jan Shoba/Lynnwood intersection base case models are summarised in Table 1 and Table 2.

Table 1: Garstfontein/Solomon Mahlangu base model output values

Direction		Avg queue length (m)	All Vehicles (veh/h)	MBT Vehicles (Veh/h)	All Vehicle Delay (s)	MBT Vehicle Delay (s)	LOS - MBT	LOS - All
Garstfontein NB	Left	131	57	6	46.3	35.2	LOS D	LOS D
	Through	131	802	64	51.1	54.8	LOS D	LOS D
	Right	131	5	1	26.7	30.2	LOS C	LOS C
Garstfontein SB	Left	15	168	11	15.7	8.7	LOS A	LOS B
	Through	15	723	46	20.1	20.9	LOS C	LOS C
	Right	15	58	3	54.8	51.6	LOS D	LOS D
Solomon Mahlangu EB	Left	7	218	16	15.1	13.7	LOS B	LOS B
	Through	18	612	31	28.2	28.5	LOS C	LOS C
	Right	18	107	6	69.7	124.0	LOS F	LOS E
Solomon Mahlangu WB	Left	6	17	1	11.6	4.2	LOS A	LOS B
	Through	24	926	10	26.4	21.9	LOS C	LOS C
	Right	24	192	1	55.7	60.3	LOS E	LOS E
		Average: 33.6	Total 3 885	Total: 196	Average: 32.8	Average: 36.2	Average: LOS D	Average: LOS C

The through movement of the Garstfontein Northbound direction is characterised by long queue lengths with oversaturated flow with the queue extending to the previous intersection resulting in a poor level of service. The average delay in the intersection is 32.8 seconds per vehicle for the average vehicle and 36.2 seconds per minibus taxi corresponding to a LOS C. The Garstfontein Northbound through movement has a delay value of 51.1 and 54.8 seconds for the average vehicle and the average minibus taxi respectively. The right turns of Solomon Mahlangu Eastbound and Westbound have a LOS F due to the queues in either direction not dissipating fast enough before the amber phase resulting in the turning queues not being able to dissipate during every cycle. These observations correspond to what was seen on the video footage obtained.

Table 2: Jan Shoba/Lynnwood base model output values

Direction		Avg queue length (m)	All Vehicles (veh/h)	MBT Vehicles (Veh/h)	All Vehicle Delay (s)	MBT Vehicle Delay (s)	LOS - MBT	LOS - All
Jan Shoba NB	Left	13	117	1	17.2	27.8	LOS C	LOS B
	Through	13	702	20	16.9	16.4	LOS B	LOS B
	Right	13	206	5	25.0	39.0	LOS D	LOS C
Jan Shoba SB	Left	28	73	2	24.9	18.4	LOS B	LOS C
	Through	28	800	24	34.9	40.4	LOS D	LOS C
	Right	28	163	6	52.1	36.7	LOS D	LOS D
Lynnwood EB	Left	32	90	4	35.6	49.2	LOS D	LOS D
	Through	32	592	25	39.9	44.5	LOS D	LOS D
	Right	32	92	1	118.2	333.7	LOS F	LOS F
Lynnwood WB	Left	27	195	12	22.8	21.1	LOS C	LOS C
	Through	27	1101	55	27.6	31.3	LOS C	LOS C
	Right	27	212	10	28.3	22.1	LOS C	LOS C
		Max: 25.1	Total 4 343	Total: 165	Average: 31.3	Average: 34.1	Average: LOS C	Average: LOS C

The Jan Shoba/Lynnwood intersection operates at a LOS D or better except for the right turning movement of Lynnwood Road Eastbound. In this case the vehicle delay is 118.2 s per vehicle and 333.7 s for an average minibus taxi. This means that the average vehicle spends about four cycles at the intersection before being able to cross. The length of the turning lane is designed sufficiently long enough to accommodate the traffic demand which is 92 vehicles per hour. Only the right turn movements of Jan Shoba Northbound and Lynnwood Westbound receive leading green phases and therefore they have a LOS C.

7.2 Priority Infrastructure Case

For both intersections, a priority signal phase was added for the minibus taxis, allowing them to skip the adjacent queue. The simulation was run with several different configurations by keeping the cycle length constant but taking time from each green phase in varying ratios to determine which design would result in the lowest overall delay per vehicle as well as reducing the minibus taxi delay for the taxis using the priority infrastructure. For both intersections a 6 s priority phase was given.

The change in queue length when the base case is compared to the case where priority infrastructure is added is illustrated in Figure 5 and Figure 6.

For the Garstfontein/Solomon Mahlangu intersection with a queue-jumping lane in the northbound direction and a queue-bypass lane in the southbound direction there was an increase in average queue lengths with all the queues being longer than in the base case except for the Garstfontein northbound direction and the right turn for the Garstfontein southbound direction. The longer queue lengths varied between 2 m longer (Solomon Mahlangu Eastbound, left) and 27 m longer (Garstfontein Southbound, through) due to shortening the green phases in both directions to accommodate the priority green phase. The queue length of Garstfontein Northbound decreases significantly by 78 m due to a combination of the priority left turn for regular vehicles and the priority green phase for minibus taxis. The result was that the average queue lengths for the entire intersection decreased by 10.6 m.

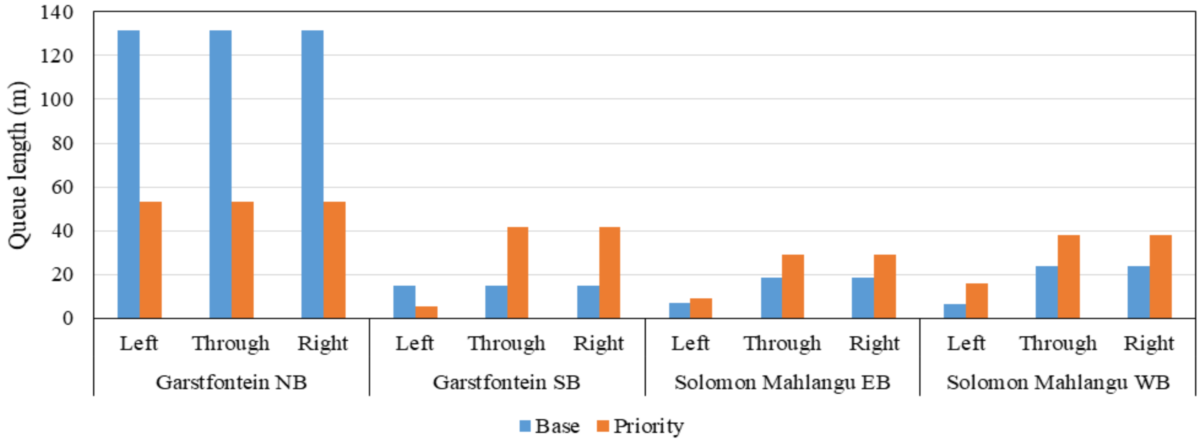

Figure 5: Garstfontein/Solomon Mahlangu average queue length comparison between base case and addition of priority infrastructure (Priority: Garstfontein NB, Garstfontein SB)

In the case of the Jan Shoba/Lynnwood intersection with its queue-bypass lane in the westbound direction, an average increase in queue length was seen in Jan Shoba southbound as this direction has a shorter green phase in comparison to the northbound direction which has a leading green phase allowing through movements as well as a protected right turn. The shorter green phase for the southbound direction means that when removing part of its green phase for the minibus taxi priority phase, it is more significantly affected in terms of queue lengths and vehicle delays. Longer average queue lengths of 24 m were observed. The longer queue lengths for the other directions are less significant, varying between 2 and 3 m. Lynnwood Westbound, the road with the priority infrastructure added, shows its queue length shortening by 8 m for the through movement and 19 m for the left turning movement. The reduction in queue length for the left turn is attributable to the fact that left turns are permitted for regular vehicles during the priority phase. Overall, the average queue length for the entire intersection increases by 2 m.

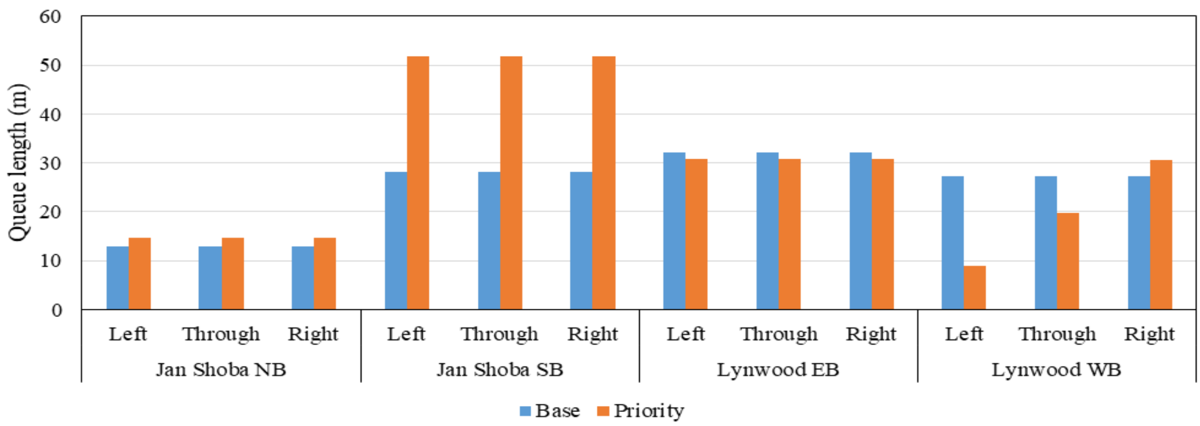

Figure 6: Jan Shoba/Lynnwood average queue length comparison between base case and addition of priority infrastructure (Priority: Lynnwood WB)

7.3 Sensitivity Analysis

Two variables were varied in the models between two bounds, whilst keeping the total volumes constant: the ratio of light and heavy vehicles to minibus taxis (between 95:5 and 80:20) and the priority green time advantage given to minibus taxis to use the priority infrastructure (between 4 s and 12 s). This was done to determine the conditions required for the infrastructure to operate optimally.

Figure 7 illustrates the Garstfontein/Solomon Mahlangu vehicle delay comparison between the base case and the various scenarios in the priority infrastructure case. The delay savings are also indicated with green and red dots to differentiate between the delay savings for the average vehicle (red) and for an average minibus taxi (green). There were only two cases where both the average vehicle and the average minibus taxi benefited by the priority interventions over the entire intersection: at a 4 s priority at a ratio of 95:5 of light and heavy vehicles to minibus taxis and at a priority of 4 s with a 90:10 ratio of light and heavy vehicles to minibus taxis. Furthermore, there are three additional cases where only minibus taxis benefit from the interventions: two at a 6 s priority and one at an 8 s priority. At 10 s and 12 s priority the delay increase from the base case for the average vehicle is, on average, 10 s and 24 s respectively. Longer periods of priority green results in longer queues in both directions. It then nullifies any benefit minibus taxis may gain as they also form part of the queue. Lengthening the turning lane, where possible, could potentially provide minibus taxis more exclusive queueing space.

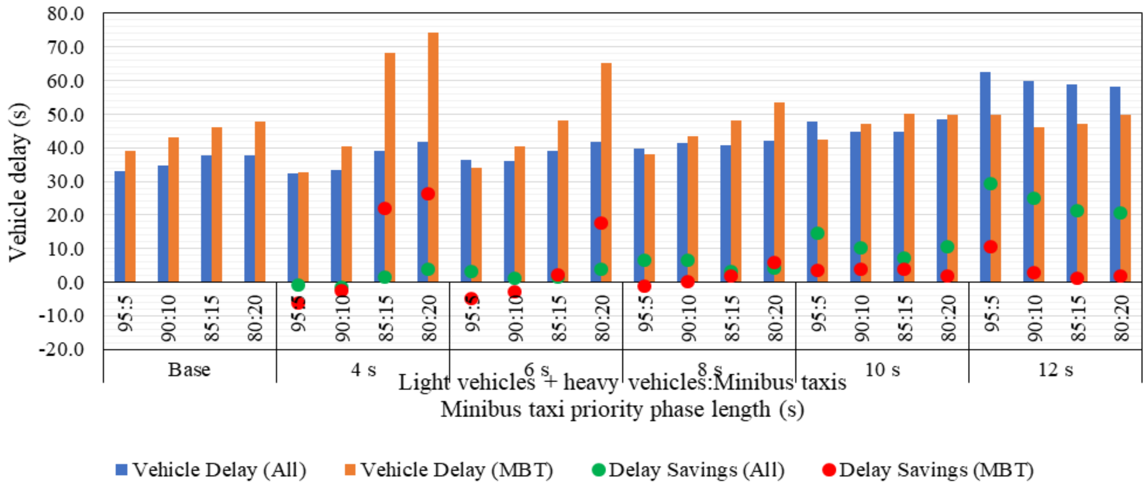

Figure 7: Garstfontein/Solomon Mahlangu vehicle and minibus taxi delay

The passenger delay savings for a sample of 100 vehicles was determined by assuming a vehicle occupancy for minibus taxis to be 14 and for the rest of the vehicles in the model to be 1.5 occupants. Firstly, the vehicle delay savings was determined by finding the difference in delay between the base case and each corresponding priority infrastructure case. The difference in vehicle delay was then multiplied by the respective proportion of the 100-vehicle sample size. To find the total passenger delay increase or savings, the vehicle delay was multiplied by the vehicle occupancy. The net delay savings was then determined by finding the sum of the two passenger delay savings values. This was done for both the southbound and northbound movements. Figure 8 illustrates the results to these calculations for the southbound movement with the queue-bypass lane.

There was a trend of a negative increase in the sum of passenger delay savings when the ratio of light and heavy vehicles to minibus taxis decreased from 95:5 to 80:20. At a ratio of 95:5 and 90:10 there were no cases where a net passenger delay savings was obtained which was attributable to the fact that the through movements in the left lane was only permitted for minibus taxis and prohibiting this movement for regular vehicles increased their delay. This, in addition to the fact that such a small number of taxis were able to benefit from the priority intervention, led to the overall negative passenger delay savings. This was especially evident at the 10 s and 12 s priority green scenarios. When the ratio of regular vehicles to taxis decreases to 85:15 and 80:20, greater overall savings were observed, particularly when the ratio was 80:20 where the overall net passenger delay savings ranged between 1 316 s to 1 749 s.

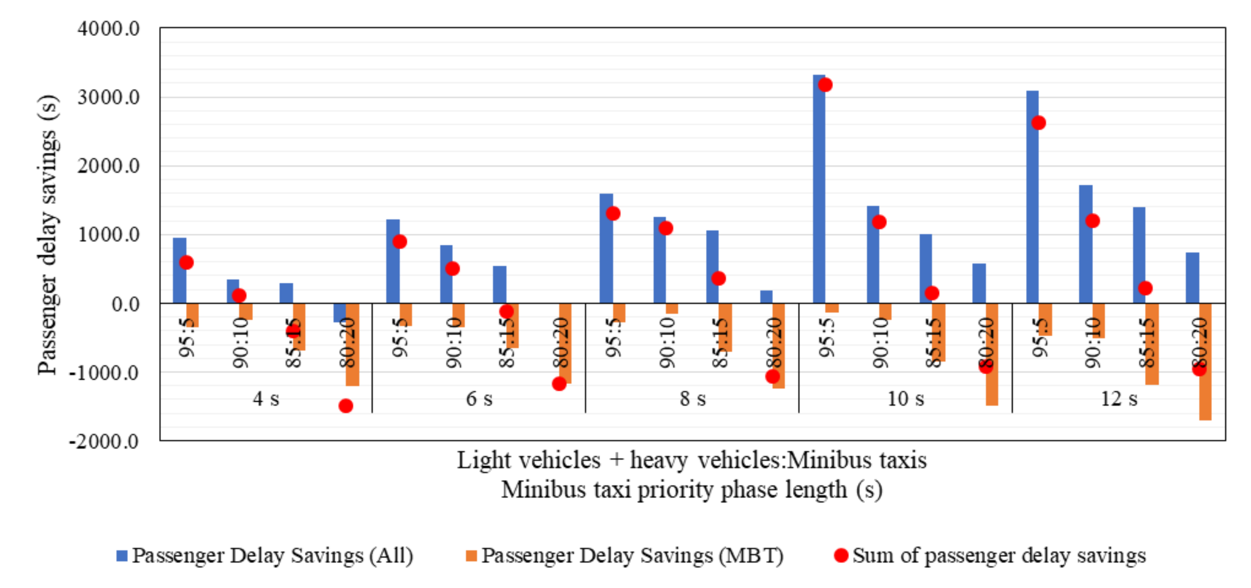

Figure 8: Garstfontein Road (Southbound) – vehicle and minibus taxi passenger delay savings

The savings in passenger delay for a sample of 100 vehicles is illustrated in Figure 9. Less of a pattern in the passenger delay savings was observed in the Northbound case as opposed to the Southbound case. Between the ratio of 95:5 and 80:20 there is an increase to a maximum savings value and then a decrease. In most of the priority green cases, a ratio of 90:10 or 85:15 yielded the most favourable results. This was not true, however, in the case of the 4 second priority green where the net delay savings were the most negative (-14 072 for a ratio of 85:15 and -24 469 for a ratio of 80:20). This is due to the minibus taxi queue in the priority lane not being able to dissipate during its priority green phase. As a result, the minibus taxi had to wait for an appropriate gap length to complete its movement or, in some cases, had to spend an additional red phase at the intersection stop line. This was observed for both the 4 s and 6 s priority green cases but became less of a problem when the priority green phase was lengthened. This situation is illustrated in Figure 10. This was not seen as a problem with the model, but rather a potential problem with the implementation of the priority infrastructure as situations similar to this could occur in a real-world scenario.

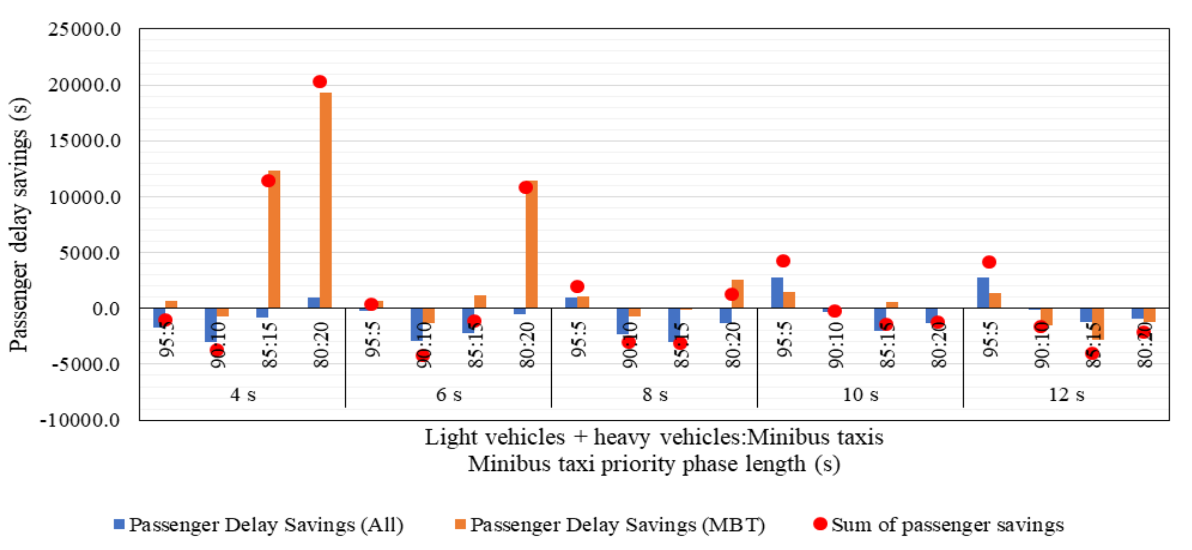

Figure 9: Garstfontein Road (Northbound) – vehicle and minibus taxi passenger delay savings

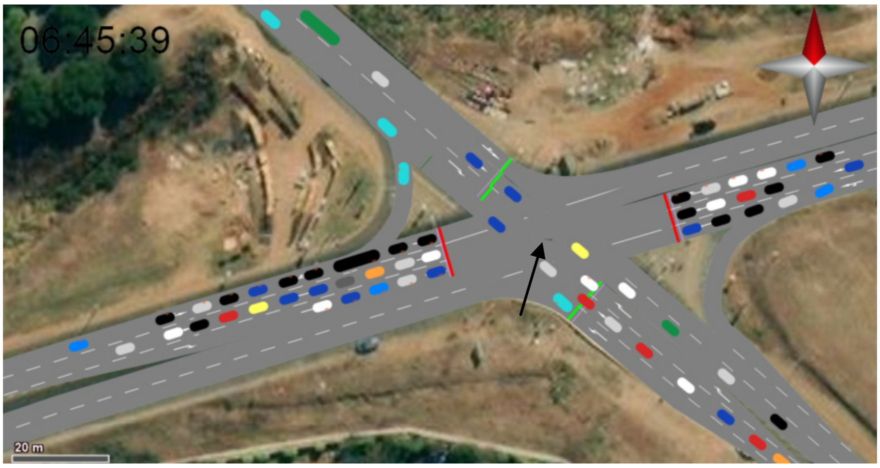

Figure 10: Minibus taxi not completing its movement during the priority green phase

The ratio of light and heavy vehicles to minibus taxis and the time advantage given to minibus taxis at the Jan Shoba/Lynnwood intersection, where the queue-bypass lane was implemented, were varied to determine the conditions for the optimal operation of the intersection. The results of the vehicle delays, when compared to the base case are illustrated in Figure 11. In none of the scenarios did the overall delay of the intersection decrease when compared to the base case. In the 4 s priority scenario, the delays increased, on average, by 2.6 s for regular traffic and 6.2 s for minibus taxis. In the 6 s scenario, a similar increase was observed: an average of 2.8 s for regular traffic and 8 s for minibus taxis. For those scenarios one could expect an overall net benefit for the lane with the priority infrastructure without significantly increasing the delay over the rest of the intersection. At higher priority green times, the increase in delay became more significant: at 12 s priority the average minibus taxi's delay increased by 117 s. This was largely due to many minibus taxis turning right (especially on Lynnwood Westbound) and, as a result, their delay increased significantly.

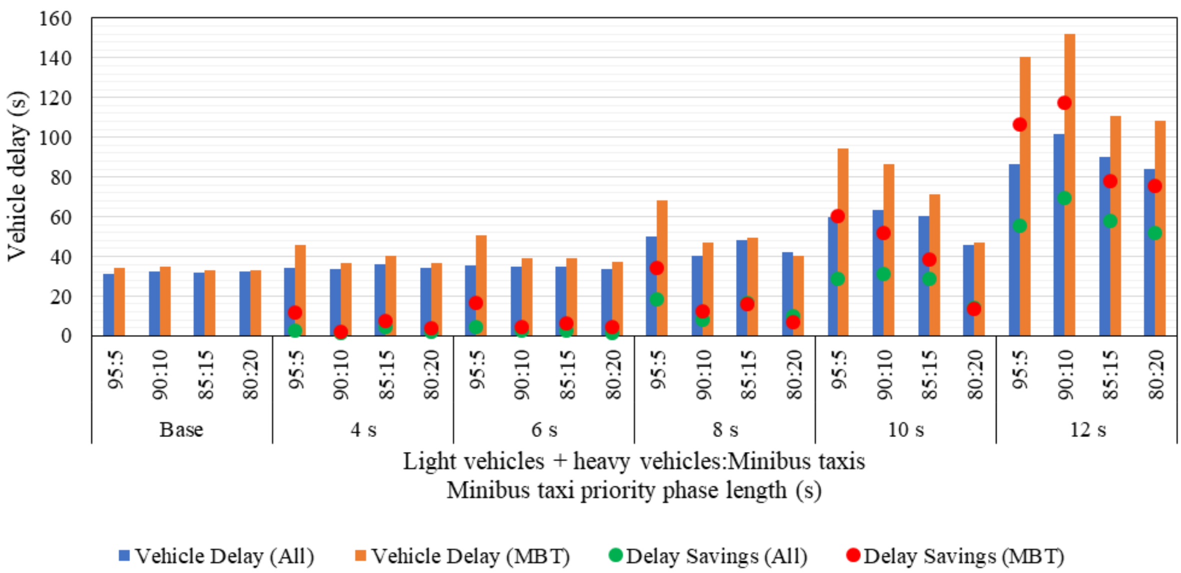

Figure 11: Jan Shoba/Lynnwood vehicle and minibus taxi delay

The savings in passenger delay for a sample of 100 vehicles is illustrated in Figure 12. A similar pattern was observed in the Garstfontein/Solomon Mahlangu Northbound case: that is, between the ratio of 95:5 and 80:20 there is an increase to a maximum savings value and then a decrease. This was only the case with a priority green phase of 4 and 6 s, where after the delay for both mixed traffic and minibus taxis increased significantly. This was caused by an increase in congestion due to the longer priority green phase and minibus taxis getting caught in between the mixed traffic and were unable to reach the priority lane in time for the priority green phase. A similar problem arose with the 80:20 split of mixed traffic to minibus taxis: due to the high number of taxis trying to reach the priority lane, a lot of weaving took place for them to reach the lane. This then slowed the vehicles down and increased their delay. This, again, was not seen as a problem with the model but rather a limitation of the priority infrastructure, particularly at high minibus taxi volumes.

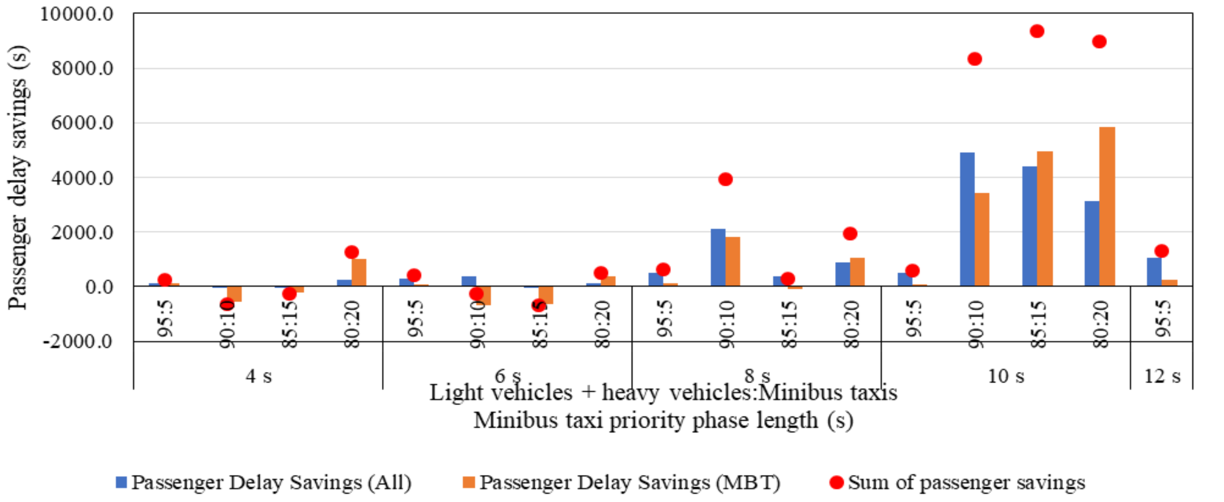

Figure 12: Lynnwood Road (Westbound) – vehicle and minibus taxi passenger delay savings

8. CONCLUSIONS AND RECOMMENDATIONS

The cumulative effect of delay reduction at an intersection over a day or a month holds substantial significance. The implications stemming from these delay savings could benefit minibus taxi operators through more efficient operations, increased earnings, and savings in fuel and maintenance costs. Users of the public transport will reap benefits through time savings, increased reliability, and improved convenience.

The queue-jumping- and queue-bypass lanes both improved the operating conditions of minibus taxis without significantly negatively impacting the operation of the intersection: a reduction in delay of up to 6 s was observed for the queue-bypass lane at (implemented at both intersections) and 8 s for the queue-jumping lane (implemented at the Garstfontein/ Solomon Mahlangu intersection). More consistent benefits were observed with the queue-bypass lane as minibus taxis were able to complete their movement even after the priority green phase which was not the case for the queue-jumping lane. It was also observed that the ratio of minibus taxis to regular traffic significantly affected the delay savings where a ratio of 90:10 of mixed traffic to minibus taxis showed the most consistent benefits to minibus taxi operators and passengers. In some cases this was at the expense of increased delay towards regular traffic. Priority infrastructure would therefore not be beneficial under all circumstances and intersections will have to be carefully considered before potentially creating greater delays.

Although the priority infrastructure was built into the model using the existing intersection, it is possible to increase the benefits of the priority infrastructure by increasing the length of the turning lane. An additional benefit to skipping a queue at an intersection for minibus taxis would be that they would be in front of the queue at the next intersection. If two or more intersections in a row made use of priority infrastructure, the benefits would be compounded. The quantification of the benefits of priority infrastructure in a network is recommended for future studies.

9. REFERENCES

AASHTO. 2018. *A Policy on Geometric Design of Highways and Streets.* 7th ed. Washington DC: The American Association of State Highway and Transportation Officials.

Bonabeau, E. 2002. Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of the United States of America,* 99:7280-7287.

Cesme, B, Altun, SZ & Lane, B. 2014. *Queue Jump Lane, Transit Signal Priority, and Stop Location: Evaluation of Transit Preferential Treatments using Microsimulation.* Arlington, Transport Research Board.

Cheng-cheng, X et al. 2014. Effects of behavioral characteristics of taxi drivers on safety and capacity of signalized intersections. *Journal of Central South University,* pp. 4033-4042.

de Beer, LR & Venter, C. 2021. Priority infrastructure for minibus-taxis: An analytical model of potential benefits and impacts. *Journal of the South African Institution of Civil Engineering,* 63(4):53-65.

Du Preez, SJ & Venter, C. 2022. Mixing the Formal with the Informal in Shared Right-of-Way Systems: A Simulation-Based Case-study in Tshwane, South Africa. *Case Studies on Transport Policy.*

Dumba, S, Vassileva, LD & Gumbo, T. 2017. Methodological issues in modelling signalised intersection capacity under informal public transport operations: Case study, Harare, Zimbabwe. *Transportation Research Procedia,* 25:4891-4915.

HCM. 2010. *Highway Capacity Manual.* Washington, D.C.: Transportation Research Board.

Kabashkin, I, Yatskiv, I & Prentkovskis, O. 2018. *Reliability and Statistics in Transportation and Communication.* Riga, 18th International Conference on Reliability and Statistics in Transportation and Communication.

Neumann, A, Joubert, JW & Röder, D. 2015. Toward a simulation of minibuses in South Africa. *Journal of Transport and Land Use,* 8(1):137-154.

Nowlin, L & Fitzpatrick, K. 1997. *Performance of Queue Jumper Lanes.* Chicago, IL, Traffic Congestion and Traffic Safety in the 21st Century: Challenges, Innovations, and Opportunities conference.

PTV, 2011. *VISSIM 5.30-05 User Manual,* Karlsruhe, Germany: PTV AG.

Ryus, P et al. 2012. Bus Preferential Treatments. In: *Transit Capacity and Quality of Service Manual, Third Edition.* s.l.:Transportation Research Board, pp. 4-27.

Schalekamp, H & Behrens, R. 2010. Engaging paratransit on public transport reform initiatives in South Africa: A critique of policy and an investigation of appropriate engagement approaches. *Research in Transportation Economics,* pp. 371-378.

Schalekamp, H & Behrens, R. 2013. Engaging the paratransit sector in Cape Town on public transport reform: Progress, process and risks. *Research in Transportation Economics,* 39:185-190.

Taieb-Maimon, M & Shinar, D. 2001. Minimum and comfortable driving headways: Reality versus perception. *Human factors: The journal of the human factors and ergonomics society,* Volume 43, pp. 159-172.

U.S. Department of Transportation, 2019. *2019 VERSION: Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software 2019 Update to the 2004 Version.* [Online]. Available at: https://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/sect0.htm#:~:text=Microsimulation%20is%20the%20modeling%20of,systems%2C%20transit%2C%20and%20pedestrians. Accessed 18 August 2022.

VDOT. 2020. *VDOT VISSIM User Guide,* Richmond: Virginia Department of Transportation.