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MODELLING THE IMPACT OF PRIORITY INFRASTRUCTURE ON THE PERFORMANCE OF MINIBUS-TAXI SERVICES IN SOUTHERN AFRICA

Theme: D
Key words: Paratransit, Transit, Model, Economic, Infrastructure

ABSTRACT

To observe the behaviour from which the driving patterns could be modelled, a low-cost, commercially available drone was used. It was observed that the drivers often try to cut corners and skip traffic to save time during peak traffic scenarios. It was also observed that there is a shortage of infrastructure for minibus taxi operators to pick up and drop off passengers often resulting in them making informal stops that cause congestion. Behaviour similar to that of a single lane pre-signal strategy and queue-jumping lane, used by buses as a means to provide them with priority over mixed traffic, was also observed.

The purpose of the paper is to quantify the economic impact that formalising this type of driver behaviour would have on minibus taxi operators, passengers, and other road users. The two forms of infrastructure were modelled according to various parts of the city where frequent stops to load and offload passengers take place. The two infrastructure forms were compared to the traditional curb-side by developing three mathematical macrosimulation models using Excel to develop a strategic understanding of how the benefits and costs of the infrastructure vary with different traffic conditions.

It was observed that the infrastructure alternatives resulted in a decrease in travel time, user cost, operating cost, and the total cost per trip for the minibus taxis. Pertaining to the car drivers, a decrease in travel time and total cost was observed because of the reduced delay due to taxi stops no longer impeding traffic. The single lane pre-signal strategy and the queue-jumping lane saw a decrease in total hourly cost of 49% and 48% respectively, which consists of construction cost, user cost, and agency cost.

The time passengers save on their often-long travel distances would go a long way to redress the transportation injustices of the past. The monthly savings of up to R32 000,00 per taxi driver in operating cost would serve as an implicit subsidy to a public transportation industry currently operating unaided. It was concluded that implementing such significant changes in the public transport industry in South Africa would be equivalent to providing minibus taxi operators with much needed financial support.

1. INTRODUCTION

The paratransit industry in South Africa has grown from a modest provider of public transport to the largest supplier to the urban public. Small-scale ownership of minibus taxis enabled the industry to develop in an adaptive and flexible way where the fares remain low, and the services respond rapidly to any change in need from the passengers (Jennings et al., 2017).

Recent initiatives to overhaul South Africa’s entire public transport systems, to address the legitimate deficiencies of the minibus taxi system, have often resulted in a complex set of formal and paratransit operations which are independent of each other subject to a regulatory framework that is disconnected (Salazar Ferro et al., 2012). There have been some efforts to improve the infrastructure for minibus taxi facilities and operations, including undercover loading lanes, public toilets, and office space (Schalekamp et al., 2018). The use of dedicated road space as well as dedicated and time-of-day-reserved public transport rights-of-way is scarce and, where implemented, is poorly enforced.

The objectives of the study are summarised as follows:

- To identify different driving behaviours displayed by minibus taxi operators that and to determine their suitability for improving operating conditions in the paratransit industry.
- To develop mathematical models to ascertain the benefits of the driving behaviours identified under a range of operating and demand conditions.
- To quantify the high-level economic impact that the modelled driving behaviours have on the paratransit operators, the passengers, and other road users.

2. EMPIRICAL OBSERVATIONS OF TAXI DRIVER

Minibus taxi operators often try to cut corners (literally and figuratively) in their efforts to save time – this is mainly due to pressure being put on them by their passengers and their need to survive financially. The more passengers they can transport in a day, the higher income they earn and thus it is often in their best interest to weave their way through traffic to get ahead of the congestion.

With the use of an unmanned aerial vehicles, commonly referred to as a “drone”, the behaviour of the minibus taxis was observed along various corridors in the Pretoria area.

2.1 CASES OF MINIBUS TAXIS OBSERVED

The three cases illustrate the delay advantage that the operators try to gain at an intersection which often corresponds to the priority infrastructure forms used by other public transport vehicles.

2.1.1 Case 1 (Queue skipping behaviour)

In Figure 1 a minibus taxi was observed driving in the right-turn lane. After the traffic signal turns green, the taxi is seen cutting into the lane adjacent to it thereby effectively skipping 8 vehicles in the queue. The behaviour displayed in the first case is similar to a queue-jumping lane form of infrastructure and jumping past such a long queue of vehicles saves this particular taxi approximately 24 seconds.

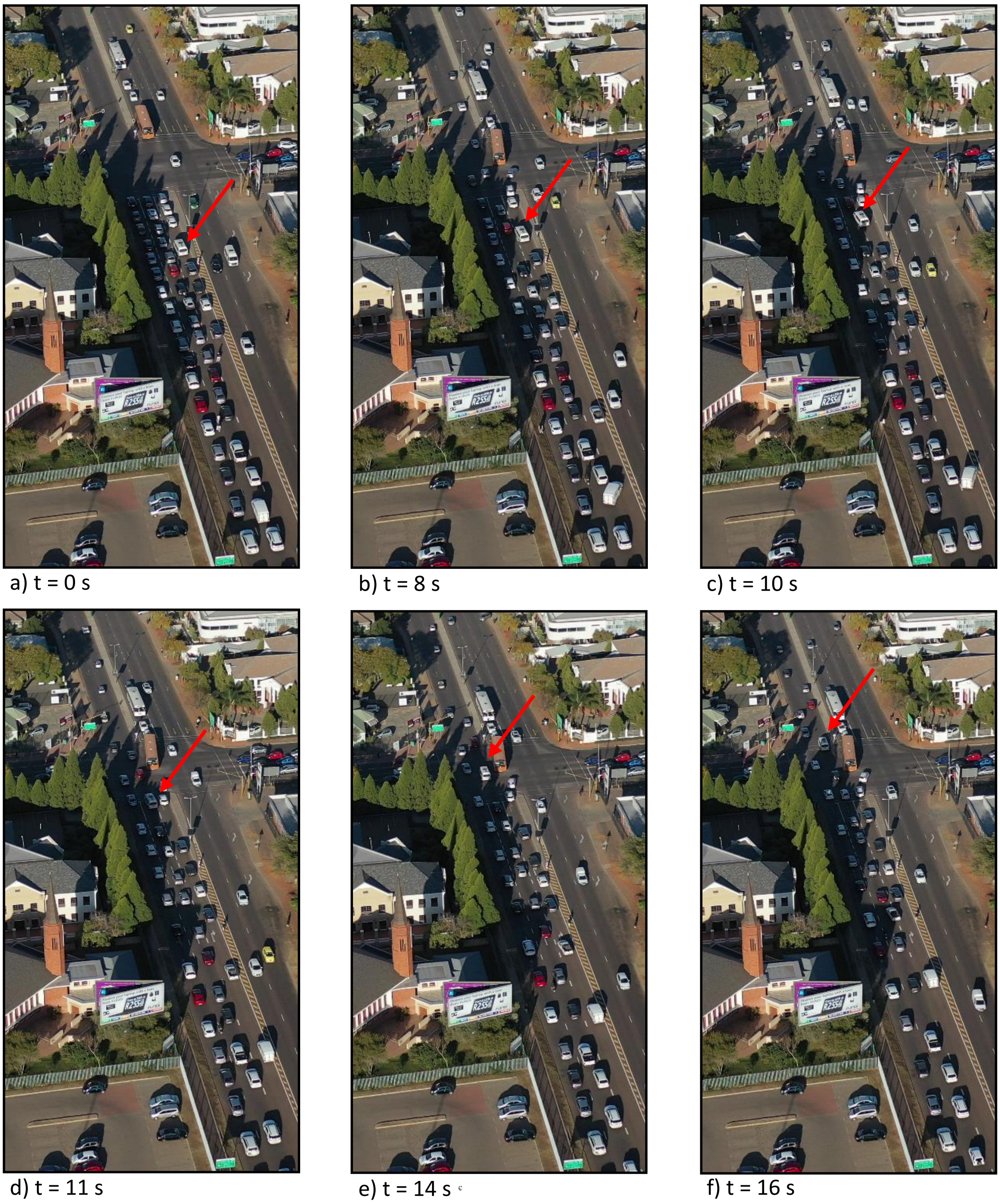

Figure 1: Minibus taxi creating own informal priority, Case 1

2.1.2 Case 2 (Queue skipping behaviour)

The second case, as Figure 2 illustrates, is similar to the first in that the operation of an informal queue-jumping lane was observed. This time, however, two minibus taxis skip the queue as soon as the traffic signal turns green. From their behaviour it is clear that the taxi travelling behind attempted to push in first after which allowing the taxi in front of it to do the same. This illustrates the sense of community minibus taxi operators have, knowing the struggles of their fellow operator, and attempting to help the other out when the opportunity arises. In this case, the two taxis skipped a queue of over 12 vehicles and were able to save an approximate 66 seconds. This is due to the traffic light turning red before the entire queue could dissipate.

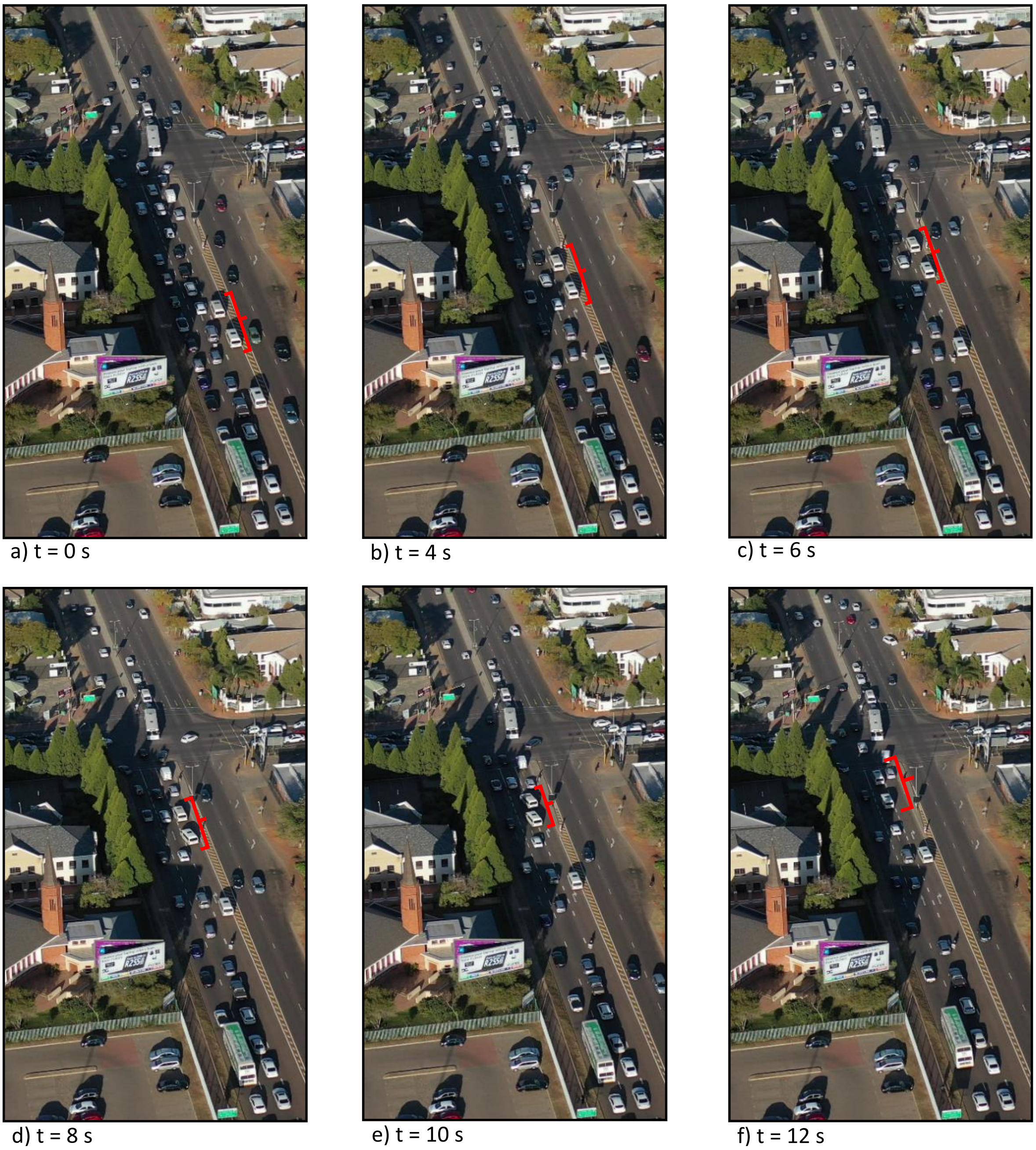

Figure 2: Minibus taxi creating own informal priority, Case 2

2.1.3 Case 3 (Opposite lane driving behaviour)

In the final case that was observed, as illustrated in Figure 3, a minibus taxi is seen travelling in the lane of the oncoming traffic after which it makes a right turn. In contrast with the previous two cases, this behaviour is quite dangerous and even though operating according to the single lane pre-signal strategy, without the necessary traffic signalling, behaviour like this can result in a road accident. The time that was saved in this case is miniscule as the queue that formed at the intersection only amounted to the single vehicle travelling on front of it.

Figure 3: Minibus taxi creating own informal priority, Case 3

2.2 THE NEED FOR PARATRANSIT INFRASTRUCTURE

It was observed that there is a distinct shortage of infrastructure for minibus taxi operators pertaining to boarding and alighting of passengers. Due to the dynamic, demand-responsive nature of the minibus taxi industry, drivers are often required to make informal stops at locations popular to pedestrians as indicated in Figure 4. The informal stops cause congestion on often busy roads and have, in some cases, lead to accidents.

a) t = 0 s

b) t = 2 s

c) t = 4 s

d) t = 7 s

Figure 4: Informal stop by a minibus taxi

3. TRANSIT PRIORITY MEASURES

Transit priority measures are interventions undertaken to provide public transport vehicles with a competitive time advantage over private vehicles. These interventions can be either physical or policy related like a bus-only roadway or legislation requiring private vehicles to yield to buses (Halifax, 2018).

The currently available transit priority measures that have proven to be effective in the public transport sphere, particularly pertaining to buses, will be considered in the research and will be discussed in the following section.

3.1 CURB-SIDE BUS STOPS

The most basic form of infrastructure intervention is the construction of taxi bays. Although much provision has been made for bus stops, little attention has been paid to providing stopping facilities for taxis (Dempster, 2018).

There are four typical loading area designs which are illustrated in Figure 2-7. They consist of linear loading areas, used for on-street bus stops as they occupy the least amount of space; and non-linear loading areas that include sawtooth, drive-through, and angle designs which allow buses to pull in and out independently of each other (Transportation Research Board, 2013).

Bus service times at a bus stop occupies a large proportion of the total operational time the bus spends on the road and the occurrence of queues forming at the entry and departure area of a curb-side bus stop is frequent. Bian et al. (2015) proposed a compound Poisson service time estimation model where the interactions among buses arriving and the number of boarding and alighting passengers is investigated.

3.2 SINGLE LANE PRE-SIGNAL STRATEGY

Ilgin Guler, et al. (2015) proposed a strategy whereby buses are given priority at signalised intersections with single-lane approaches by adding traffic signals to the road such that a bus can jump a portion of the car queue by making use of the travel lane in the opposite direction. Two additional pre-signals are placed upstream at a distance x_{2u} km and downstream at a distance x_{2d} km from the main signal. These two signals then operate together to create an intermittent bus priority lane. When there is no bus present both the pre-signals will remain green and cars will be able to discharge through the intersection normally. When a bus approaches and reaches a distance x_1 km from the main signal, both pre-signals at x_{2u} and x_{2d} turn red indicating cars from both directions to stop. The bi-directional segment is now cleared, and the bus is free to drive onto the opposite lane and travel without being impeded until it can merge back onto its original lane. Figure 5 illustrates the setup.

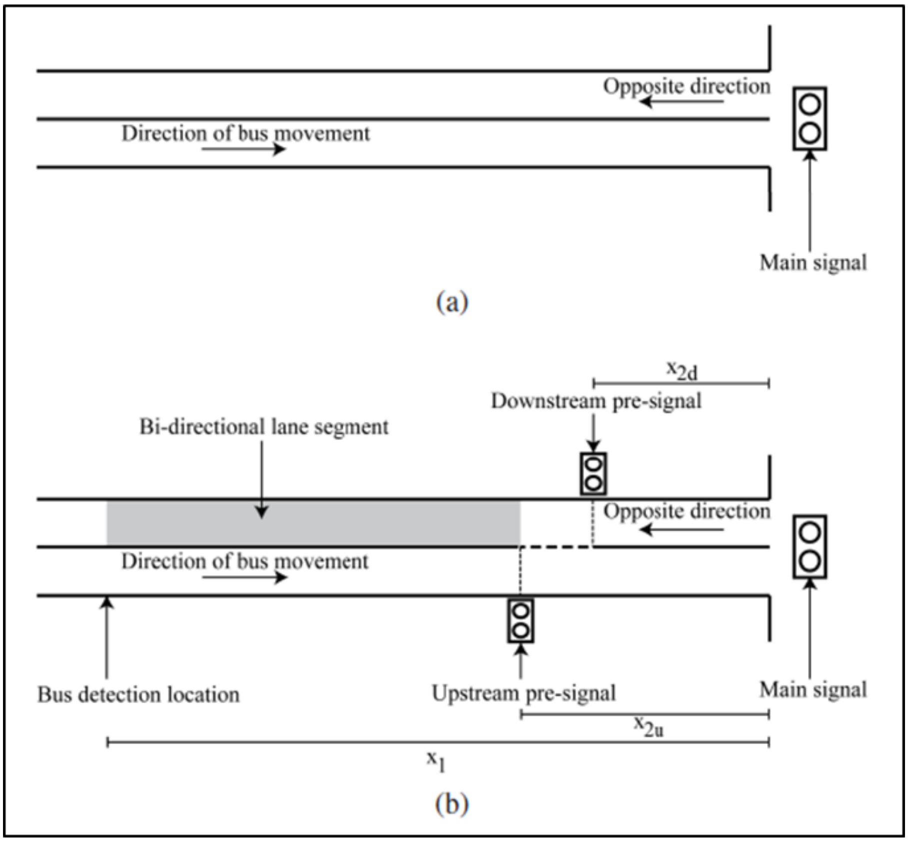

Figure 5: (a) Intersection with single lane approaches; (b) Pre-signal strategy (Ilgin Guler, Gayah, & Menendez, 2015)

The authors quantified the delay savings that the buses achieved as well as the negative impact that cars experienced when this method was applied. The study found that, in the under-saturated case, significant bus delay savings and/or improved system-wide delays overall can be achieved with sigle-lane approaches under the following conditions:

- V/C less than 0.85,
- A distance of at least 7 meters between the pre-signal location and the intersection,
- A turning ratio from the cross-street of less than 25% is observed.

A theoretical analysis of an over-saturated case, however, suggests that although the average bus delay savings can be up to 30 seconds, the loss in capacity can be as much as 25%.

3.3 QUEUE-JUMPING LANE

A queue-jumping lane allows the proposed high occupancy vehicle to bypass queued traffic, giving them the opportunity to gain an advantage at a signalised intersection. As the vehicle approaches the intersection, they leave the queue and enter the queue jump lane. A priority signal, thereafter, allows them to get a head-start on the other traffic and merge into the general traffic lane.

Preferential treatments are needed for high-occupancy transit vehicles to improve their operations. Zlatkovic et al. (2013) evaluated the individual and combined effects of a queue-jumping lane and transit signal priority on the performance of a BRT system. They found that for each case, namely, queue-jumping, transit signal priority, and a combination of the two, the BRT was offered significant benefits whereas certain impacts were imposed on vehicular traffic. The greatest benefit to the BRT was observed with the combination scenario: the BRT travel times were reduced by between 13% and 22%; there was a significant improvement of the progression of the BRT vehicles through the networks; a reduction in intersection delays and waiting time; a significant increase in speed of 22%; and the travel time, reliability, and headway adherence were better than the other two scenarios. Furthermore, it was found that the implementation of any of the three transit preferential treatments did not affect vehicular traffic negatively. In fact, in some cases small improvements of 2% in the reduction of travel times were observed. The network performance of the BRT vehicles was also improved in all the transit preferential treatments when compared to the base case, the greatest of which was observed in the combination of queue-jumping and transit signal priority scenario.

The largest draw-back in the implementation of the transit preferential treatment is the deterioration of the vehicular traffic performance on a network-wide level, the majority of which was observed on cross-streets.

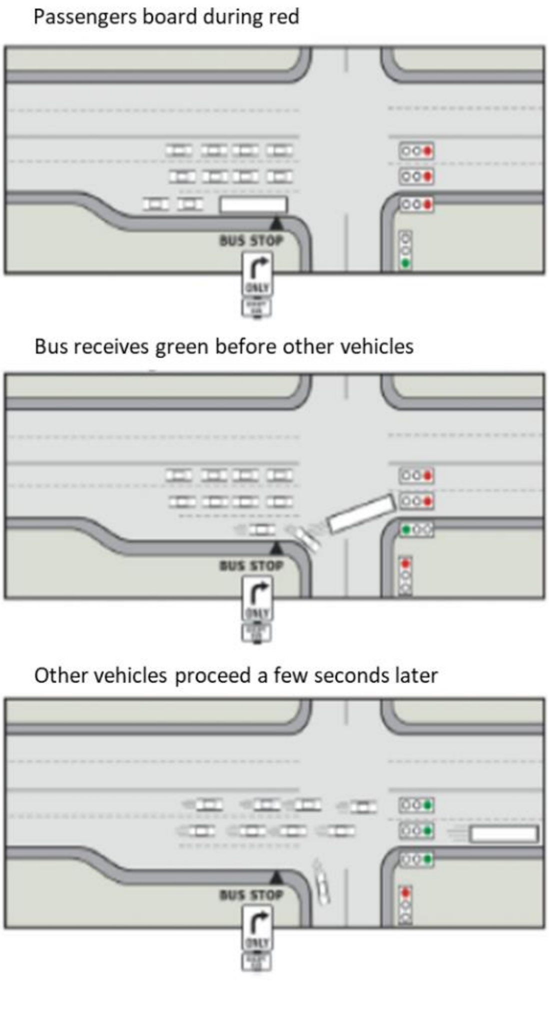

Figure 6: Queue jump lane (adapted from Cesme et al. (2014))

4. MODEL DESIGN

4.1 MODEL INPUT PARAMETERS

4.1.1 Signalised Intersection Design

The design of the intersection forms the base of the model development: the signalised intersection determined the waiting time at the intersection as well as the queue lengths that formed as a result. These values are then used to determine the subsequent user costs and operating costs.

Table 1 provides the input variables used in the signalised intersection design. Each variable is briefly explained.

Table 1: Input variables used in the signalised intersection design

Variable	Description
Average delay per vehicle (minibus taxis and private vehicles)	• The average delay per vehicle is given by the following equation: $d_{avg} = \frac{r^2}{2C(1-{}^{v}/_{s})}$ (10) Where: r: Effective red time for a traffic movement in seconds C: Cycle length in seconds v: Arrival rate in vehicles/second s: Departure rate in vehicles/second • This value is used as an input value to determine the red cycle time for each case. • An average value of 12 seconds per vehicle, corresponding to a level of service (LOS) B is used. • In the infrastructure forms where minibus taxis receive a priority signal, the average delay is calculated separately for this mode.

Variable	Description
Cycle length in seconds	• The cycle length of 60 seconds is used in the intersection design.
Arrival rate in vehicles/second	• The arrival rate is based on traffic counts that were carried out on a road corridor where different transportation modes operate.
Departure rate in vehicles/second	• Minibus taxis and private vehicles are assumed to have the same departure rate. • A departure rate of 3600 vehicles/hour is used, or 1 vehicle/second.

4.1.2 User Cost

Determining the user cost depends on the relevant vehicle characteristics for both private vehicles as well as minibus taxis. The values of the variables that were kept constant for the entire analysis were determined from observations performed on traffic footage.

The travel speeds of vehicles at various locations in and around a city were also required. The speeds were obtained from the public transport cost model that del Mistro and Aucamp (2000) developed. Table 2 provides a summary of the different speeds as they relate to the possible locations where the infrastructure can be implemented. Table 3 provides the salient input variables used in calculating the user cost with each variable being briefly explained.

Table 2: Travel speeds at various locations in a city

Location	Speed (Vf)
CBD/Commercial in-peak	25 km/h
Arterial in-peak	50 km/h
Residential in-peak	60 km/h
CBD/Commercial off-peak	25 km/h
Arterial off-peak	50 km/h
Residential off-peak	60 km/h

Table 3: Input variables used in calculating user cost

Variable	Description
Acceleration and deceleration rate, a	• The acceleration and deceleration rates are assumed to equal and the same for private vehicles and minibus taxis. • An average acceleration rate of 3.5 m/s^2 was used.
Vehicle capacity	• The maximum capacity of a private vehicle is assumed as 5 passengers whilst that of the minibus is taken as 18 passengers. • A ratio of 18 minibus taxi passengers to 1.5 private vehicle passengers is used.
Passenger handling time	• The passenger handling time includes the time a passenger takes to board and alight a minibus taxi. • This variable was not considered with the case of non-public transport forms. • 8 seconds per passenger is used for modelling.
Time for opening and closing doors, c	• Time taken to open and close doors of the minibus taxi was assumed to equal that of a BRT which is 3 seconds.
Vehicle length	• The length of the minibus taxi is based on the length of the Toyota Quantum which is 5.38 m.
Speed on entering the curb-side stop	• This speed forms part of the calculations determining the total service time of a minibus-taxi on the curb-side stop form of service infrastructure. • A speed of 3 m/s was used for the speed at which minibus taxis enter and exit the curb-side stop.

To determine the user cost in terms of a monetary value it is necessary to have a value of time to attach to each of the three main income groups: low, medium, and high. Since the year 2010 several value of travel time savings (VTTS) have been made in South Africa. Different survey types and choice models were conducted to estimate these values (Hayes, 2018). Table 4 summarises the income groups and their corresponding values of time along with the percentage of each income group that makes use of cars and minibus taxis respectively (Department of Transport, 2013).

Table 4: Private vehicle and minibus taxi user income group, value of time, and proportion

Income group	Value of time	Proportion (%)
Private Vehicle User		
Low income	R4.00	7.4
Middle income	R18.00	18.5
High income	R31.00	74.0
Minibus Taxi User		
Low income	R4.00	28.1
Middle income	R18.00	45.9
High income	R31.00	26.0

4.1.3 Operator Cost

The operator cost consists of all the costs incurred whilst operating a vehicle. The vehicle operator salary, as well as the subsequent variables in the operating cost pertaining to the minibus taxis, were attained from the Taxi Recapitalisation Viability Model (Department of Transport, 2008). The values were adjusted for inflation using a rate of 4.5%.

Table 5 summarises all the input variables used in calculating the operating cost as well as briefly describing each.

Table 5: Input variables used in calculating operator cost

Variable	Description
Vehicle operator salary	• The monthly salary of a minibus taxi operator is R20 000,00.
Tyres and other expendables	• Contingencies and the cost of tyres per month amounts to a total of R5 735,00.
Vehicle maintenance	• The cost of maintaining a minibus taxi over a month totals R4 303,00 per month.
Facility maintenance	• The cost to rent the premises where the minibus taxis are stored costs R811,00 per month.
Administrative costs	• The administrative costs consist of unemployment insurance fund, a cell phone payment, and a bookkeeping cost, which amounts to R1 168,00 per month.
Supervision and control centre	• Satellite tracking and the cost of the vehicle license add up to a total of R1 104,00 per month.

Variable	Description
Fuel cost	• The cost of fuel, per litre, was taken as R16.48, the price as at the 1st of June 2019 (Automobile Association, 2019).
Fuel consumption	• The travelling consumption for fuel for private vehicles and minibus taxis were chosen as 7 *l*/100km and 12 *l*/100km respectively (Automobile Association, 2013; Hill, 2017).
Fuel idling	• The idling fuel for private vehicles and minibus taxis were taken as 1.2 *l*/hour and 1.5 *l*/hour respectively.
Vehicle-Hours	• The number of hours that a minibus taxi travelled in a month, which was taken as 264 hours.
Vehicle-Distance	• The distance that the average minibus taxi operator travels in a month. • 18 000 kilometres was used (Department of Transport, 2008).

4.1.4 Construction Cost

The construction costs, as enumerated by del Mistro and Aucamp (2000) in their research *"Development of a public transport cost model"* is summarised in Table 6. These values were used to determine the capital costs of each form of infrastucture.

Table 6: Output variables used in the signalised intersection design

Variable (Unit)	Value
Cost of way (Rm/lane-km)	1.045
Land cost - CBD/Commercial (Rm/lane-km)	0.875
Land cost - Outer section (Rm/lane-km)	0.23
Land cost – Residential (Rm/lane-km)	0.105
Minimum cost of station/stop (Rm)	0.4
Life of terminals (years)	20

4.2 MODEL OUTPUT VARIABLES

4.2.1 Signalised Intersection Design

The two main outputs required in the design of the signalised intersection are the effective red time and the effective green time, summarised in Table 7, will be used to determine the waiting time at the intersection and the flow of vehicles through the intersection respectively.

Table 7: Output variables used in the signalised intersection design

Variable	Description
Effective red time in seconds	• The effective red time is the time during which a traffic movement is not effectively utilising the intersection. • The value is calculated using the following equation: $r = \sqrt{d_{avg} \cdot 2C \cdot (1 - {}^{v}/_{c})}$ (1)
Effective green time in seconds	• The effective green time is the time during which a traffic movement is effectively utilising the intersection. • The value is calculated with the following equation: $g = C - r$ (2)

4.2.2 User Cost

The user cost, for minibus taxis, consists of the sum of the estimated service time, waiting time at the red traffic signal phase, time taken to accelerate and decelerate, and travel time. For cars, this variable is the same as that of minibus taxis except service time is excluded. The output variables are described in Table 8.

Table 8: Output variables used in calculating user cost

Variable	Description
Estimated service time	• In the case of the curb-side taxi stop, the minibus taxis will make their stop according to the following equations (adapted from Bian et al., 2015):

Variable	Description
	$T_s = T_d + T_m$ (3) $T_d = c + \left\{ \sum_{h=1}^{m} a_h + \sum_{q=1}^{n} b_q \right\} + t_{we} + t_{wl}$ $= T + t_{we} + t_{wl}$ (4) $T_m = t_e + t_l$ (5) Where: T : Bus dwell time at bus stop a_h : Consumed time of each passenger h for boarding b_q : Consumed time of each passenger q for alighting m : Number of boarding passengers n : Number of alighting passengers C_d : Time for opening and closing doors T_s : Service time at the bus stop T_d : Dwell time in and/or out of the bus stop T_m : Time in which buses move in and out of the bus stop t_{we} : Time in which buses wait to enter the bus stop t_{wl} : Time in which buses wait to leave the bus stop t_e : Time in which buses enter the bus stop t_l : Time in which buses leave the bus stop • For the remaining two forms of infrastructure, namely, the queue-jumping lane, and the single lane pre-signal strategy, the minibus taxis will pick up and drop off passengers during the red phase of the traffic cycle.
Wait time at red	• The waiting time during the red phase is the same value as the pre-set average delay experienced by each vehicle as determined in the input variables. • In the cases of the queue-jumping lane and the single lane pre-signal strategy, where the minibus taxis receive a pre-signal advantage, the wait time is calculated separately.
Acceleration and deceleration time	• The following equation was used to calculate this time in hours:

Variable	Description
	$$T_a = 2 \times \frac{\frac{Vf}{3.6}}{\frac{a}{3600}} \quad (6)$$ Where: Vf : Final velocity (km/h) a : Acceleration/deceleration rate (m/s^2)
Travel time	• The travel time consists of the distance of the corridor divided by the speed as well as the time taken to accelerate and decelerate.
User cost	• The user cost, finally, is the total travel time multiplied by the value of time for each income proportion of the respective transportation form.

4.2.3 Operator Cost

The operator cost for minibus taxis consists of the fuel cost, and the vehicle-time, -distance, and -fleet costs. For the private vehicle operator costs, the running cost and maintenance cost were obtained from the Automobile Association of South Africa. The operating cost output variables are described in Table 9.

Table 9: Output variables used in calculating operating cost

Variable	Description
Fuel cost	• The fuel cost is the sum of the idling fuel cost and the travelling fuel cost.
Vehicle-time cost for taxis	• The total time-dependent cost for a minibus taxi is divided by the total number of hours travelled during a 1-month period and multiplied by the number of hours it would take a taxi to travel the length of the corridor.
Vehicle-distance cost for taxis	• The total distance-dependent cost for a minibus taxi is divided by the total number of kilometres travelled during a 1-month period and multiplied by the length of the corridor in consideration.
Vehicle-fleet cost for taxis	• The total fleet-dependent cost for a minibus taxi is divided by the fleet size which, for the sake of this model, was kept at 1. • The vehicle-fleet cost was converted to a rate per hour and then multiplied by the number of hours it would take a taxi to complete the route.

Variable	Description
Running cost for cars	• A value of R3.74/km was used to determine the running cost (Automobile Association, 2013).
Maintenance cost for cars	• The maintenance cost was calculated using the value of R0.40/km (Automobile Association, 2013).
Operating cost	• The total operating cost is obtained by finding the sum of the relevant values.

The construction cost for the different forms of priority infrastructure was determined by using the input cost values and multiplying it by the length of the road infrastructure. It is necessary to note that the single lane pre-signal strategy had no construction costs involved as an existing section of road would be utilised for its purpose. The outputs considered in the model are summarised in Table 10.

Table 10: Output variables used in calculating construction cost

Variable	Description
Construction cost per hour	• The construction cost per hour reduces the total cost of the infrastructure to an hourly cost by dividing it by the design life in years, which has been converted into the equivalent hours.
Construction cost per one-way trip	• The cost of the infrastructure for a one-way trip takes the construction cost per hour and multiplies it by the time a minibus taxi takes to complete a one-way trip.

5. APPLICATION: MODEL OUTPUTS

5.1 SIGNALISED INTERSECTION DESIGN OUTPUTS

A constant cycle time of 60 seconds was used to determine the intersection queueing diagram and an average delay of 12 seconds per vehicle, relating to a level of service of B, was used to calculate the duration of the effective green and red times. The arrival and departure lines were plotted using the rates determined from conducting traffic counts along a busy corridor in Pretoria. The arrival rates of private vehicles and minibus taxis are summarised in Table 11.

Table 11: Arrival rate of private vehicles and minibus taxis

Location	Private vehicle arrivals (veh/h)	Minibus taxi arrivals (veh/h)
CBD/Commercial in-peak	1273	350
Arterial in-peak	1965	94
Residential in-peak	985	225
CBD/Commercial off-peak	634	144
Arterial off-peak	1364	42
Residential off-peak	534	81

The signalised intersection queueing graph that applies to the curb-side taxi stop intersection is illustrated in Figure 7.

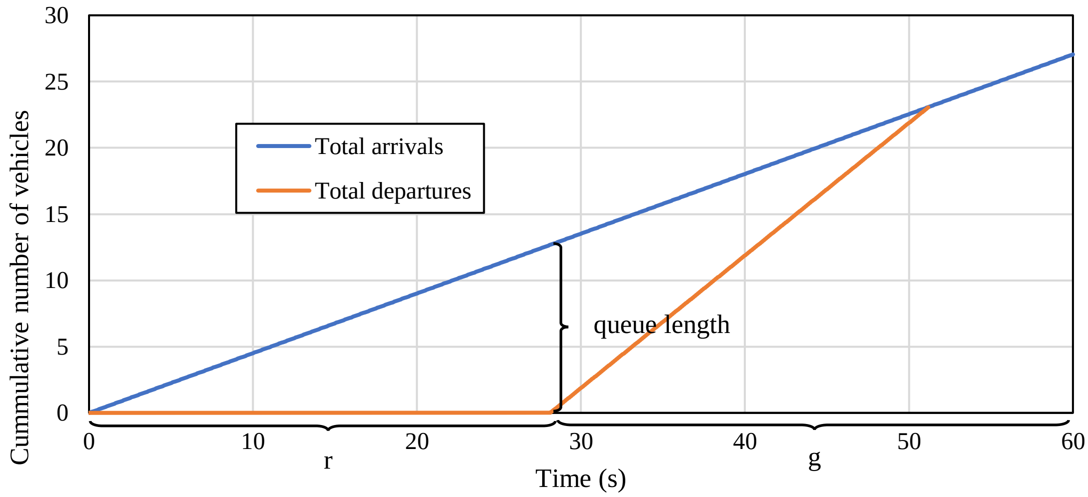

Figure 7: D/D/1 signalised intersection for the curb-side taxi stop intersection

The intersection for the curb-side taxi stop form of infrastructure causes the longest queue to form over the duration of the red (r) traffic cycle. Over the 28.1 second red cycle, a queue length of 12.7 vehicles form with a combination of private vehicles and minibus taxis. The entire queue dissipates after 51.2 seconds from the start of the red cycle or 23.1 seconds into the green (g) cycle. The intersection capacity, as is the case with all the queueing diagrams, amounts to 1913 vehicles per hour and is therefore able to accommodate all the traffic arrival rates as they were identified in different locations in the city except for the in-peak flow rate on an arterial road. This flow exceeds the intersection capacity by 197 vehicles per hour.

The intersection queueing diagram pertaining to the queue-jumping lane and the single lane pre-signal strategy is illustrated in Figure 8. The same design applies to both forms of infrastructure as their methods of providing minibus taxis with a pre-signal priority is similar. In the first phase of the queueing diagram both the minibus taxi (t) and the private vehicle (c) queues start to build. The minibus taxis then receive a priority green after which they re-join the regular traffic as can be seen in the change in gradient of the "mixed-traffic arrivals" curve.

The dedicated green phase for the minibus taxis is not granted at the cost of green time for the private vehicles, but rather by shortening the red time. This means that the delay for private vehicles would not be affected by the priority green phase.

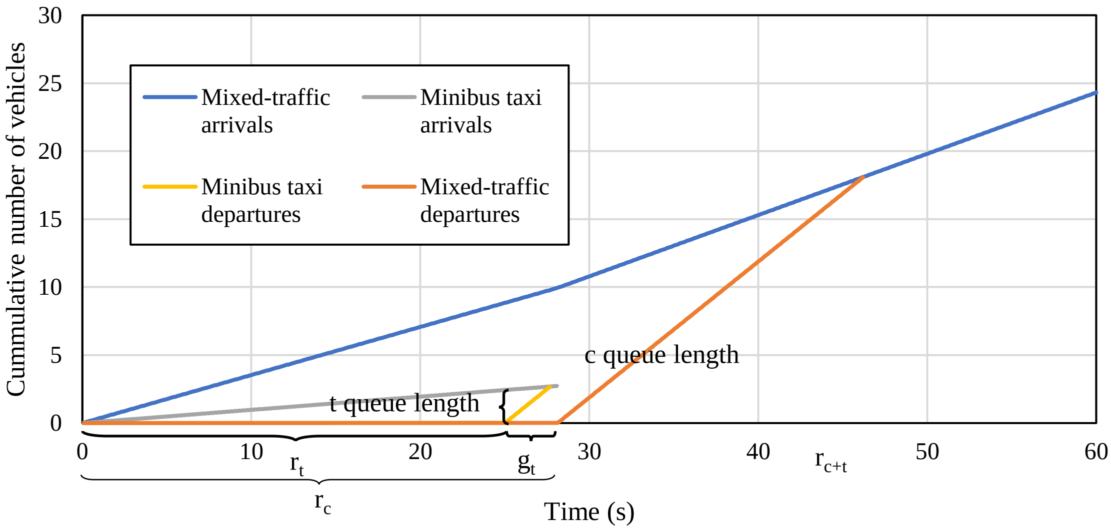

Figure 8: D/D/1 signalised intersection for the queue-jumping lane and the single lane pre-signal strategy intersections

Providing the minibus taxis with a pre-signal priority of 3.1 seconds effective green time allows an average of 2.7 taxis to skip the queue over each traffic cycle. This amount of time is sufficient to allow the queue of minibus taxis to dissipate. The length of the section of road on which the minibus taxis queue is designed to be at least 11 metres long which will accommodate the highest flow of these vehicles. At the end of the pre-signal priority the minibus taxis and private vehicles travel in the same lane as the stream of mixed traffic. This results in an increase in traffic flow at 28 seconds into the cycle. The entire queue dissipates after 46.2 seconds which is 5 seconds shorter than in the case of the curb-side taxi stop.

The private vehicle delay of 12 seconds per vehicle was kept constant over all modes of infrastructure whereas the minibus taxi delay varied due to the pre-signal priority. Over the duration of the red cycle, the delay was 12.3 seconds per taxi but after the pre-signal phase ends, the delay per taxi drops to 5.1 seconds. This is due to minibus taxis joining the mixed traffic once the queue has started dissipating.

5.2 COST OUTPUTS

5.2.1 Travel Time

The travel time comparisons between minibus taxis and private vehicles across the three forms of transit infrastructure are illustrated in Figure 9. The vertical axis indicates the time taken to complete a one-way trip of one kilometre.

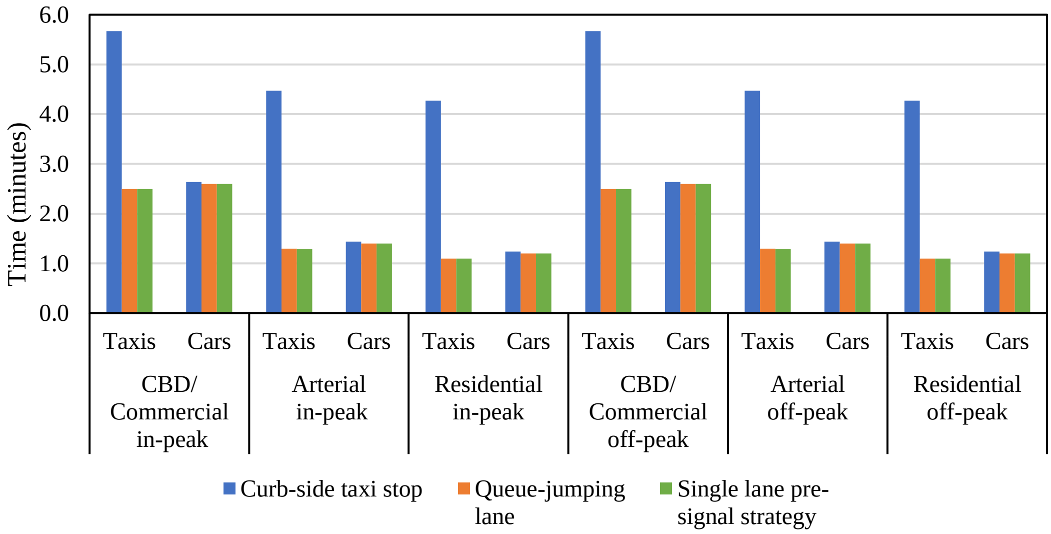

Figure 9: Travel time comparison between minibus taxis and private vehicles

Considering the CBD/commercial in-peak route, there is a significant decrease in travel time when comparing the curb-side taxi stop to the other two infrastructure forms with a 56% decrease equating to a faster travel time of 3.2 minutes. This is attributable to the priority green phase that minibus taxi operators receive over each cycle. At the end of the dedicated green phase the minibus taxis travel with the mixed traffic but the delay that they experience over the all-green phase is significantly smaller than what they would have experienced had such a priority not been granted.

In the case of private vehicles, there is a 1% decrease in travel time when comparing all the transit infrastructure forms to that of the curb-side stop. This is due to the delay that minibus taxis cause when they decelerate to enter the curb-side bay which is not the case for the remaining four transit infrastructure forms.

When considering the three different locations in the city, the CBD/commercial corridor has the longest travel time, followed by the arterial and the residential corridor. The travel times correspond to the average speed inputs used in the model.

5.2.2 User Cost

The comparison in user cost per hour between minibus taxis and private vehicles across the three forms of transit infrastructure are illustrated in Figure 10. This considers the total cost of all passengers that are transported along the corridor.

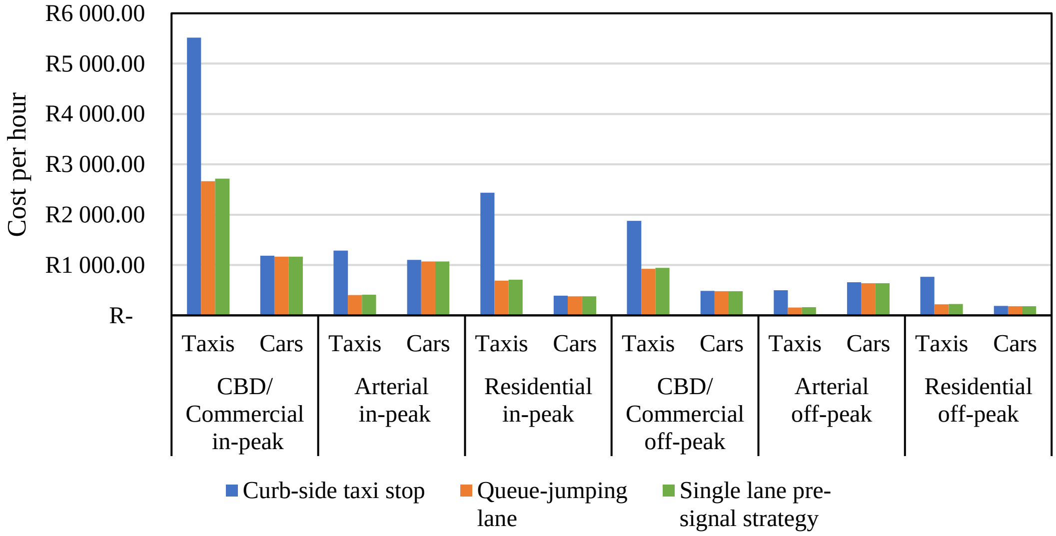

Figure 10: User cost per hour comparison between minibus taxis and private vehicles

The outputs from the user cost comparison correlates with the outputs obtained from the travel time. The decrease ranges between 52% and 72% when the infrastructure forms are compared to their respective curb-side taxi stops.

The user cost is not only affected by the travel time but also by the number of passengers travelling on the route – more passengers equate to a greater total value of time. This explains the decrease in user cost over the corridor locations. The output from the private vehicle traffic corresponds to the arrival rate at the intersection and there are no significant fluctuations across the transit modes.

The results from Figure 10 are reduced to a user cost per passenger per trip by dividing the total hourly user cost by the number of traffic arrivals per hour and the vehicle occupancy which is 18 and 1.5 for minibus taxis and private vehicles respectively. Figure 11 illustrates these results.

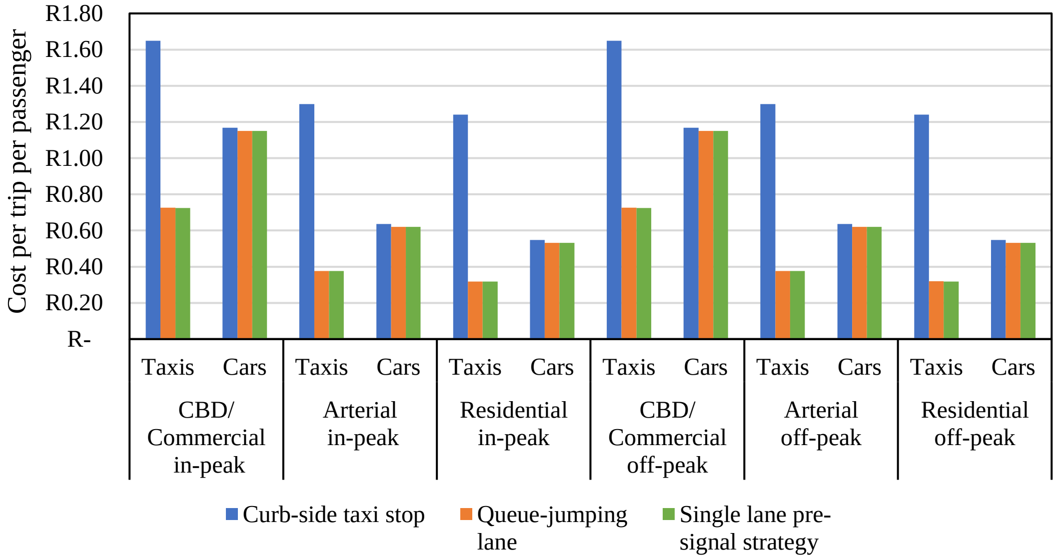

Figure 11: User cost per passenger per trip comparison between minibus taxis and private vehicles

The value of time for private vehicle users, as discussed earlier, is significantly greater than that of a minibus taxi passenger comparing at R26.57 and R13.36 per passenger respectively. Including the value of time for different income groups, however, is necessary to compile an economic model that reflects the situation accurately. It was observed that for both the queue-jumping lane and single lane pre-signal strategy, the minibus taxi user cost is R0,24 lower than the private vehicle user cost. This needs to be taken into consideration when deciding which forms of infrastructure to implement and to what extent it will be successful.

5.2.3 Operator Cost

The operating cost per hour of travel for minibus taxis and private vehicles is illustrated in Figure 12.

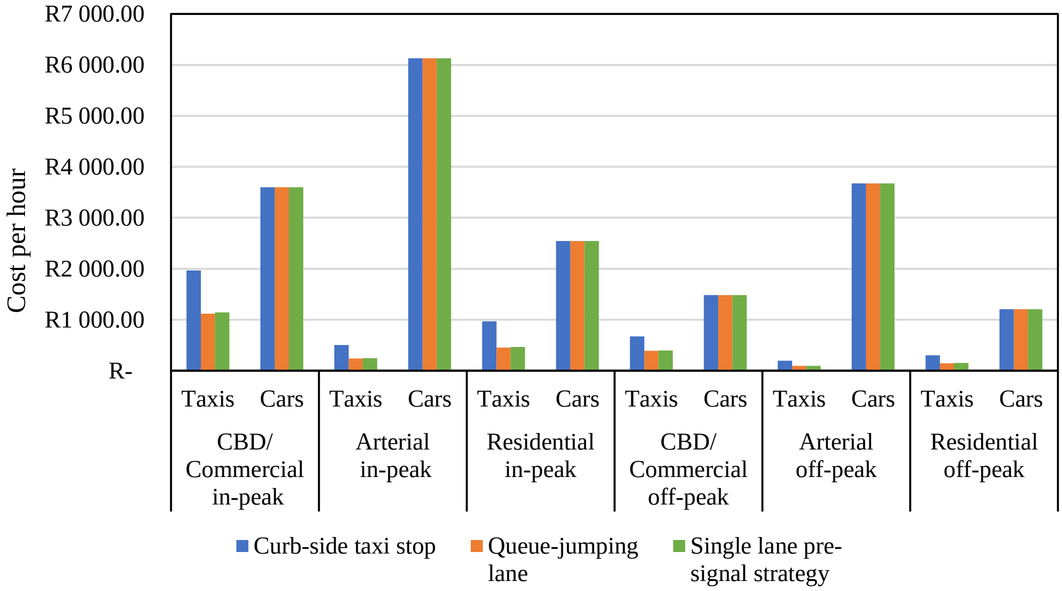

Figure 12: Operating cost per hour comparison between minibus taxis and private vehicles

The operating cost for both minibus taxis as well as private vehicles are functions of time, distance, and vehicle arrival rate. Since the distance was not varied in the base scenario of the model, travel time and frequency of vehicles travelling along the route are directly related.

The minibus taxi operating cost sees a 51% decrease when the curb-side stop is compared to the queue-jumping lane and a 50% decrease when it is compared to the single lane pre-signal strategy.

Considering the inputs of the base scenario of a minibus taxi operator working 264 hours in a month, the results summarised in Table 12 are obtained pertaining to the monthly savings due to the priority infrastructure.

Table 12: Monthly savings per minibus taxi with each infrastructure form

Infrastructure	Savings cost/taxi	Trips/month	Monthly savings/taxi
Queue-jumping lane	R5.09	6 345	R32 298
Single lane pre-signal strategy	R5.10	6 352	R32 396

The cost in savings that a minibus taxi operator can make, when driving along the same corridor for the entire month can amount to over R32 000. It should be noted that this is an idealised situation. This does, however, make a strong case for the implementation of these infrastructure forms on busy corridors as it is clear that significant monthly savings would be one of the biggest benefits to adopting this solution.

5.2.4 Total Cost

The total cost per one-way trip for minibus taxis and private vehicles is illustrated in Figure 13.

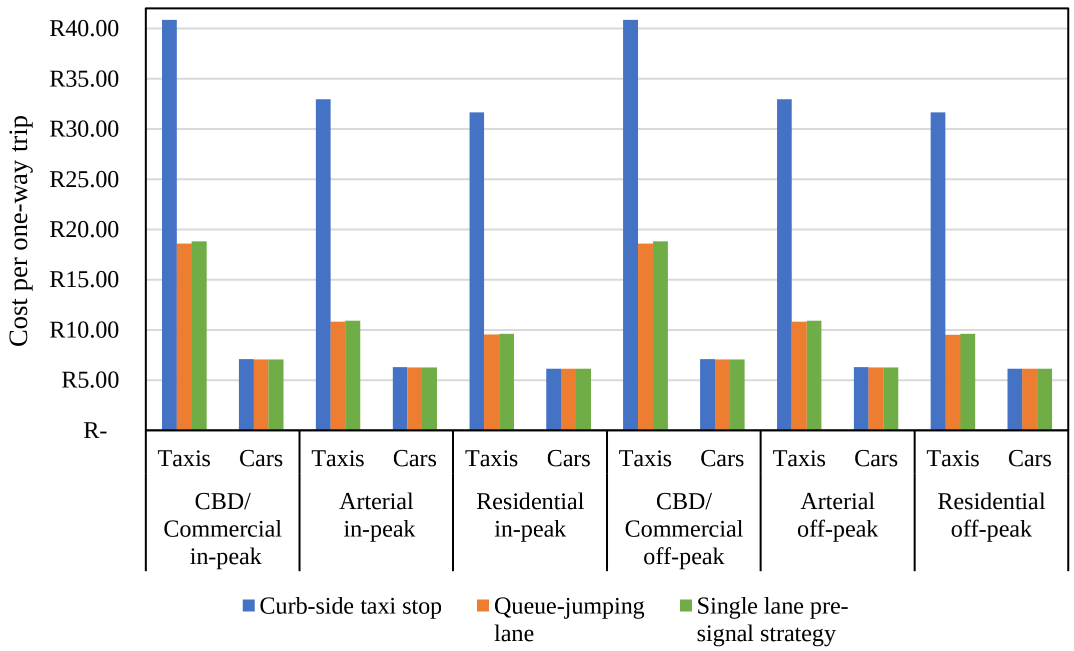

Figure 13: Total cost per vehicle per one-way trip comparison between minibus taxis and private vehicles

The total cost per hour takes the user, operating, and construction costs into account. The construction cost, however, is only applied to the cost for minibus taxis. In the CBD/commercial location during peak traffic there is a 54% reduction in total cost per one-way trip when the curb-side taxi stop is compared to the other infrastructure forms. In this traffic scenario the queue-jumping lane has the lowest cost per trip at R18.60, followed by the single lane pre-signal strategy at R18.80. The cost per trip for a private vehicle amounts to R7.07 which is significantly less costly than the minibus taxi. This cost, however, is not a truly indicative cost as it does not consider the number of passengers in the vehicle.

The total cost per passenger per one-way trip for minibus taxis and private vehicles is illustrated in Figure 14.

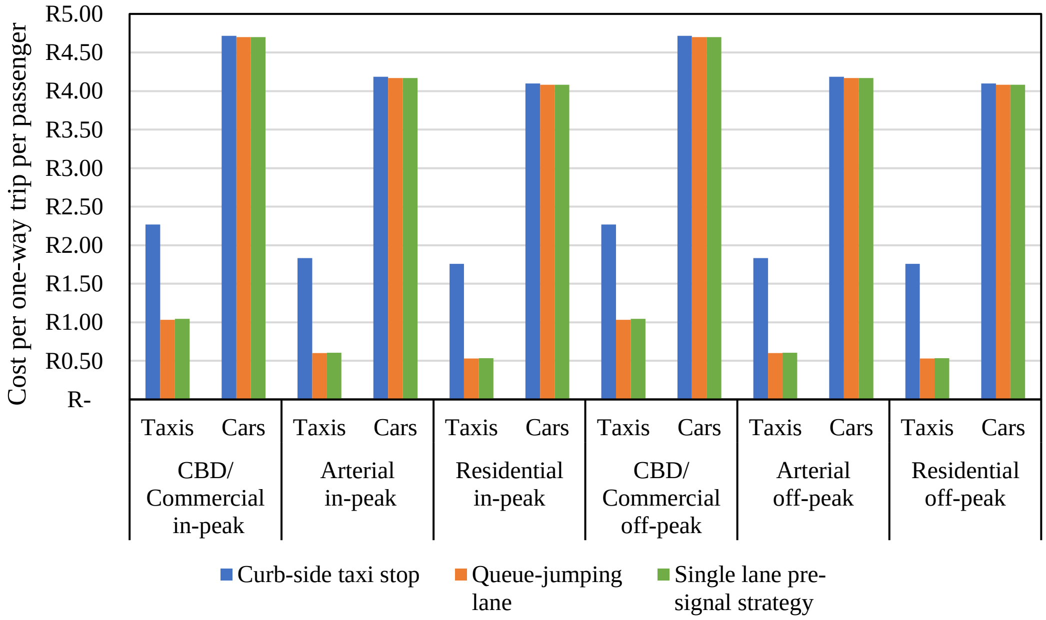

Figure 14: Total cost per passenger per one-way trip comparison between minibus taxis and private vehicles

When the cost per passenger is considered, it becomes clear that the total cost per trip for minibus taxis is significantly less than that of private vehicles. When considering the CBD/Commercial location, the cost per trip ranges between R1.04 for the single lane pre-signal strategy, and R2.27 for the curb-side taxi stop. The cost for a passenger-trip in a private vehicle is R4.72.

6. CONCLUSIONS

The outputs delivered by the model included travel time, user cost per hour, operating cost per hour, fuel cost per one-way trip, and total cost per hour. The results of the outputs are summarised as follows:

- When compared to the curb-side taxi stop, the queue-jumping lane and single lane pre-signal strategy both show the greatest reduction in travel time with a 56% decrease equating to a 3.2-minute reduction in travel time.
- Both forms of infrastructure, when compared to the curb-side taxi stop, show a reduction in user cost varying between 52% and 72%.
- When the user cost is reduced to a cost per passenger per trip, the user cost per minibus taxi passenger is lower than that of a private vehicle passenger for both the single lane pre-signal strategy and the queue-jumping lane.
- The operating cost decreases by 51% when the curb-side taxi stop is compared to the queue-jumping lane and 50% when compared to the single lane pre-signal strategy.

- The monthly minibus taxi operator savings was over R32 000 in the case of the queue-jumping lane and single lane pre-signal strategy.
- When the total cost per passenger-trip is considered in the CBD/Commercial location, the cost per trip ranges between R1.04 for the single lane pre-signal strategy, and R2.27 for the curb-side taxi stop. The cost for a passenger-trip in a private vehicle is R4.72.

Providing minibus taxis with the advantage of reduced delay not only saves the operator money due to reduced wear and tear on the vehicles, and also not only saves the driver time allowing more trips to be made and thus increasing the income but, perhaps most importantly, it saves time for the passengers, often travelling very long distances, spending numerous hours on the road each week due to living far from work as a result of spatial injustices of the past.

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