STRATEGIC ASSESSMENT OF THE IMPACT OF THE PRIORITY INFRASTRUCTURE ON THE PERFORMANCE OF MINIBUS-TAXI SERVICES IN THE CONTEXT OF SOUTHERN AFRICA

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ABSTRACT

The minibus taxi industry has grown to become the largest provider of transport to the urban public. Attempts have been made by government to regulate, integrate, and upgrade this sector but all such efforts have been largely unsuccessful. Taxi drivers face immense pressure from passengers and the taxi industry to increase their performance which leads to hostile driving behaviour and often fatal accidents on the road. Transit priority measures have been used to advance the quality of service of buses and BRT vehicles but have not been extended to include the paratransit industry. The single lane pre-signal strategy was identified as an alternative to the traditionally used curb-side stop to load and offload passengers. The purpose of the paper was to quantify the economic impact that such a form of infrastructure would have on minibus taxi operators, passengers, and other road users. It was observed that there was 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. It was concluded that not only is South Africa ready for such a disruptive change, but it is a necessity to redress the injustices of the past.

1. INTRODUCTION

The paratransit industry in South Africa has grown from a modest, small 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 & Behrens, 2017). It is necessary for governing entities in developing-world cities to appreciate paratransit services in that they provide a large number of the population with the essential service of mobility and to not merely view them as a necessary nuisance. Promoting the taxi industry has been found to hold many scientific, social, and political opportunities to those using the service (Woolf & Joubert, 2013).

Attempts made by government to regulate, upgrade, and integrate the paratransit sector into the formal sector have been met with great resistance. Schalekamp and Behrens (2010) argue that the reason for this is that the processes that have been undertaken to incorporate the informal with the formal transport industry have been flawed and unless the current processes are earnestly reviewed, there is little chance for the formalisation of the paratransit industry. Schalekamp and Behrens suggested that structured and detailed negotiations will have to become the norm when engaging with the operator and companies and such negotiations will have to take place at a much more decentralized level.

There have been recent initiatives to overhaul public transport systems in an attempt to address the legitimate deficiencies of the minibus taxi system with the result often being 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 among which include undercover loading lanes, public toilets, and office space (Schalekamp & Klopp, 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.

2. OBJECTIVES OF THE PAPER

The objectives of the study are summarised as follows:

- To identify priority infrastructure alternatives from literature and to determine its suitability for improving operating conditions in the paratransit industry.
- To develop mathematical models to ascertain the suitability of various priority infrastructure measures under a range of operating and demand conditions.
- To quantify the high-level economic impact that selected priority infrastructure would have on the paratransit operators, the passengers, and other road users.

3. THE CHALLENGES FACING THE PARATRANSIT INDUSTRY

There is great concern among road users in South Africa regarding road crashes in which minibus taxis are involved. Between the years 2013 and 2016 there have been a total of 648 fatal taxi crashes in Gauteng that have resulted in 857 deaths (Arrive Alive, 2016). The three main road user categories in which the fatalities occur are the passengers, the drivers, and pedestrians – almost the same number of pedestrians are killed as vehicle occupants. 43% of minibus taxi occupant fatalities occur in urban areas, followed by 32% on main arterials and 25% on freeways.

Govender and Allopi (2007), investigated the trends and factors causing the accidents and identified the two as the most significant: defective brakes and driver pressure. Minibus taxis, by virtue of being the most popular form of public transport in South Africa, are subjected to operating conditions far more severe to that of an ordinary passenger car. Operating at higher speeds to reduce travel time and overloading greatly increases the stopping distance which often results in fatal consequences. This issue gets compounded by the taxi driver having to meet strict daily requirements in terms of number of passengers transported and trips made. In the event of a brake pad or lining requiring replacement, the driver would make the cheapest purchase as this directly influences his wages.

Despite the growth that the industry saw over the past three decades, taxi operators still receive no formal training and do not enjoy any employment protection. There are two main models which are used for the salary structure of a minibus taxi operator: in the first, and most common, the taxi owner specifies the daily amount that the driver has to make – this amount is based on the distance of the operating licence route of that of the vehicle (Woolf & Joubert, 2013). From the total weekly earnings, the driver receives his salary which is typically 30% of the earnings. The money that the driver makes in excess of the specified amount is his to keep. In the second model, the owner will establish a weekly contract price. The driver will then spend the first part of the week working to achieve the contract price. The money the driver makes once the contract price has been reached is his income for the week.

All of the problems that minibus taxi operators face and the negative view that the public has towards them regarding traffic etiquette, safety, consideration, and following the rules of the road stem from the their need to survive financially which encompasses the frequency of their routes travelled, passenger capacity, and the number of passengers transported (Joubert & Woolf, 2014). It is necessary to provide minibus taxi operators with more enabling infrastructure that would give them a greater advantage compared to the regular traffic stream. Transit priority measures have been used to advance the quality of service of buses and BRT vehicles but has not been extended to include paratransit.

4. IDENTIFYING SUITABLE PRIORITY INFRASTRUCTURE

4.1 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).

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.

The service time estimation was used as the basic model for the study and considers the number of passengers boarding and alighting the bus and the dead time **(Bian, et al., 2015)**:

$$\boldsymbol{T = C + max\left\{\sum_{h=1}^{m} a_h, \sum_{q=1}^{n} b_q\right\}} \quad (1)$$

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 : Time for opening and closing doors

There are two types of time delay that can occur at a curb-side bus stop: this first is when a bus can only enter a service area when there is enough space otherwise it must wait for one to open. The second type of delay occurs when the bus attempts to re-enter traffic but has to wait for a large enough gap. The following equations contain the revised service time formulations:

$$\boldsymbol{T_s = T_d + T_m} \quad (2)$$

$$\boldsymbol{T_d = C + max\left\{\sum_{h=1}^{m} a_h, \sum_{q=1}^{n} b_q\right\} + t_{we} + t_{wl}}$$

$$\boldsymbol{= T + t_{we} + t_{wl}} \quad (3)$$

$$T_m = t_e + t_l \quad (4)$$

The definitions of a_h, b_q, m, n, and C are the same as in Eq. (1)

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

4.2 Single lane pre-signal strategy

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 1 below, adapted from research conducted by Guler, et al. (2015), illustrates the setup.

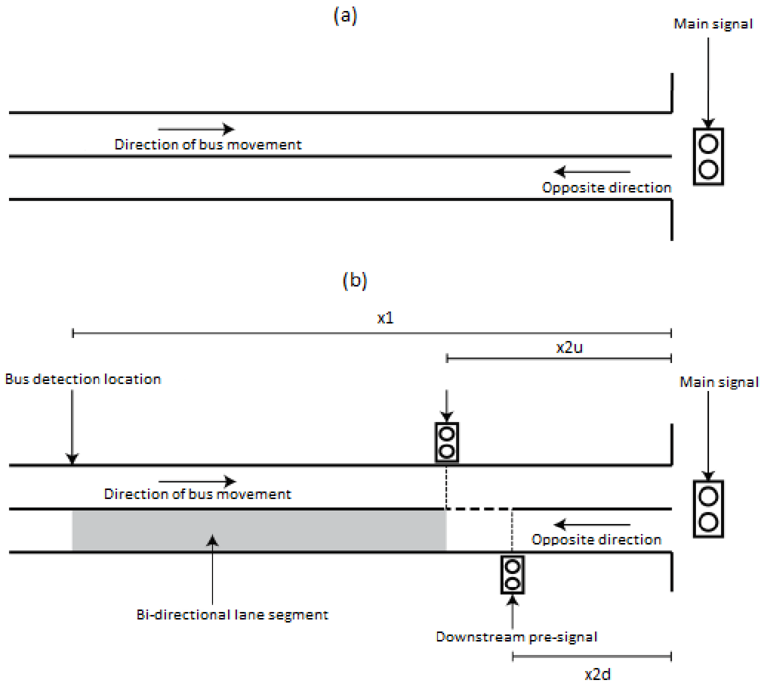

Figure 1: (a) Intersection with single lane approaches; (b) Pre-signal strategy

The author 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.

5. METHODOLOGY

The models are simplifications of the real-world infrastructure forms. Several assumptions were made to simplify the model and to reflect how they would operate as a multi-modal transport environment:

- The travelling speeds as well as acceleration and deceleration rates for minibus taxis and normal vehicles as assumed to be the same.
- A running time of 22 days per month and 12 hours a day is used.
- A design period of 20 years is assumed.
- The cycle time for each case will be kept constant.
- The cost of fuel is taken as R16.00 per litre.
- All models will consist of a single-direction, 1-kilometre corridor.

The intersection consists of a North-South and an East-West single lane-road. The minibus taxis and regular vehicles travel mixed as there is no priority for the paratransit vehicles at the intersection pertaining to the curb-side stop. This form of infrastructure, as with all the following forms, will be compared to a base case of taxis pulling over to the side of the road to pick up travellers as is customary the case. Figure 2 illustrates the schematic model upon which calculations will be based. The taxi stops in the subsequent figures are indicated with a red triangle.

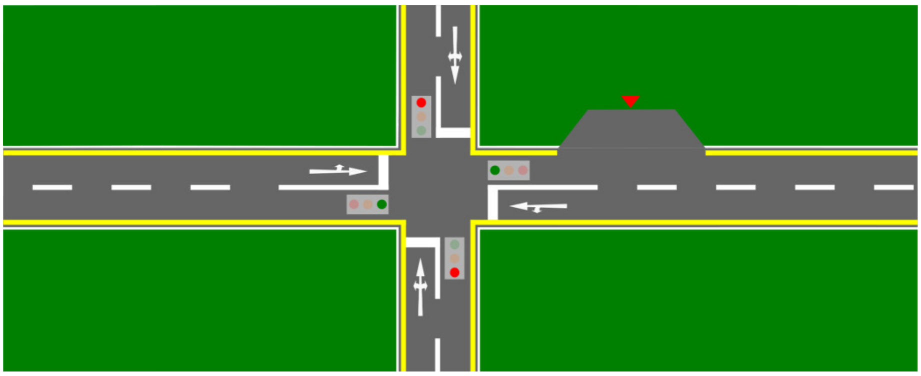

Figure 2: Schematic representation of the curb-side taxi stop

The single lane pre-signal strategy priority infrastructure provides with taxis a time advantage without incurring construction costs. During the North-South green cycle, the vehicles on the East-West corridor start to form a queue. At the end of this cycle minibus taxis will be given a priority green cycle where they can use the right lane to cross the intersection thereafter returning to the left lane. After the taxis have cleared the priority lane, the all-green phase will start, and the intersection will continue to function as normal.

The length of the priority section of road will be designed to account for the number of mixed traffic vehicles that will queue over the duration of the North-South green cycle. Only taxis adjacent to the priority section of road will be permitted to use it to gain a time advantage. The phases of the infrastructure are illustrated in Figure 3.

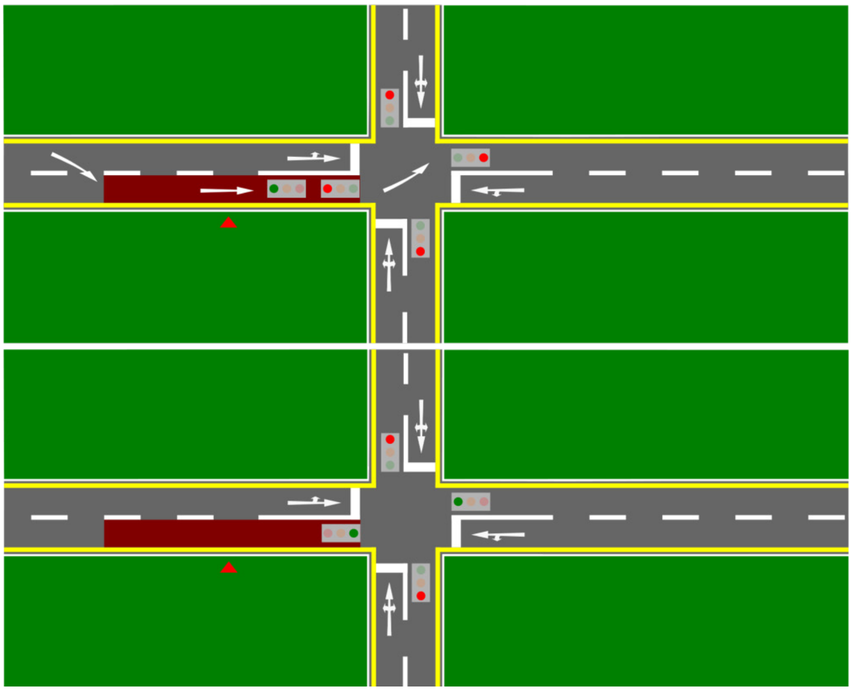

Figure 3: Schematic representation of the single lane pre-signal strategy

Table 1: Variables used in the modelling process

Section	Variable
Signalised intersection design	- Average delay per vehicle - Cycle length in seconds - Arrival rate in vehicles per second - Departure rate in vehicles per second

User cost	- Vehicle capacity
	- Passenger handling time
	- Time for opening and closing doors
	- Acceleration and deceleration rate
	- Income group value of time
	    - Low income (R4.00/hour)
	    - Medium income (R18.00/hour)
	    - High income (R31.00/hour)

Agency cost	- Vehicle operator salary - Tyres and other expendables - Vehicle maintenance - Facility maintenance - Administrative costs - Supervision and control centre - Vehicle-hours - Vehicle-distance
Construction cost	- Cost of way (1.045 Rm/lane-km) - Land cost – Residential (0.105 Rm/lane-km) - Minimum cost of station/stop (1 Rm) - Life of terminals (20 years)

The modelling process requires defining the variables used. The variables are broadly divided into four sections, namely, signalised intersection design, user cost, agency cost, and capital cost. This information in Table 1 provides the variables that are of importance to the user, to gain an understanding of the interface and subsequent results that are calculated by the model as part of the simulation process.

The user cost is calculated by determining the time a vehicle spends driving the length of the corridor, which includes acceleration and deceleration time, travel time, service time, and waiting time at the red. This value is then multiplied by the average cost per hour over the three income groups. The agency cost takes all the vehicle operating costs into account and is multiplied by the time spend in the system or the length of the route to determine the operating cost per hour.

6. RESULTS

The results displayed in this section consists of the travel time, user cost per hour, agency cost per hour, fuel cost per one-way trip, and the total cost for a one-way trip. The model, for both priority infrastructure cases considered the maximum number of passengers that could board and alight the taxi during the service period. Figure 4 illustrates the results obtained pertaining to the travel time difference between the two main modes: taxis and motor vehicles.

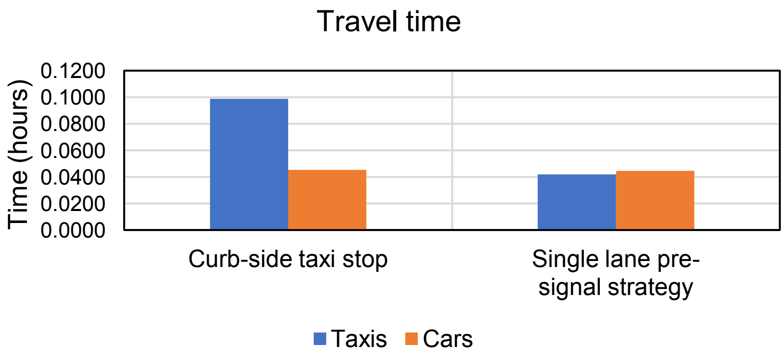

Figure 4: Travel time comparison between taxis and cars

There is a significant decrease in travel time when comparing the minibus taxi travel time of the two different infrastructure forms. This is due to the time constraint applied to the single lane pre-signal strategy: the number of passengers that are able to board and alight the service is dependent on the length of the red phase of the traffic signal. In the case of the curb-side taxi stop, there is no limit to the service time. More passengers are able to transfer with a curb-side taxi stop but this is unnecessary and ineffective as most minibus taxi users completely alight the taxi at the taxi ranks.

There is a 57% decrease in travel time of the taxis between the two infrastructure and a travel time decrease of 2% pertaining to the regular vehicles. The travel time decrease of the cars is due to not having to decelerate when the minibus taxi driver has to slow down to make a stop as is the case with a curb-side taxi stop.

Figure 5 illustrates the user costs per hour when comparing the two transport modes.

The high taxi user cost for the curb-side taxi stop is attributable to the high travel time as a result of the significant service time. The user cost, however, decreases for both the minibus taxis as well as for the cars when the single lane pre-signal strategy is implemented, by 57% and 2% respectively. The difference in user cost when the two transport modes are being compared is due to the minibus taxis having a capacity of 18 passengers, whereas the cars, on average, transport 1.5 passengers at a time.

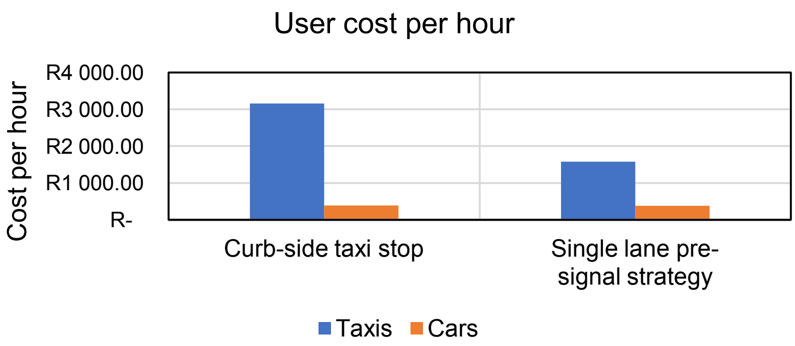

Figure 5: User cost per hour comparison between taxis and cars

The agency cost per hour is illustrated in Figure 6.

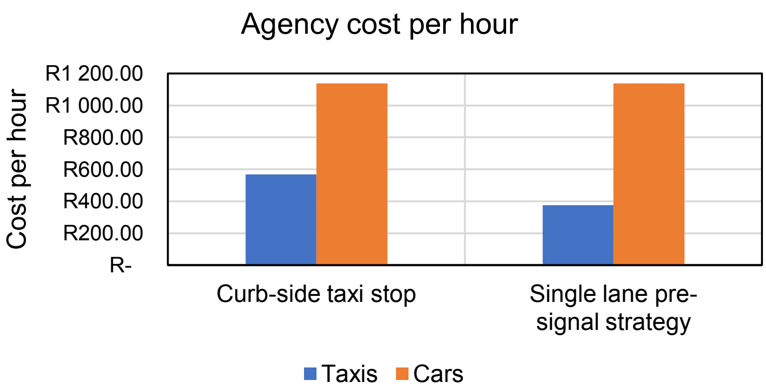

Figure 6: Agency cost per hour comparison between taxis and cars

The minibus taxi agency cost sees a decrease of 34% when moving to the single lane pre-signal strategy. The used cost for cars, however, remains unchanged.

Figure 7 illustrates the fuel cost for a one-way trip.

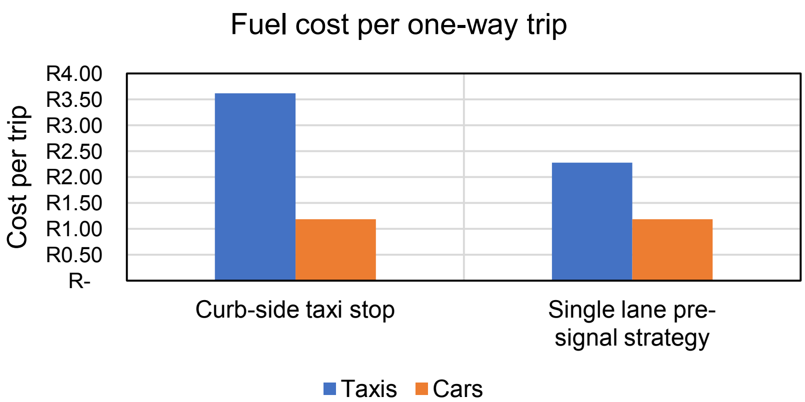

Figure 7: Fuel cost per one-way trip comparison between taxis and cars

The single lane pre-signal strategy is again the more cost-effective solution of the two forms of infrastructure in that there is a 37% reduction in fuel cost of the minibus taxis when compared to the curb-side stop. The reason for this is the travel time is reduced as well as the service time spend which make up the travelling fuel cost and idling fuel cost components respectively. The fuel cost for the cars remain unchanged as the travel time and time spent idling at the intersection stay the same across the two forms of infrastructure.

The cost per one-way trip compassion between minibus taxis and cars over the two infrastructure forms is illustrated in Figure 8.

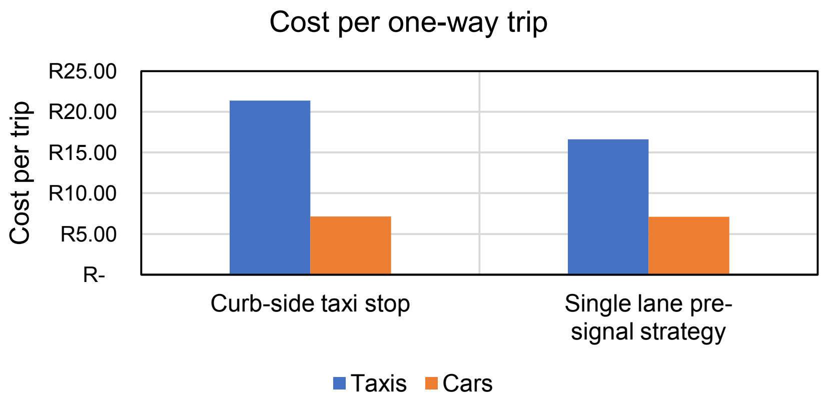

Figure 8: Cost per one-way trip comparison between taxis and cars

Finally, when the sum of the user, construction, and agency costs are calculated, there is a clear benefit to the implementation of the single lane pre-signal strategy: the total cost for a one-way trip reduces by 22% for the minibus taxis and 4% for the cars.

Although more passengers can board and alight the curb-side taxi stop service, most passengers travel the full duration of the route, with occasional passengers boarding and alighting over the route corridor. The single lane pre-signal strategy is therefore more effective in time savings for the passengers, taxi operators, and other vehicles on the road as well as reducing operating costs for all vehicles on the road.

7. CONCLUSIONS

The study consisted of investigating and identifying a form of priority infrastructure and to determine its suitability in terms of the high-level economic impact that the infrastructure would have on paratransit operators, the passengers, and other road users. The results can be summarised as follows:

- A single lane pre-signal strategy was identified as being a cost-effective solution to reduce the delay experienced by buses in the under-saturated case and well as improving system-wide delays overall.
- A mathematical model was developed to determine the economic impact of this solution when applied to minibus taxi operators.
- There was a 57% decrease in travel time for the taxis and a 2% decrease for car drivers.
- A 34% reduction in agency cost for minibus taxis was observed.
- There was a 37% decrease in fuel cost for the taxis.
- The cost per one-way trip decreased by 22% for the minibus taxi drivers and 4% for car drivers.

Reducing the overall cost of minibus taxis as a form of public transport and constructing infrastructure to aid this endeavour will improve the public's perception of this industry. If the taxi industry starts being viewed as a world-class transportation system, it will be a more attractive alternative to many members of the public who currently travel in cars. By decreasing the travel times, often long hours spent by many minibus taxi users the overall trip time will be significantly reduced. Such a significant change in how the minibus taxi industry operates, however disruptive at first, should be viewed as a necessity as it goes significant lengths in redressing the transportation injustices of the past.

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