MEASURING HOW LONG PASSENGERS WAIT TO DEPART IN MINIBUS TAXIS

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ABSTRACT

The purpose of this paper is to make two empirical observations. Firstly to observe the queueing of minibus taxi vehicles at a loading bay waiting to reach the platform where passengers board. Secondly, the paper measures the in-vehicle waiting times of passengers waiting for the minibus taxi to fill-up and depart. Both of these observations are made through an application of principles adapted from queuing theory and linear regression. Data collection included 28 minibus taxi vehicle observations, and 365 (n=337) passenger boarding times for a minibus taxi route between a popular shopping complex in Mmabatho and the Central Business District of Mahikeng. It is found that the average waiting time to depart is much closer to 3 minutes for passengers – which is the headway for these operations. But for the minibus taxi vehicles, they cumulatively spend nearly 60 minutes to reach the boarding bay again. Little over 20% of the sample of passenger observations wait for less than a minute for to depart and 90% wait for at most 5 minutes for the taxi to depart. From the regression analysis coefficients reveal that at a 95% confidence level, the time in the system is a statistically significant and inversely proportional determinant of when a passenger should be boarding a taxi. The study is limited only to "waiting time" and does not include the total travel time. More applications of these types of processes are recommended for paratransit research.

Keywords: Minibus taxi, paratransit, waiting time, queueing theory, public transport.

1. INTRODUCTION

Public transport operations have a number of key fundamental operating elements and performance measures. Vuchic (2005) describes the interplay between spacing, headways, density and frequency as operating elements that are reliant on the size of the vehicle, or transit unit. Passengers seek to minimise waiting time for scheduled services, while transport agencies seek to operate large TUs, and have long headways because it is cheaper. For scheduled transport, headways are a predetermined equilibrium between the minimum level of service required by passengers and the cost of operations. Waiting times for passengers largely relate to how long they wait for scheduled transport to arrive at the station, or designated stops along a route.

Paratransit operations are rather different, and heterogeneous, but the unscheduled minibus taxi seems to be responsive to demand. Unlike scheduled public transport, minibus taxis in South Africa tend to depart once the vehicle is full. This is termed the 'fill-and-go' model. As a result, operating and performance elements are not direct decisions made by the operator, but instead they are a result of passenger travel demand. The higher the travel demand, the lower the waiting time. As a result, the headways of minibus taxi operations departing from the terminal are dictated by the waiting time to depart and this has ripple effects in the broader minibus taxi system.

Between certain times, minibus taxis are dispatched into the network on condition that they fill-up at the taxi terminal, or “Rank”. To illustrate the dynamics, a conceptual description is necessary. As shown in Figure 1, two TU queues and two passenger queues describe the operations of a typical local minibus taxi terminal. The internal queues are where TUs queue to reach the platform where passengers board; and where passengers have boarded the TU and are in a queue for it to fill-up and depart. Queues outside of the system are where there are travel demand is low, and thus TUs overflow the terminal’s capacity; and where TUs are few and passengers queue at the platform waiting for another vehicle (thus no to little waiting to depart problems are likely).

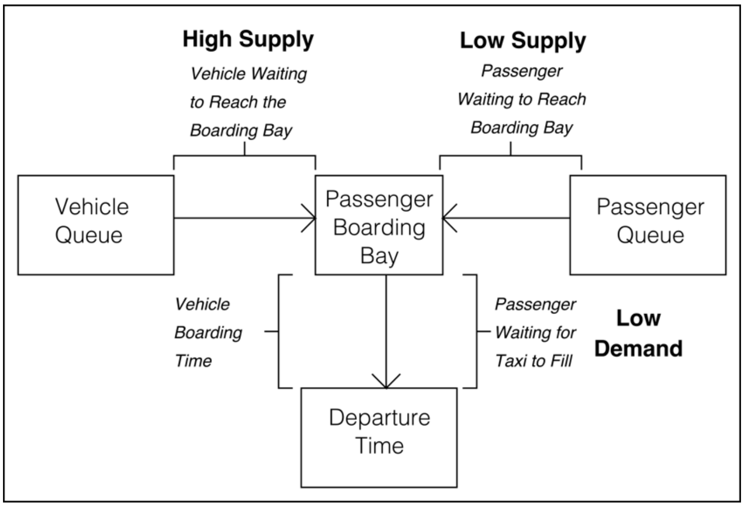

Figure 1: Conceptual Framework

This paper focuses only on the internal queues, the boarding times for TUs already in the passenger boarding area, and waiting to depart for passengers already in the vehicle.

2. PURPOSE OF THIS PAPER

The purpose of this paper is to make two empirical observations. Firstly to observe the queueing of minibus taxi vehicles at a loading bay waiting to reach the platform where passengers board. Secondly, the paper measures the in-vehicle waiting times of passengers waiting for the minibus taxi to fill-up and depart. Both of these observations are made through an application of principles adapted from queuing theory and linear regression. In making these observations the paper has two main objectives:

1. To measure the waiting-to-depart phenomenon as it relates to minibus taxi passengers and vehicles.
2. To estimate how the timing of a passenger’s arrival impacts on the amount of time they spend waiting idle in the vehicle.

This paper, therefore, applies the basic operating fundamentals described by Vuchic (2005) to minibus taxi operations. It contributes to literature that is focused on hybrid operations between scheduled and unscheduled public transport (Del Mistro & Behrens, 2012; Salazar Ferro & Behrens, 2015; Schalekamp & Klopp, 2018; Plano, Behrens, & Zuidgeest, 2018). But more explicitly, it follows-on from studies which explore the potential impact of analysing the characteristics of paratransit operations (Cevero, 2017; Saddier, Patterson, Johnson, & Wiseman, 2017; Coetzee, Zhuwaki, & Blagus, 2019). However, a distinguishing characteristic of this paper is the explicit focus on minibus taxi vehicle queuing and in-vehicle waiting time for passengers.

To better describe the contribution of this paper in the literature, the above-mentioned studies are reviewed in the next section. Then the research methods and procedure are described, from which results are estimated and conclusions are drawn.

3. LITERATURE REVIEW

3.1 Paratransit Operations and 'Waiting to Depart'

Paratransit has a number of definitions and classes characterised as flexible, "informal" and unscheduled public transport services operating parallel to scheduled and traditional services (Cervero & Golub, 2007; Neumann, 2014; Behrens, McCormick, & Mfinanga, 2015). However, a degree of context specificity is necessary for the passenger vehicle, the nature of the enterprise, and the national policy and administrative position related to minibus taxis.

In South Africa minibus taxis are the dominant form of paratransit, accounting for 61% of household travel demand (StatsSA, 2021) and dominating the public transport market for the past two decades.

By citing Godard, Behrens, et al. (2015), Behrens, McCormick and Mfinanga (2015) define paratransit as *"small-scale, private enterprise-based public transport services operating in [the] developing world".* Second, the term "minibus taxi" refers to *"a passenger vehicle used to provide a transport service to the public, distinct from conventional mass transit passenger vehicles, characterised by frequent but unscheduled operations of small vehicles designed to carry up to 15 seated passengers"* (Pienaar, 1998).

At a policy level, minibuses taxi-type service specifies the mode and service offering beyond the vehicle in the form of *"an unscheduled public transport service operated on a specific route or routes…within a particular area, by means of motor car or, minibus or midibus"* (NDoT, 2009).

As a form of paratransit, minibus taxis can be observed in terms of vehicle size; service frequency (i.e., unscheduled); and routing. The Minimum Requirements for Integrated Transport Planning primarily require data about routes-per mode, fares, capacity and capacity utilisation. In terms of administering the data collection for paratransit, the minimum requirements indicate that: *"waiting time surveys may be conducted during taxi rank surveys as an optional extra to supplement information about under- or over-supply on routes"* (NDoT, 2016). This should in theory influence the number of operating licences issued, thus the total number of vehicles per route. As an operating element, waiting time is a precondition for the 'frequency' of vehicles dispatched, headways along routes, and it affects the total travel time for commuters. Definitions, policy and administration reflect the unscheduled nature of the service, but past studies tended to miss *waiting time* as a component of the service offering and design.

3.2 Approaches to Analysing Transit Operations

Various approaches exist to analyse transit operations, but they are usually underpinned by principles from scheduled operations. Some literature has leaned toward proposing that minibus taxi services operate along fixed schedules, however, the authors found that customer satisfaction increases when operations scheduled - in addition to other service improvements (Saddier, McLachlan & Dass, 2019).

Other studies estimate the probability that minibus taxi operators are willing to serve as feeders for Bus Rapid Transit systems (Plano, Behrens & Zuidgeest, 2018). The authors find that this propensity is dependent on higher earnings and the presence of law enforcement (ibid). Most empirical studies of paratransit seem to exclude the *waiting to depart* component of the transit trip as one of the variables (Gaibe & Vanderschuren, 2010; Saddier & Johnson, 2018; Coetzee, Zhuwaki & Blagus, 2019). In Saddier & Johnson (2018) and Coetzee et al. (2019) important operational characteristics are presented, which are in line with Vukan Vuchic's seminal work (Vuchic, 2005, p. 10). This paper argues prerequisites for the dispatch from the terminal, vehicle headways, and thus service frequency along routes may also be influenced by *fill-and-go* practices.

Most minibus taxi services in SA only leave the terminal once the vehicle is full, they continue their journeys with passengers randomly getting on or off along the route. This is not part of traditional transport operational planning for scheduled services, but authors are axiomatically aware of this *waiting time* phenomenon because it is part of some surveys (Saddier, McLachlan & Dass, 2019). Much of the interest in terms of simulation and data collection is associated with agent decision making along the route, reflecting dynamism and responsiveness to change in passenger location (Neumann, Röder, & Joubert, 2015). In principle this requires both map making techniques which improve the transit information in the area (i.e. wayfinding) and advances the data collection solutions (Klopp, Williams, Waiganjo, Orwa & White, 2015; Saddier, Patterson, Johnson & Wiseman, 2017, Coetzee, Krogscheepers & Spotten, 2018).

In practice, Gaibe & Vanderschuren's (2010) approach reflects the role of paratransit data in the Current Public Transport Records of municipalities' ITPs, by capturing the *total time taxis spend without being utilised*; however, the passenger waiting time within the vehicle is not considered in the paper. There is a gap to be filled, at least where fill-and-go practices exist, but this depends on an understanding of minibus taxi operations and exploring potential approaches to empirically estimate observations.

4. RESEARCH METHODOLOGY

4.1 Queuing Theory Considerations

A basic application of queuing theory has three major elements: (1) customers waiting for services; (2) servers providing a service; and (3) the waiting line for customers, or queue of servers – they are embedded in how the customers, service and system are characterised and configured (Evans, 2013, pp. 403-409). In the transportation context, queuing is composed of throughput, congestion and crowding, lost customers, queue percentage, service costs and productivity of the service (Wall, 1999, pp. 115-116). For both the basic and transport specific application of queuing theory the Poisson process is a principal basis with three major assumptions.

The first assumption is that passengers and vehicles arrive randomly, independently of each other, and one at a time. This assumption only holds in part, as sometimes passengers and vehicles board in groups or arrive at the terminal as a bunch (sometimes more than one vehicle is open for boarding, creating an overlap). The second assumption is that past arrivals do not influence future arrivals. This assumption holds in the models estimated. The third assumption is that passengers and vehicles arrive at more or less the same rate over time. This assumption is tested in the data collected, and it is clear that there are outliers in arrivals.

4.2 Model

Firstly, the average time it takes for passengers to arrive, λ, should be less than how long the total time, $\mu -$ or else a the system will be overloaded, therefore $\lambda < \mu$ (Evans, 2013). Using the service rate principle enables assumptions about the offering of unscheduled services (i.e. total time). With only one minibus taxi vehicle being observed at a time, this paper only tests the Single-Server Model through the following performance measures:

Average rate of arrival[1]: $$\lambda = \frac{\sum M_n^a}{TU_c - 1} \quad (1)$$

Average number of passengers in the queue: $$L_q = \frac{\lambda^2}{\mu - (\mu - \lambda)} \quad (2)$$

Average number of passengers in the system: $$L = \frac{\lambda}{\mu - \lambda} \quad (3)$$

Average waiting time in the queue: $$W_q = \frac{\lambda}{\mu(\mu - \lambda)} \quad (4)$$

Average time in the system: $$W = \frac{1}{\mu - \lambda} \quad (5)$$

Probability that the system is empty: $$P_0 = 1 - \frac{\lambda}{\mu} \quad (6)$$

To develop the initial model, the author boarded an empty minibus taxi vehicle which had just arrived at the terminal and timed the boarding of each additional passenger, with the author as the base. The taxi has a capacity for 12 seated passengers (TU_c). A time sheet was completed and the arrival time, a_{it}, between each passenger, i, was inputted – call this the marginal arrival time, M_i^a. As each passenger arrives, waiting time within the minibus taxi begins to accumulate as B_i^t begin to add up. Therefore, the last passenger will have a smaller B_i^t, while the first one has the largest one. The in-vehicle travel time, or service rate, is an estimated number of minutes travelled along the route for passenger i, called μ_i^t. Described in equation (6) time within the system (F_i^t) is the sum of all the marginal arrivals and the estimated travel time, less the cumulative waiting time. All three of these are part of scenario tests in the next section.

$$F_i^t = \mu_i^t + \sum M_n^a - B_i^t \quad (7)$$

Where:

$$B_i^t = M_i^a + B_{i-1}^t \quad (8)$$

Time in the system for the first passenger is therefore:

$$TT_i^t = (F_i^t - B_i^t) + M_i^a \quad (9)$$

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[1] $TU_c - 1$ is used to describe the instance where the first passenger initiates the system and there is no information about the idle time of the vehicle before passengers arrived. This will be part of future work.

The queuing model is used to describe the characteristics and dynamics of the performance of the fill-and-go model in minibus taxi operations. In addition, correlation analysis and a linear regression analysis is performed with the intention to assess how the timing of a passenger boarding relates to some of the performance indicators in the queuing model.

In order of notation, the model regressed without a constant argues that when a passenger boards (as first or 12th passenger) could be determined by their arrival time, their end time, their idle time in the vehicle and the time they spent in the system.

$$i_j^{TU} = f(a_{it}, F_i^t, D_i, TT_i^t) \tag{10}$$

The queuing theory is used to estimate, and provide evidence of the fill-and-go model, and its performance. Using the queuing theory to develop performance indicators in order to achieve the second objective of this paper, enables an improved assessment of the minibus taxi system.

5. RESULTS

5.1 Research Procedure

An experimental survey design was developed in which vehicle and passenger queuing data could be collected. For the TUs, a vehicle number (first three letters on the number plates), time of arrival at the rank, time at boarding bay and departure time were recorded. Passenger queuing data included a passenger count and time of boarding. Thirty (30) copies of the survey were printed and completed with a digital watch and pencil on a hardboard.

A local taxi association was approached to provide access to the taxi rank for a one-day round of data collection. This association is among those included in a Community Engagement project facilitated by the university, specifically for scholarship-led community engagement. Thus, the association expected research activities to take place, prior to the data collection. They were requested to participate only one day before data collection would commence.

5.2 Overview of Operations

On the 6th of January 2021, 28 TUs were observed, and 365 passenger boarding times were recorded for a minibus taxi route between a popular shopping complex in Mmabatho and the Central Business District of Mahikeng. Data collection took place between 08:00 and 10:45, because taxis are required to only begin queuing and boarding passengers at the rank from 08:00, before this time they may roam and board passengers within their jurisdiction.

Furthermore, the day of data collection included social grant travel demand makes it a relatively busy day. However, the focus of this paper is to observe the presence of queues and collect data about them, not to represent or estimate average daily traffic models. Thus, the primary data collected focuses on TU queuing time and in-vehicle waiting time.

5.3 Queuing Results

In Table 1, results from the observations and queuing models are presented. The average waiting time between passengers as they board is 21.6 seconds. For the minibus taxi vehicles, it is closer to 5 minutes with little variation between being at the boarding bay and passengers boarding.

The average waiting time to depart is much closer to 3 minutes for passengers – which is the headway for these operations. But for the minibus taxi vehicles, they cumulatively spend nearly 60 minutes to reach the boarding bay again. Assuming an 18-minute travel time to town, waiting to depart only accounted for 1 minute. However, for the minibus taxi vehicles, the time in the system is elongated by the assumed the trip time (for one direction).

Table 1: Passenger and Minibus Taxi Vehicle Queues

		Passenger Queue	**Minibus Taxi Vehicle Queues**	
Notation		Aggregated Passenger Queuing Results	Arrival at the Loading Bay	Departure from the Loading Bay
	Waiting Time between Observations (Minutes)	0.36	5.04	5.01
	Average Waiting Time to Depart	2.41	55.59	54.45
	Average Time in System	18.57	74.83	73.05
Assumed	Assumed trip time (Minutes)	18.00	18.00	18.00
Queuing Theory Estimations				
L_q	Average Number in Queue	0.71	0.00	0.00
W_q	Average Waiting Time in Queue	0.06	0.00	0.00
L	Average Number in System	1.04	0.00	0.00
W	Average Time in the System	0.11	0.06	0.06
Assumed	Average Service Time	18.00	18.00	18.00
λ	Arrival Rate (Customers Per Unit)	5.89	0.01	0.01
P_0	Prob System Empty	67%	100%	100%
	Prob at least 1 in System	33%	0%	0%

Queueing theory results indicate that there is not always a passenger in the queue, and there is always a passenger in the system. But the time they spend is a third of the waiting time between passengers. Furthermore, passengers arrive at a rate of 5 to 6 passengers per minute which gives an indication of the busyness of this route. In general, transport planners should expect that there is at least one passenger waiting to depart 33% of the time. From a vehicle operation perspective, the queueing models reveal that there is very little queuing that takes place in terms of reaching the bay and departing – thus a significantly efficient operation.

In Figure 2 passenger boarding and time related data are presented: (a) The time spent between passenger boarding throughout the data collection period starts off taking longer and after 09:30, much lower waiting time emerges; (b) Passenger idle time reveals a similar trend, but it shows how this tapers off with the outlier being the 2nd taxi where the first passenger waited over 16 minutes for the taxi to fill up; (c) It is rather evident that the first passenger to board is most probably going to wait the longest, but there is some variation in this regard – especially depending on the time of day; (d) Time spent in the system increases as the amount of time spent waiting to depart increases – thus for the first passengers, delays are accumulated.

To better represent this, Figure 3 shows how little over 20% of the sample of observations waits for less than a minute for to depart and 90% of passengers wait for at most 5 minutes for the taxi to depart.

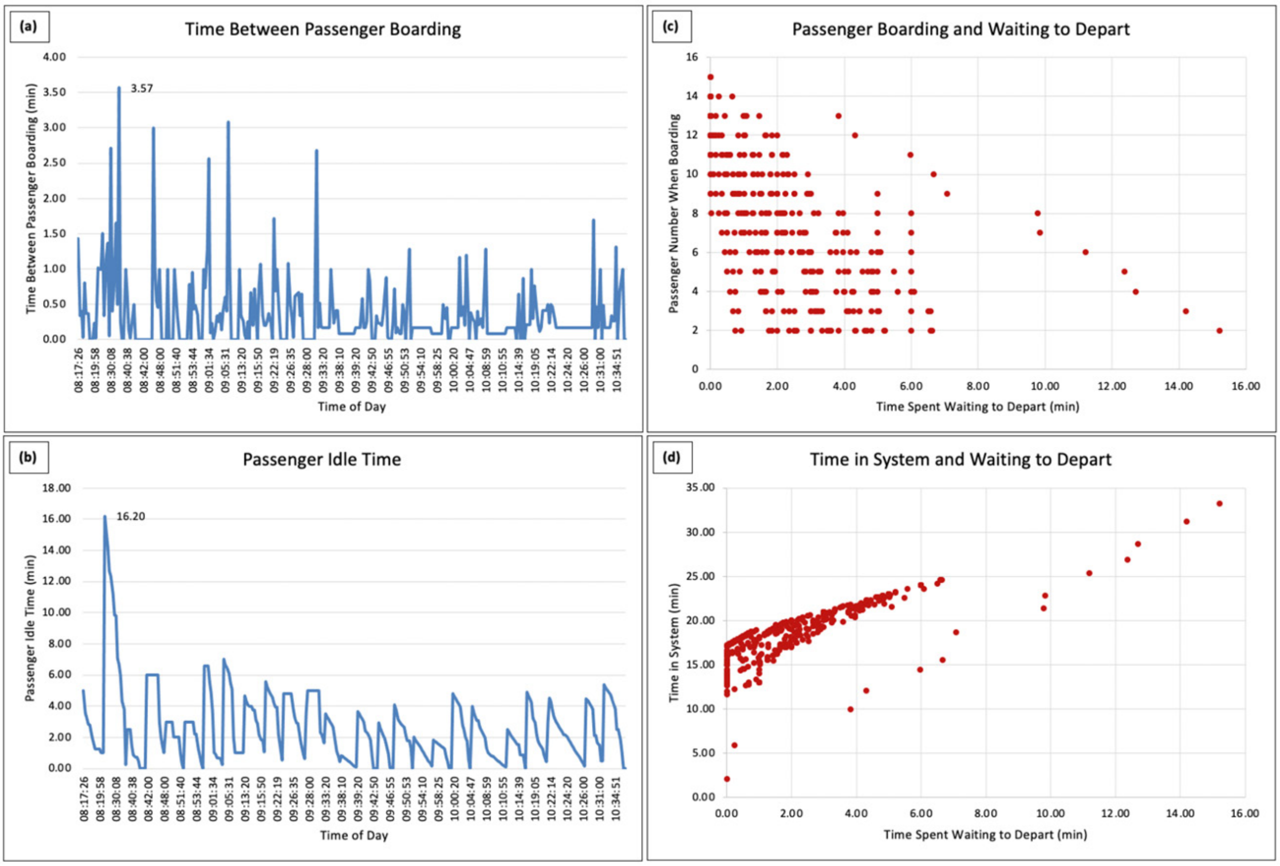

Figure 2: Passenger Boarding and Time Spent

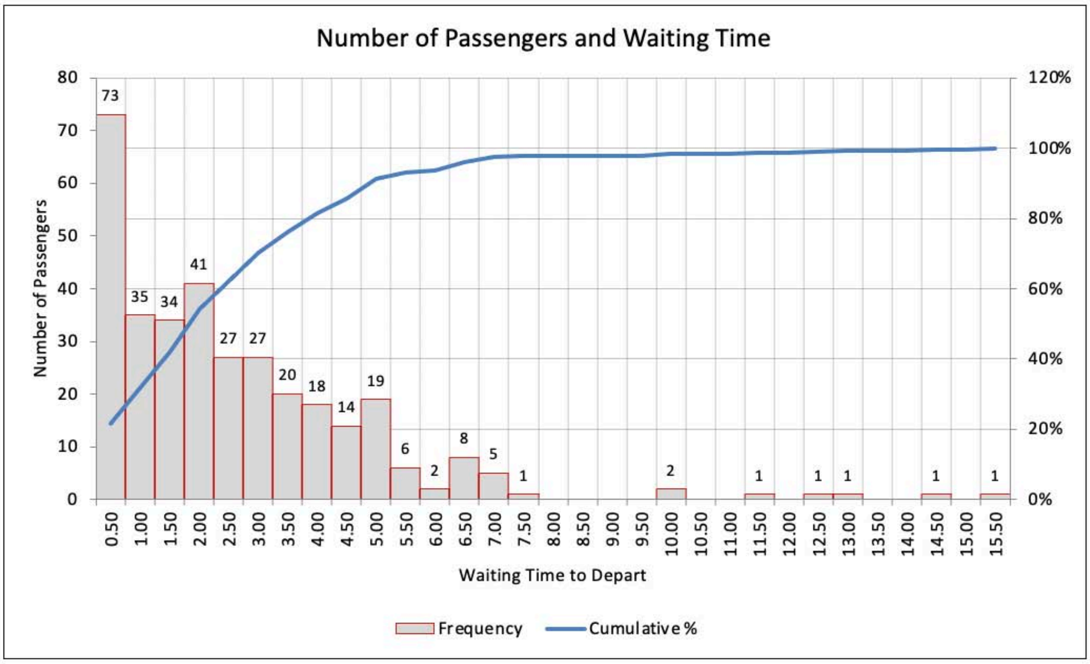

Figure 3: Histogram of Passengers and Waiting Time

5.4 Regression Results

Correlation analysis indicated that strong correlations between when a passenger boards (passenger number) and their arrival time (0.65), end time (-0.55), waiting time to depart (-0.55), idle time (-0.50) and most intensely the time spent in the system (-0.78). Thus, as expected, there is an inverse relationship between when a passenger boards and how much time they will spend waiting to depart.

Table 2 presents the regression results. Through various iterations, the final regression model includes a constant to account for the assumed travel time of 18 minutes, the time spent waiting to depart, the arrival time and the time spent in the system. The model represents 62% of the data indicating how waiting, arrival and time in the system could be used to determine when to board a minibus taxi based on 337 observations. Based on the F-sig, the results were not attained by chance, and have a high likelihood of being accurate for this route.

The coefficients reveal that at a 95% level of significance, the time in the system is a statistically significant determinant of when a passenger should be boarding a taxi. Thus, if one wants to be the first passenger on board, expect to spend a long time in the system. Conversely, if minimising the time spent in the system is a key factor, then being the last passenger to board is ideal.

Table 2: Regression results, ANOVA and Model

Regression Statistics					
Multiple R	0.79240168	**Adjusted R Square**	0.62454817	**Standard Error**	2.18139448
R Square	0.62790042			**Observations**	337
ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	3	2673.89438	891.298128	187.307245	3.7897E-71
Residual	333	1584.57446	4.75848186		
Total	336	4258.46884			
Model					
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	**18.895751**	4.90509744	**3.8522682**	**0.00014038**	
Waiting Time Depart	-0.0405127	0.28637149	-0.1414689	0.88758506	
Arrival Time	0.3221755	0.24899288	1.2939147	0.19659155	
Time in Sys	**-0.6423471**	0.27155353	**-2.3654531**	**0.01858058**	

6. CONCLUSION

This paper measured the waiting-to-depart phenomenon as it relates to minibus taxi passengers and vehicles. The use of queueing theory was found to be useful, especially for the passenger data. A less busy route and the collection of rank utilisation data would improve the analytical rigour of the minibus taxi vehicle data.

The paper also sought to estimate how the timing of a passenger’s arrival impacts on the amount of time they spend waiting idle in the vehicle. In this regard, it was found that waiting time not only varies by time of day, and it is also experienced by a significant number of passengers. The paper presents empirical evidence that the boarding a minibus taxi when it is empty increases the likelihood that the time spent in the system would be higher.

The limitations of the paper include the lack of vehicle queueing data, and commuter surveys to supplement the empirical findings. Furthermore, "waiting time" alone is only one part of a broader passenger journey, thus assuming a total travel time limits the paper from observing the impact of waiting on travel time – especially as destinations are heterogenous.

Further applications of this type of data collection process are necessary in order to begin to formulate conclusions about service offering, vehicle queueing and operational performance measures. The findings of this approach could vary depending on the route, and the service characteristics (i.e. long-distance vs local taxis).

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