THE USE OF MONTE CARLO SIMULATION TO DETERMINE THE OPTIMAL CONFIGURATION FOR MINIBUS TAXI LOADING AREAS

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ABSTRACT

National guidelines for the design of minibus public transport facilities provide general advice for determining the number of loading berths, based on the number of vehicles servicing a specific destination, or for choosing between parallel island and oval island layouts, without taking the specific demand and loading patterns of a rank into account.

This paper provides quantitative guidelines on the determination of the number of loading berths that are required and the layout that would provide the best operational efficiency under a range of loading conditions. A simulation method was developed and calibrated to simulate passenger queuing and boarding, for both parallel and serial boarding of vehicles, which allowed us to test the impact of factors like passenger volumes, fleet size, loading and queuing behaviour of passengers (e.g. whether single or multiple vehicles are boarded from the same queue), and the shunting time between vehicles, on a number of measures of effectiveness.

We offer recommendations regarding the threshold values of demand and vehicle operations that can be used by practitioners when considering the appropriate layout of a facility and the number of berths (loading areas) that would be required. These findings will be of particular interest to designers and engineers involved with the design or upgrading of minibus taxi facilities.

1. INTRODUCTION

1.1 SCOPE OF THIS RESEARCH

The focus of this research was on the loading area of minibus taxi facilities, where there is interaction between a queue of passengers awaiting transportation and a queue of vehicles that provides the transportation. Several key factors need to be considered when designing a loading area for minibus taxi transportation. These are :

- The layout of the facility (parallel island vs. oval island layouts – NDoT, 2007).
- The estimated volume of passengers requiring transport (per destination).
- The number of vehicles (fleet size), servicing the demand.
- The loading behaviour of passengers (average boarding time per passenger for a particular vehicle type).
- The queuing behaviour of passengers (one queue of passengers forms per destination irrespective of whether of single or multiple vehicles are boarded).
- The shunting time in between vehicles (the time that expires between a full vehicle departing and another empty vehicle taking its place, ready to load awaiting passengers).

The aim was to determine thresholds pertaining to these factors when considering the appropriate layout of a minibus taxi loading facility and the number of berths (loading areas) that would be required. The purpose was to assist designers of minibus taxi facilities, either during the design of new facilities or for the upgrading of existing facilities.

1.2 LOCAL DESIGN GUIDELINES ON THE DESIGN OF MINIBUS TAXI FACILITIES

Guideline documents for the design of minibus public transport facilities were developed in the 1980s by the South African National Department of Transport (NDoT, 1990). This document was recently updated to incorporate new material and revisions. The guideline (NDOT, 2007:10-4) indicates that:

"*The loading area is the most important element of a facility and the main factor determining its size. Depending on the type of facility, the loading area consists of one or more loading lanes. Each loading lane consists of a number of berths with different functions. Due to the priority departure system commonly used at facilities the first and sometimes also the second berth in line, are used for loading purposes and the rest for queuing or holding purposes.*"

This approach distinctly assumes a "Parallel Island Layout" design configuration as shown in Figure 1 below. The "Oval Island Layout" design configuration may also be considered according to the NDoT guideline.

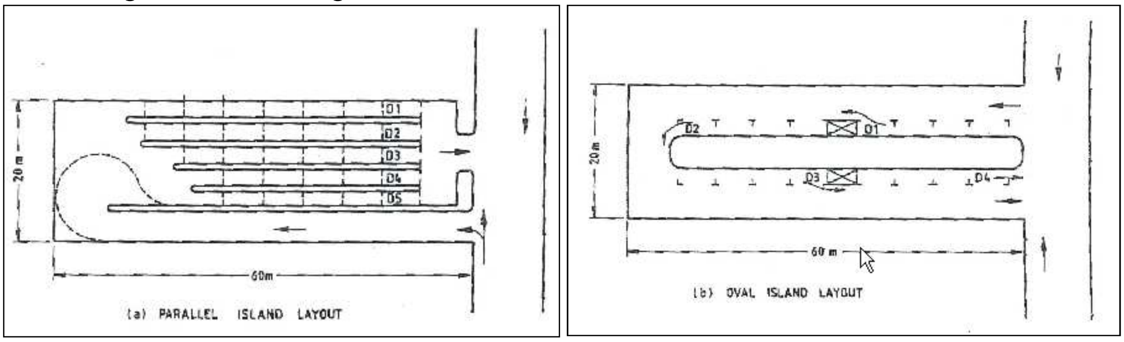

Figure 1: Parallel and Oval Island Design Layouts (NDOT, 2007)

The importance of calculating the correct berth lengths is emphasized in the 2007 NDoT guideline document. The 1990 NDoT guideline expresses a preference towards use of a parallel island layout over an oval island layout, mainly on the premise that it is more space efficient, can accommodate more vehicles, and can separate different vehicle routes into separate loading lanes. The 2007 guideline echoes this sentiment and states that the only benefit of using an oval island layout (parallel or concurrent loading) over parallel island layout (serial type loading) is that it minimises pedestrian/vehicular conflicts. We have not found any research that validates these claims, apart from anecdotal evidence. It is also not clear that the operational boarding capacity (in terms of passengers, not vehicles) of the parallel layout is superior, since serial boarding limits the number of vehicles that can be boarded at any one time, and blocks the departure of vehicles behind the first one in a lane (assuming there is no space to pass).

1.3 SHORTCOMINGS IN THE CURRENT RECOMMENDED METHODOLOGY

1.3.1 Assumptions made

For the sizing of loading areas at minibus taxi facilities, the NDoT guideline document (NDoT 2007) recommends supplying a minimum of one berth for every three taxis using the facility. This 1:3 ratio is based on the assumption that while one combi taxi is at the facility, there are two others on the road (inbound and outbound respectively). In smaller urban areas the ratio is suggested to change to 1:2 because of shorter routes.

The problem with this ratio approach is that the actual number of taxis in the available fleet needs to be known. This is not the case for the design of new facilities, and even for existing facilities the present number of taxis might not be appropriate for the demand and for the specific design.

The ratio method further assumes uniform (or average) route lengths, uniform arrivals and departures, and disregards the impacts of the layout of the facility. The assumed "size" of the urban environment ranging between "large" and "small" leaves a lot of room for ambiguity because size ranges are not specified.

1.3.2 Evaluation of Existing NDoT Method: Simplified Deterministic Method

To test the implications of the deterministic 1:3 ratio recommended by the NDOT guideline on facility design, we developed a hypothetical example. Passenger demand flows were tested ranging between 100 passengers per hour to 900 passengers per hour. To estimate the number of vehicles that will be using the facility, three cases were tested (one destination only):

- The number of vehicles expected to use the facility is the total number of passengers divided by the capacity of the vehicles. This implies that each vehicle makes only one trip in the peak hour, and corresponds to a case with long routes and long turnaround times;
- The expected number of vehicles is *half* the total number of passengers divided by the capacity of the vehicles – corresponding to the case where each vehicle makes two round trips per hour;
- The expected number of vehicles is *a third* of the total number of passengers divided by the capacity of the vehicles – each vehicle makes three round trips per hour.

Theresults are shown in Figure 2 below.

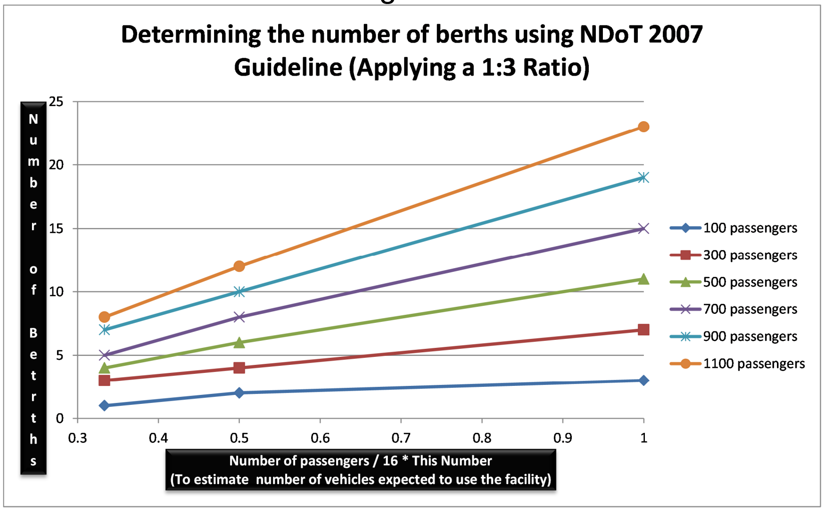

Figure 2: Determining the number of berths using the NDoT 2007 method

Using the constant ratio of one berth for every three vehicles, the number of berths needed vary widely depending on the case studied. For a demand of 500 passengers for a specific destination, the number of berths supplied may range between 4 and 11 berths -- a difference of 7 berths. It is thus important to include local information on the turnaround time of vehicles, and to clarify how these calculations should be applied to oval island layouts.

1.4 PURPOSE OF THIS RESEARCH

This research was aimed at providing quantitative guidelines on the number of loading berths required, and the layout that would provide the best operational efficiency for loading operations of minibus taxi facilities. A simulation method (using Monte Carlo Simulation) was developed to test the optimal number of minibus loading berths required to serve a specific destination under varying loading patterns. This allowed us to determine loading berth capacities and efficiencies more accurately, and to derive threshold values for the optimal use of oval island versus parallel island layouts.

The model was calibrated for operational conditions and boarding times found in urban (commuter) minibus taxi systems in South Africa, but can be adapted to investigate efficiencies for other vehicle types as well.

2. SIMULATION MODEL

2.1 WHY USE SIMULATION MODELLING?

Simulation modelling offers a way of analysing the performance of a complex system in which the interaction between various agents with stochastic behaviour is important. In our case, the variability of demand and loading patterns consistent with real minibus taxi operations needed to be captured.

Stochastic simulation (or Monte Carlo simulation) can deduce, from the interaction of a number of random and assumed fixed variables, complete probability distributions of outcomes by simulating a statistically meaningful number of discrete events. Simulation further offers control over time by simulating real time events in different manifestations to represent results of a long period of time as observed over a relatively short time (Van As, 1999). Simulation is specifically useful to ask “what if” questions and can be used to investigate the behaviour of both existing and conceptual systems (Banks, 1998) – this specifically overcomes many of the shortcomings in the existing approach. During the concept and design stage, “what if” scenarios are relevant (Winston, 2004).

2.2 SCOPE OF THE MODEL

The objective of the model is to simulate the loading of passengers onto minibus taxi vehicles, assuming different loading configurations. The different configurations are:

- Parallel island layout (single or serial loading)
- Oval island layout (simultaneous or concurrent loading)

The simulation is for a single destination. The strategy is therefore not to develop a model that simulates an entire facility, but rather individual loading areas servicing single destinations within a facility. The loading area has two sets of agents interacting with each other namely commuters and vehicles. This approach was followed to simplify the number of basic variables to take into account in order to evaluate what issues are of fundamental importance when considering the design of such facilities.

The model allows for a single queue of commuters to form irrespective of the number of vehicles that may be loading concurrently. The model allows for one vehicle to load at a time (parallel island layout) or for multiple vehicles loading concurrently (oval island layout), but does not allow for concurrent loading at parallel island layouts as this is essentially an extension of the single-destination case.

Operational variables specified by the user or varied by the programme include:

- The demand for minibus travel (number of passengers) for each destination;
- The supply of minibus vehicles (number of vehicles is fleet);
- The passenger arrival pattern;
- The minibus taxi arrival pattern;
- The boarding time of passengers;
- The shunting time between departing (full) vehicle and an arriving (empty) vehicle.

As output, the model provides:

- The passenger queue at the end of the simulation period;
- The maximum passenger queue that formed;
- The percentage of passengers that departed in the simulation period;
- The average waiting time of passengers before departure;
- The number of vehicles that has departed during the simulation period;
- The vehicle queue at the end of the simulation period;
- The maximum vehicle queue that formed during the simulation period; and

- The percentage of loading vehicles that departed during the simulation period.

2.3 BASIC AGENTS OF THE MODEL PROCESSES

The simulation model had to take into account the behaviour and interaction of two types of "agents" namely the minibus taxis and the passengers. There are a number of decisions that need to be made by both passengers and vehicles. A passenger may arrive at the facility and join a queue of other passengers that arrived prior to the point in time. There may or may not be a queue of passengers. The queue may be there because the rate at which passengers are arriving and boarding vehicles are slower than the rate at which the vehicles are able to service the demand (Figure 3). Or there may not have been a vehicle at all to load passengers, and therefore there is a queue of passengers waiting.

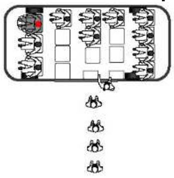

Figure 3: Diagrammatical depiction of queue of passengers boarding a mini-bus taxi

Similarly, vehicles may arrive empty and join a queue of other vehicles waiting for their turn to load passengers. Depending on the configuration of the facility, vehicles may load one at a time until fully loaded and then depart or they may load simultaneously.

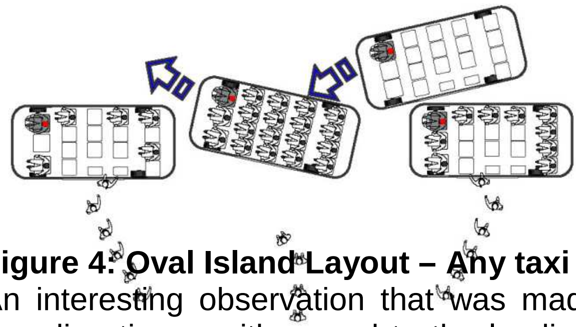

Figure 4: Oval Island Layout – Any taxi can depart when full

An interesting observation that was made at the sites that were surveyed to research boarding times, with regard to the loading of passengers, was that even if simultaneous loading occurs, only one queue of passengers is formed and not numerous queues to match the number of vehicles loading. This is shown diagrammatically in Figure 5 below, and adopted in the simulation model.

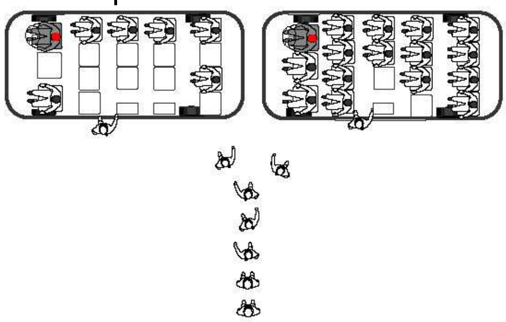

Figure 5: Diagrammatical depiction of one queue of passengers boarding 2 mini-bus taxis

2.4 SELECTION AND APPLICATION OF PROBABILITY DISTRIBUTIONS

Statistical distributions had to be selected for the determination of arrival times for both passengers and vehicles (taxis) into the modelling space, and for determining passenger boarding times onto vehicles once they reach the front of the queue and it is their turn to board.

2.4.1 Exponential Distribution

The exponential distribution is frequently used in studying traffic headways and other phenomena characterised by random arrivals (Van As, 1993) and was selected for the calculation of both vehicle and commuter arrival times. The exponential distribution provides the probability of inter arrival times (t) from:

$$t = -\frac{1}{Q}.Ln(1 - R_i) \text{ ... (Eqn 1)}$$

Where $\mathbf{R_i}$ is the random number with a value between 0 and 1 and **Q** is the mean rate of arrivals of passengers per second.

2.4.2 Inverse Log-Normal Distribution

For the determination of passenger boarding times onto vehicles once they reach the front of the queue, an inverse log-normal distribution was used. The advantage of the distribution is that it avoids the non-zero probability of negative values associated with the normal distribution (Van As, 1993). The form of the distribution is:

$$f_Y(y) = \frac{1}{\sigma_Y.\sqrt{2\pi}}.e^{\frac{-(y-\mu_Y)^2}{2\sigma_Y^2}} \quad \text{for } -\infty \leq y \leq \infty \text{ ... (Eqn 2)}$$

As input, the average boarding time (μ_Y)and variance of the boarding times (σ_Y^2) (obtained from field surveys) is specified. Note that the model takes into account a distribution of boarding times and not only the mean.

2.5 MODEL CALIBRATION

2.5.1 Data surveys

For the purpose of calibrating the model, a number of field surveys were conducted at three selected taxi ranks in Pretoria, Gauteng Province, South Africa. A sample size of 178 boarding times was recorded during the afternoon peak period on normal weekdays. The ranks that were surveyed are:

- Bosman Street Taxi Rank
- Bloed Street Taxi Rank
- Marabastad Taxi Rank

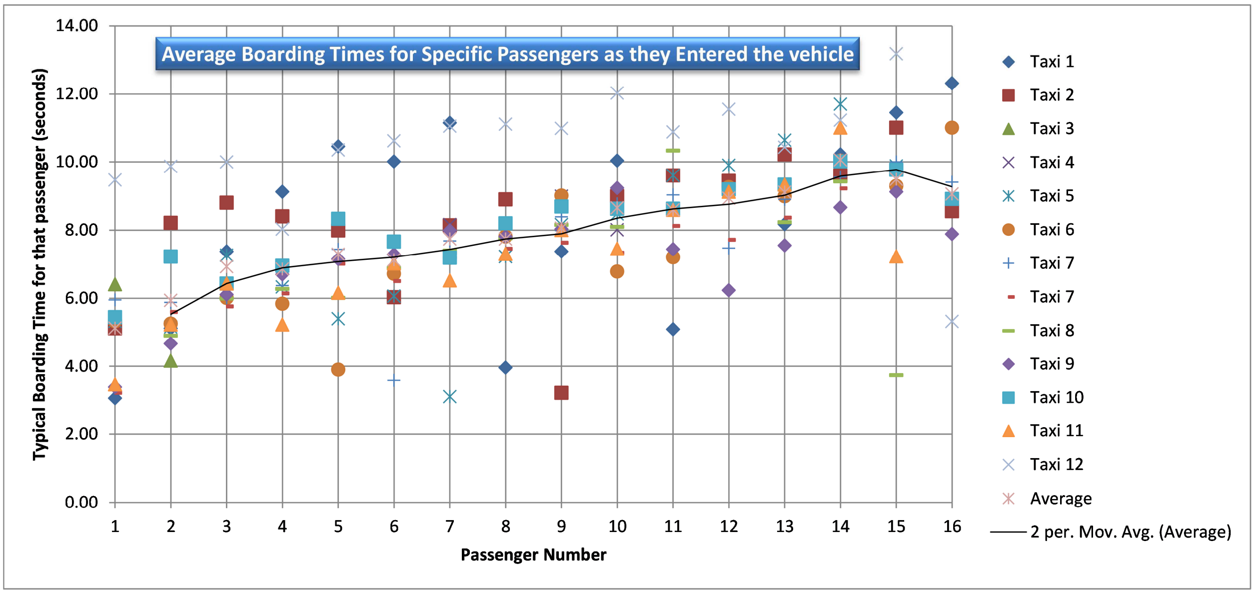

Figure 6: Average Boarding Times for Specific Passengers

The average boarding time was calculated at 7.87 seconds and the standard deviation at 2.06 seconds. As shown in Figure 6, an interesting observation was that the boarding time was not constant but increased as the vehicle became fuller. This is probably unique to the loading of small vehicles, and is caused by the need to negotiate foldable seats and increasing congestion as loading progresses. We do not believe this has been reported in the literature before.

The shunting time between vehicles – or the time it takes from the moment a full vehicle departs until the next vehicle takes its place and is ready to start loading – was also surveyed.

2.5.2 Testing Statistical Assumptions: Chi-Square test

A chi-square (χ^2) test was used to confirm the validity of the selected statistical distributions. The inverse log-normal distribution performed very well for the estimation of passenger boarding times, as shown in Figure 7 below. Four independent statistical runs were done to synthesize data using the inverse log-normal distribution. These values were compared with the actual observed values (shown in red). The goodness of fit is evident from this graph as well as from the calculated values.

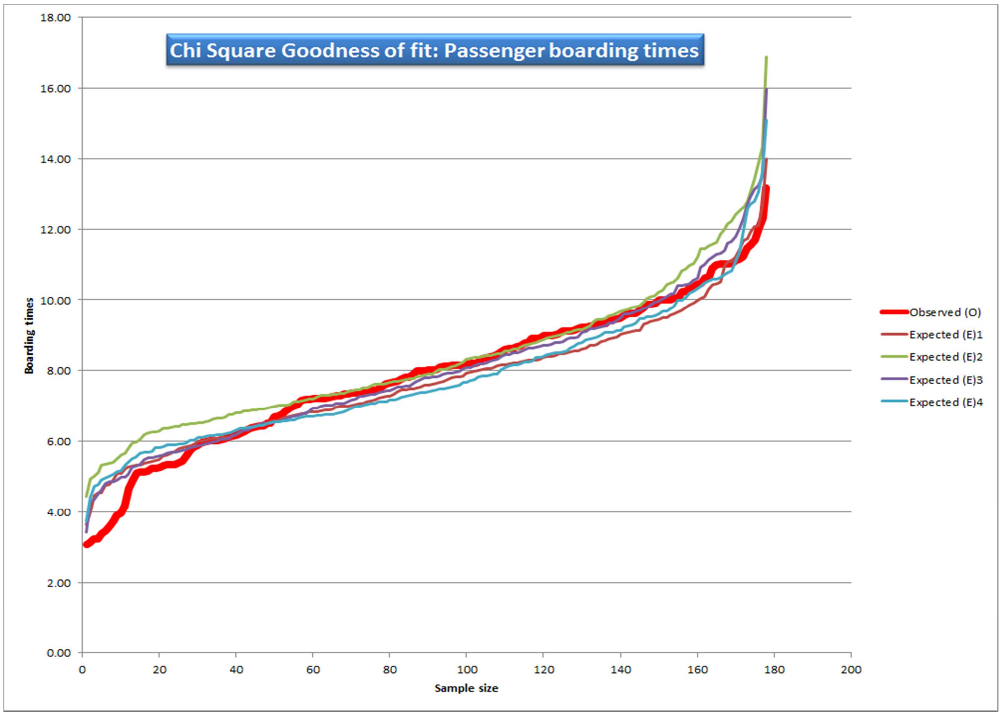

Figure 7: Chi Square Goodness of Fit – Passenger Boarding Times

3. MODEL OUTPUTS

3.1 DESIGN GUIDELINES

The simulation model was implemented using Visual Basic code in Excel. Table 1 below shows the typical output values that are generated by each model run.

Table 1: Model Output Table

Summary results of simulation:	
Passengers Arrived in simulation period:	900.0
Passengers Departed:	338.0
Initial Passenger Queue:	90
Passenger Queue end of simulation period:	562.0
Maximum passenger queue:	562
Passengers arrived after simulation period:	0
Percentage passengers that departed in simulation period:	38%
Average waiting time of passengers before departure	23.0
Vehicles in Fleet:	56
Vehicles Arrived in simulation period:	54
Vehicles Departed:	21
Initital Vehicle Queue:	6
Vehicle Queue end of simulation period:	33
Maximum Vehicle queue:	33
Vehicles arrived after simulation period:	2
Percentage vehicles that departed in simulation period:	38%

From this table, key metrics regarding the passengers and the vehicles can be obtained. The outcomes were evaluated by comparing measures of effectiveness (MOEs) that represent measurable outcomes that relate to both efficiency and convenience of both affected agents in the model. Five basic MOEs were used:

- The percentage of passengers that departed during the selected simulation period of one hour (MOE 1);
- The percentage of vehicles that departed during the selected simulation period of one hour (MOE 2);
- The average waiting time per passenger during the selected simulation period of one hour (MOE 3);
- The maximum passenger queue that forms during the selected simulation period of one hour (MOE 4); and
- The maximum vehicle queue that forms during the selected simulation period of one hour (MOE 5).

From the simulation runs, tables were developed to serve as design aids. The table allows the designer to estimate the percentage of passengers that are likely to depart based on a selection of the MOEs listed above. The tables make use of a new variable termed the *fleet factor*, which is defined as:

$$Fleet\ factor = \frac{Total\ vehicle\ arrivals * Vehicle\ capacity}{Passenger\ demand} \quad \text{(Eqn 3)}$$

The fleet factor reflects the ratio between the supply of seats provided by the number of available vehicles (the vehicle fleet), and the demand to be served. An insufficient fleet size of vehicles may, in some instances, will by definition cause delays. The introduction of this variable assists with the understanding of typical threshold points, where the number of available vehicles may start to influence the efficiency of the design.

The tables are shown below. Areas of the table that are shown in green are indicative of better efficiency, whilst yellow, orange and red show areas that are likely to result in inefficient loading operations.

Table 2: Loading Area Design Guideline Tables

% Passengers Departed								
		Fleet Factor						
Passenger Demand	Loading Vehicles	0.5	0.75	1	1.25	1.5	1.75	2
100	1	39%	72%	86%	92%	95%	92%	92%
100	2	41%	61%	75%	87%	95%	89%	88%
100	3	41%	65%	83%	92%	93%	91%	92%
100	4	40%	61%	84%	91%	93%	92%	92%
300	1	42%	65%	84%	79%	82%	83%	83%
300	2	42%	67%	79%	82%	85%	86%	86%
300	3	44%	68%	80%	85%	88%	84%	83%
300	4	45%	68%	85%	87%	86%	78%	86%
500	1	45%	64%	66%	65%	67%	68%	67%
500	2	45%	66%	80%	83%	75%	80%	76%
500	3	47%	69%	77%	76%	76%	73%	81%
500	4	47%	66%	77%	77%	79%	82%	83%
700	1	44%	49%	50%	50%	49%	49%	49%
700	2	46%	65%	72%	71%	75%	71%	72%
700	3	46%	67%	75%	76%	75%	72%	75%
700	4	48%	65%	70%	69%	69%	74%	76%
900	1	39%	39%	39%	39%	39%	39%	39%
900	2	45%	61%	61%	68%	67%	67%	70%
900	3	46%	64%	68%	68%	68%	61%	59%
900	4	47%	64%	62%	68%	74%	73%	67%

% Vehicles Departed								
		Fleet Factor						
Passenger Demand	Loading Vehicles	0.5	0.75	1	1.25	1.5	1.75	2
100	1	81%	81%	84%	68%	62%	50%	41%
100	2	81%	74%	72%	58%	58%	43%	36%
100	3	83%	76%	77%	61%	54%	43%	36%
100	4	80%	74%	78%	59%	54%	43%	37%
300	1	86%	85%	80%	62%	53%	45%	45%
300	2	84%	86%	74%	64%	54%	46%	40%
300	3	88%	87%	73%	64%	55%	44%	38%
300	4	90%	87%	76%	63%	51%	39%	38%
500	1	87%	86%	65%	51%	44%	38%	33%
500	2	85%	88%	78%	64%	48%	43%	36%
500	3	89%	90%	74%	58%	48%	39%	38%
500	4	88%	85%	73%	58%	49%	43%	38%
700	1	87%	64%	49%	39%	32%	27%	24%
700	2	90%	85%	70%	55%	48%	39%	35%
700	3	89%	86%	72%	59%	48%	40%	36%
700	4	91%	82%	66%	52%	43%	40%	36%
900	1	77%	51%	39%	30%	26%	22%	19%
900	2	89%	80%	60%	54%	44%	38%	34%
900	3	90%	83%	67%	53%	44%	34%	28%
900	4	91%	82%	59%	52%	48%	40%	32%

Average Passenger Waiting Time

Passenger Demand	Loading Vehicles	Fleet Factor 0.5	0.75	1	1.25	1.5	1.75	2
100	1	27.0	20.4	5.2	2.3	0.2	0.1	0.1
100	2	27.6	18.8	10.2	1.0	0.0	0.0	0.0
100	3	26.9	20.5	7.8	0.6	0.0	0.0	0.0
100	4	23.6	21.0	7.5	1.1	0.0	0.0	0.0
300	1	27.1	21.5	4.0	0.7	0.7	0.6	0.6
300	2	26.0	15.1	1.6	0.7	0.0	0.0	0.0
300	3	25.7	17.0	3.5	0.1	0.0	0.0	0.0
300	4	25.9	18.5	1.8	0.0	0.0	0.0	0.0
500	1	29.3	23.1	17.9	17.7	19.2	19.9	19.2
500	2	28.2	16.6	1.3	0.2	0.1	0.1	0.1
500	3	27.5	14.9	2.0	0.0	0.0	0.0	0.0
500	4	27.9	14.6	1.3	0.2	0.0	0.0	0.0
700	1	29.4	28.4	29.1	28.5	27.2	27.5	27.3
700	2	27.0	19.7	1.8	1.6	1.3	1.3	1.3
700	3	27.4	12.7	1.4	0.1	0.1	0.1	0.1
700	4	27.2	12.8	1.0	0.0	0.0	0.0	0.0
900	1	29.6	29.4	29.6	29.7	29.5	29.4	29.5
900	2	29.1	15.3	8.9	11.2	11.6	11.2	11.2
900	3	27.6	12.7	1.3	0.3	0.2	0.2	0.2
900	4	24.2	11.9	0.6	0.0	0.1	0.1	0.1

Maximum Passenger Queue

Passenger Demand	Loading Vehicles	Fleet Factor 0.5	0.75	1	1.25	1.5	1.75	2
100	1	98.52	93.6	71.82	65.6	18.94	14.5	12.5
100	2	98.88	89.94	80.2	40.44	10.52	15.56	15.66
100	3	99.02	86.96	81.64	66	12.04	12.9	12.82
100	4	99.04	99.18	64.74	39.08	12.38	19.28	14.26
300	1	277.06	256.48	133.5	82.9	66.8	65.32	65.32
300	2	288.54	216.78	103.72	122.22	56.36	53.04	56.96
300	3	294.42	215.7	156.58	83.12	51.88	60.02	63.8
300	4	273.96	238.58	173.96	54	54.18	75.88	56.14
500	1	454.88	357.76	276.84	278.58	273.08	275.32	275.14
500	2	448.34	338.28	185.26	103.22	135.64	116.5	132.26
500	3	432.46	307.54	181.54	132.84	137.26	151.96	115
500	4	442.82	335.08	163.84	137.96	122.66	106.24	108.08
700	1	618.74	518.5	542.8	532.5	539.3	533.16	535.14
700	2	628.18	498.48	209.54	254.68	190.68	223.44	214.36
700	3	618.28	419.78	264.18	183.06	195.08	208.16	184.64
700	4	601.68	430.58	304.92	223.9	222.94	199.06	178.54
900	1	777.7	753.38	766.16	770.3	758.92	759.76	769.08
900	2	817.7	642.62	481.5	423.14	447.4	397.86	407.06
900	3	799.88	580.1	320.92	297.18	295.38	351.02	366.54
900	4	749.34	511.72	391.12	299.64	248.14	248.5	298.9

Maximum Vehicle Queue

Passenger Demand	Loading Vehicles	Fleet Factor 0.5	0.75	1	1.25	1.5	1.75	2
100	1	2	3	5	6	8	10	12
100	2	2	3	5	8	9	11	13
100	3	3	4	5	7	9	12	13
100	4	2	3	5	7	9	11	13
300	1	4	7	13	21	26	31	31
300	2	4	10	16	20	24	30	37
300	3	3	7	15	21	28	31	37
300	4	3	9	15	21	27	32	37
500	1	6	12	25	34	40	49	60
500	2	4	12	20	33	42	53	60
500	3	4	18	24	35	46	53	62
500	4	5	22	25	35	44	53	63
700	1	10	25	37	49	62	73	86
700	2	8	13	37	50	61	74	82
700	3	5	19	34	51	63	75	83
700	4	5	22	36	54	65	73	84
900	1	10	25	37	49	62	73	86
900	2	7	31	48	64	82	92	105
900	3	5	21	46	64	78	93	109
900	4	10	34	48	58	76	92	111

3.2 FINDINGS

The results suggest that the following factors are important as potential guidelines for the design of minibus loading facilities:

i. The layout of the facility determines the type of loading that is likely to occur.
   a. At a parallel island layout, the common practice is that one taxi loads until full and departs before the next taxi is allowed to load. At busy facilities, 2 taxis are sometimes allowed to load simultaneously but the 2nd taxi can only depart when the 1st taxi is fully loaded and has departed, due to the layout of the facility.
   b. An oval island layout allows for loading of more than one vehicle simultaneously. A vehicle can depart as soon as it is full because the geometry of the facility does not trap the vehicle.

ii. The estimated volume of passengers per destination.
   a. From an operational perspective, if the number of passengers is less than 400 per hour for a single destination, a parallel island layout is acceptable.
   b. For more than 400 passengers per hour, an oval island layout is preferable.
   c. For more than 700 vehicles per hour, concurrent loading of more than 2 vehicles at a time is more efficient (3 vehicles or more)

iii. The number of vehicles (fleet size), expressed as a fleet factor in this paper.
   a. A fleet factor of less than 1.0 compromises the efficiency of loading operations from a passenger perspective.
   b. A fleet factor of more than 0.75 is inefficient from a vehicle perspective because the likelihood of a full departure of the available fleet within the hour analysed decreases exponentially beyond a fleet factor of 0.75.

c. A fleet factor of less than 1.0 is acceptable if the number of passengers to be loaded per hour is more than 700 passengers per hour and oval island type loading (simultaneous loading) is allowed.
d. A fleet factor of more than 1.0 offers only marginal benefits to commuters in terms of the improvement of the overall efficiency of loading.

iv. The loading behaviour of passengers.
a. The typical boarding times that were used for the purpose of this research report are unique to minibus taxis. Surveys will therefore be required to ascertain the boarding behaviour associated with other modes such as buses, to apply this method to other modes.

v. The queuing behaviour of passengers.
a. Based on the simulation findings, there is a benefit to loading more than 2 vehicles simultaneously only when the passenger demand is in excess of 700 passengers per hour.
b. This applies to current operating practice where all passengers to a particular destination form a single queue. If more than one queue of passengers is allowed to form, simultaneous loading might be beneficial at lower passenger demands than 700 per hour.

vi. The shunting time between vehicles.
The shunting time between the time when a fully loaded vehicle departs until another vehicle takes its place and is ready to load, was kept constant for this research. Improving the efficiency of this movement will save significant time between the departures of full loads and will therefore logically translate into improved performance of the facility.

A simple guideline (Table3) for the selection of the number of loading berths -- and by extension the type of layout -- required for a loading facility, was developed based on the passenger demand only. This table is a summary guideline of some of the findings contained under point (ii) above.

Table3: Guideline for the selection of number of loading berths based on passenger demand (Note: single berth corresponds to parallel layout with one vehicle loading; more than 1 corresponds to oval island layout with simultaneous loading)

Passenger Demand per hour	Number of Vehicle Loading			
100	1	2		
200	1	2		
300	1	2		
400	1	2		
500		2		
600		2		
700		2	3	4
800			3	4
900			3	4

4. RECOMMENDATIONS

- The possibilities for further research that were unearthed with the development of this simulation model are numerous. The National Department of Transport recognises in its official design guidelines that the design of minibus taxi facilities has largely been ignored by researchers. So foremost among the conclusions is a recommendation that further research into the behaviour of agents within the taxi facility environment should be done. Funding is currently being spent by various levels of government on the provision of public transport facilities. The underlying fundamentals of such facilities play a big role in the size and layout of such facilities, and as a result, the efficiency and cost of such facilities. A better understanding of parameters used and more accuracy in the guidelines provided will have significant benefits to all stakeholders involved in the planning, design and implementation process.

- A full set of guidelines can be developed using simulation modelling. There are many opportunities for improving the sophistication and accuracy of the existing model. Further research may build on this and provide further important insights.
- It is recommended that the findings of this research be presented to authorities and to stakeholders, for inclusion in new designs.
- This report provided some evidence of the operational benefits of an oval island layout facility over a parallel island layout. Further research is however required into the safety and convenience aspects of alternative layouts , as well as ways to innovatively combine the strengths of both types of designs in the same facility.
- It is recommended that practitioners use the figures and tables contained in section 4 of this paper as a tool to augment the existing NDoT design guidelines (NDoT, 2007)

5. REFERENCES

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