Relating bus dwell time and platform crowding at a busway station

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1 Introduction

Bus dwell time is traditionally modelled as a function of the number of alighting and boarding passengers plus an amount of time for door opening and closing. Such an approach can be used to estimate bus dwell time at an on street bus stop. However, it could be less accurate for a busway station, where more than one loading area is available, due to crowding on the platform.

This paper discusses an approach to understand platform crowding and its effects on bus dwell times by way of a pilot study. Video footage using digital cameras was captured and later analysed in the laboratory in two phases. In the first phase, the bus-side data (dwell time, service time per passenger, etc) was extracted. In second phase, passenger-side data (reaction time to bus, walking time, crowd density, etc) was extracted.

This paper tests the hypothesis that the platform crowding effects bus dwell time. To support this hypothesis the behaviour of passengers while waiting at the platform is discussed. Later the effect of platform crowd on bus dwell time is analysed.

2 Background

One of the earliest studies towards the understanding of bus dwell time was published by Levinson (1983). He used a simple regression approach to analyse and predict bus dwell time for bus stops across US cities (Equation 1), where *N* is the sum of boarding and alighting passengers at the stop.

$$DwellTime = 5.0 + 2.75N \quad \text{Equation 1}$$

This model includes a constant, which is presumed here to reflect lost time that could be attributed to door opening and closing amongst other activities. It also includes another constant presumably for the time spends in processing each passenger. Guenther and Sinha (1983) in a study on bus service found that each boarding or alighting passenger contributes 3 to 5 seconds towards total dwell time of the bus at the stop.

From these earlier single variable dwell time models, research started to consider dwell time as a multi-variable model. This approach considered the number of alighting passengers and number of boarding passengers as two separate variables. Vuchic (2005) related dwell time to the number of boarding and alighting passengers plus a constant, which accounts for the time taken by the bus to perform door opening and closing. An identical equation was suggested by the TCQSM (Kittelson and Associates) in 1999 and subsequently in 2003 (Equation 2). Note that this equation includes two constants, one each for the processing time per alighting passenger and processing time per boarding passenger. Values for the constants mainly related to ticketing system were recommended in the literature.

$$t_d = P_a t_a + P_b t_b + t_{oc} \quad \text{Equation 2}$$

where:

t_d	=	Average dwell times (s)
P_a	=	Alighting passengers per bus through the busiest door (p)
t_a	=	Alighting passenger service time (s/p)
P_b	=	Boarding passengers per bus through the busiest door (p)
t_b	=	Boarding passenger service time (s/p)
t_{oc}	=	Door opening and closing times (s)

Although very useful for estimating dwell times at typical on street bus stops, these multi-variable dwell time models still do not account for the effect of crowding at a busway station platform, unless processing times per passenger are especially calibrated for such conditions, which has not been found in the literature surveyed. (It is noted that congestion inside of the vehicle has been accounted for in the Kittelson model, through an increment to processing time per passenger when standees are present.) Nor do they account for any additional lost time for the first boarding passenger to reach the door.

Puong (2000) developed an Ordinary Least Square regression model for train dwell time at a railway station where only one platform is used for loading and unloading passengers. The model includes a cubic term for through standees inside the train, which cause congestion at the door (Equation 3). This model provides insight into an effect that congestion may have, although not outside of the vehicle on the platform, as is the case on the busway platform.

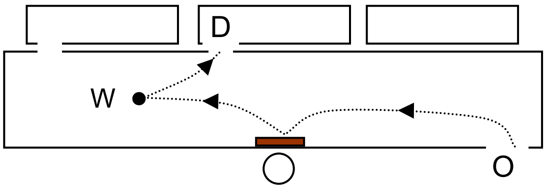
$$DT = 12.27 + 1.82A_d + [2.27 + 6.2\times10^{-4}(TS_d)^3]\times B_d \qquad \text{Equation 3}$$

where:

DT	=	dwell time
A_d	=	alighting passenger per door
B_d	=	boarding passenger per door
TS_d	=	through standees per door
$[2.27 + 6.2\times10^{-4}(TS_d)^3]$	=	marginal boarding time per passenger

3 Problem conceptualisation

In the previous section it was identified that the conventional dwell time models do not account for passengers beyond their boarding and alighting numbers and the processing times per boarding and alighting passenger. These models do not explicitly address crowding that can be observed on a busway platform. Crowd density at the platform has a manifold effect on its operation. Not only does it affect the manoeuvrability of passengers, it also obstructs the clear line of sight to approaching buses. This may result in an increased reaction time for passengers on the arrival of expected bus. This can be shown by considering the typical path of passengers at a platform to catch their desired bus (Figure 1).



where:
O = Origin
D = Destination
i = Information signage
= Trip route
W = Waiting point

Figure 1 – Origin and Destination of trip segment at platform

For simplicity, it can be considered that the length of the trip segment can be equal to or less than the platform length. However, the ease in traversing this segment depends on the prevailing passenger density at the platform. The time spent by the passenger walking between waiting point W and the bus door (point D) is hypothesised to influence the bus dwell time. As passenger density increases, walking speed may decrease, and therefore within the dwell time some lost time may occur prior to passenger service time.

On the whole, the dwell time may vary in a manner related to the crowd encountered by the passenger on the way to the bus door. Not only may this affect the individual bus, but it may also affect other buses by delaying their entrance to the loading area, and consequently affect the loading areas' bus capacity.

4 Methodology

The methodology reported here is for a pilot study, which was conducted to examine whether the hypotheses above are realistic. Many parameters related to analysis period, study area and observational variables have been considered while conducting this study.

4.1 Analysis period and site characteristics

Mater Hill station in Brisbane, Australia is the third station on the 16 km long South East Busway corridor to the south of the Brisbane Central Business District (Queen Street Station) as shown in Figure 2. Mater Hill Busway Station has three signed and striped loading areas as shown in Figure 3. Occasionally some buses stop very close to the dwelling bus in front thereby creating a temporary fourth loading area.

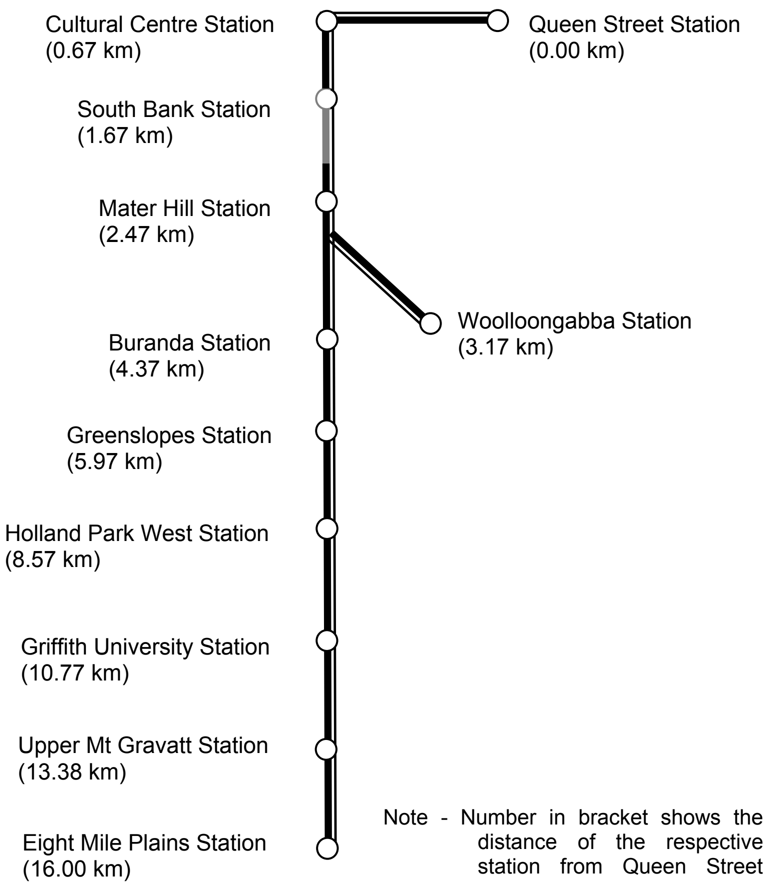


Figure 2 – Brisbane South East Busway route map at early 2008

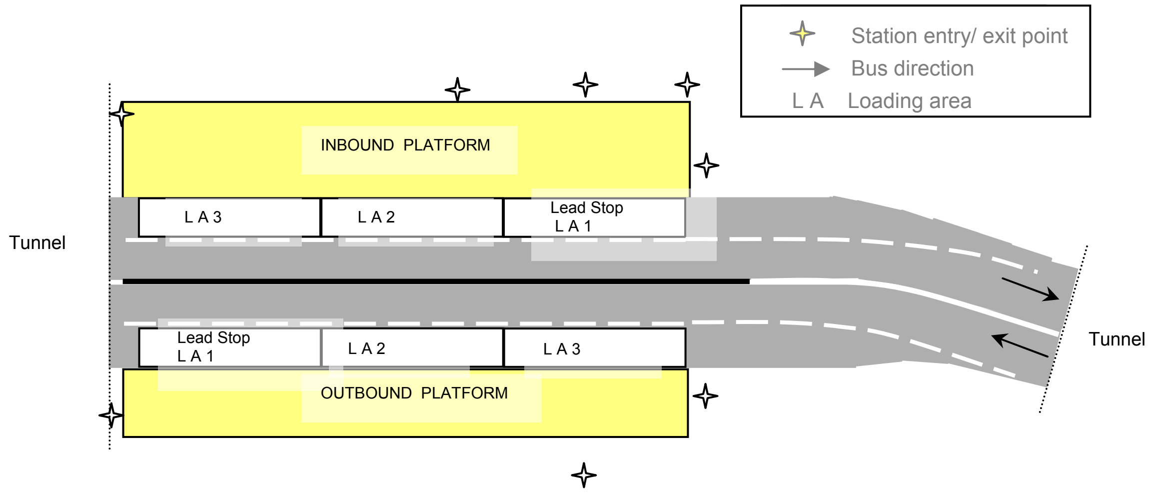


Figure 3 – Configuration of Mater Hill busway station

Passenger demands and bus flow rates through the station vary between off-peak and peak time times. The characteristics of the South East Busway corridor are such that, during the morning peak, flow of passengers toward the city is high, contributing to high numbers of passenger alighting at the inbound platforms of inner urban stations. This situation is reversed during the afternoon and evening peak periods when there are more boarding passengers on the outbound platforms of inner urban stations. During daytime off peak periods passenger demands and bus flow rates are more even between directions and for a given bus there is a greater evenness between alighting passengers and boarding passengers. For this pilot analysis, a daytime off peak period was selected.

Although an off peak period was selected, passenger demands and bus flow rates at the subject station platform were still relatively high. The data collection method was therefore selected with care. On site manual counting can prove to be very laborious and may be susceptible to high human error. Video recording of the station and then laboratory counting was selected to eliminate much of this potential error.

The passengers using the station during the analysis period included general public such as university students, hospital visitors, and workers.

4.2 Observation at the station platform

The aim of this pilot study was to gather the evidence of how the passenger density at the platform affects the dwell time of buses. It was therefore important to record the attributes explaining how passengers approached the entry door of their desired bus. It was also important to record the passenger density to relate it to crowd formation, and to identify the distribution of crowding along the platform. Observations related to the buses' dwell times such as service time at the platform and door opening and closing time were are also made.

Each bus entering the station platform was monitored. In a station having multiple loading areas, the amount of time required by the passenger to cover the distance between the waiting location to their bus door varies from loading area to loading area. Therefore, the loading area used by each bus was also recorded. Referring to Figure 1, a selected number of passengers were tracked on video from their waiting location at the platform (W) to their bus door (D). The numbers of passengers alighting and boarding were recorded. The time between door opening and first passenger boarding for each bus was also recorded.

4.3 Data collection

Video recordings were made on the outbound platform of the Mater Hill Busway station, Brisbane between 10:00 AM and 11:00 AM on a typical Wednesday. The passengers on the platform were unaffected by the video recording as footage was captured using busway security cameras mounted on the ceiling of the busway platform. Cameras record the activities on the platform on a 24hr / 7 day basis.

For measuring the bus dwells time, the guidelines from Transit Capacity and Quality of Service Manual (TCQSM) (Kittelson, 2003) were followed:

1. Record the bus route number and bay number on which it is serving passenger (s).
2. Record the time at which the bus comes to a complete halt.
3. Record the time of full opening of the bus front door.
4. Count the number of alighting passengers separately from the front and rear door and number of boarding passenger onto the front door.
5. Record the timing for first and last passenger alighting.
6. Record the timing for first and last passenger boarding.
7. Record the time of full closing of the bus front door.
8. Record the time when bus left the bay.

The steps of recording the passenger side data were derived from the concepts explained above. The following steps were involved in the measurement –

1. Select a passenger on the platform and tag them (say x_i)
2. Record the time of that passenger's reaction to their desired bus.
3. If that passenger needed to queue at the bus door, due to any passenger/s alighting from the bus or any passenger/s boarding in front of them, then record the time when that passenger joined the queue.
4. Record the time at which the passenger boarded the bus.
5. Record the number of passengers on the platform encountered by that passenger between point W and point D (refer to Figure 1).
6. Record the total number of passengers present on the platform at this time.

A total of 80 passengers, randomly selected from the platform crowd during the one hour analysis period, were observed from the time when they first reacted to their desired bus until the time when they boarded.

Passengers were categorised on the basis of the loading area through which their desired bus served the platform. Each selected passenger was observed for a series of attributes shown in the form of Table 1.

Table 1 – Passenger attributes

Attribute	*Type*		
Approximate age type	Student	Office worker	Aged/disabled
Waiting location on the platform	Area 1	Area 2	Area 3
Position while waiting	Seating	Standing	Moving
Number of passengers passed and crossed on the platform while walking to bus door			
Number of passengers in front while queuing			
Time required to cover the walking distance between point W and point D			

5 Data analysis

From initial observations of the video footage it was found that the passenger and the bus driver were involved in a state where they both interact but perform their activities independently. We called such state the passenger – bus interface (*IF*). The interface starts when the passenger first sees the desired bus and hails it and starts walking towards the point by anticipating its stopping location. Similarly, the driver of the bus, after seeing the hailing passenger, prepares to stop the bus at the available loading area. During this course of action both actors act independently but anticipate each other. Therefore we called this the passenger – bus interface. The interface ends when the passenger – bus interaction (*IA*) starts, which is when the passenger boards the bus. Hence the duration of interface is the time lapse between initial reaction and boarding, including any time in queue at the bus door. The assumption made is that the duration of interface affects the dwell time of the bus.

It was hypothesised that much variation among the platform loading areas in passenger interface time can be explained by the level of platform crowding or the number of passengers encountered.

5.1 Passenger behaviour while waiting

Passengers on the platform were observed to follow a particular pattern in selecting their waiting location. During the pilot study period, sometimes a relatively low crowd condition occurred. During these times, passengers preferred to wait within the area between an imaginary line x-x drawn in the middle of loading area 1 and the information point located at the middle of the platform (Figure 4), approximately in the middle of loading area 2. The bus entry door at loading area 1 and loading area 2 are nearly equidistant of the imaginary line x-x (d_{x1} is approximately equal to d_{x2}). Therefore, the distance between the bus door on loading area 1 and shaded area centroid y-y (d_{y1}) will be more than the distance between the bus door on loading area 2 and the shaded area centroid (d_{y2}) (Figure 5). The duration of interface for loading area 2 was found to be less than for loading area 1.

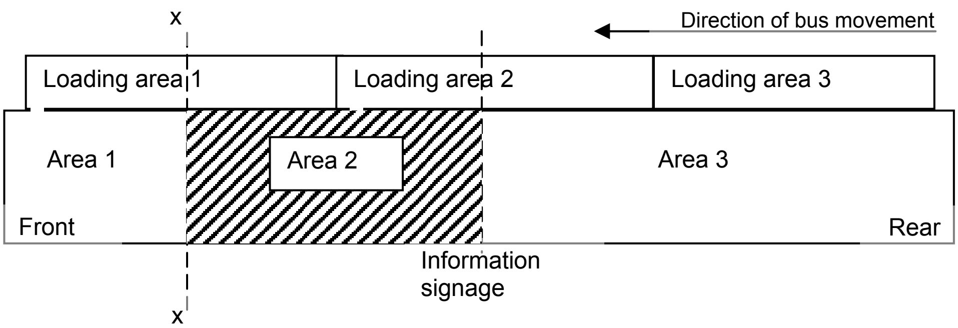


Figure 4 – Observed passenger preferred waiting area on the outbound platform under low crowding condition

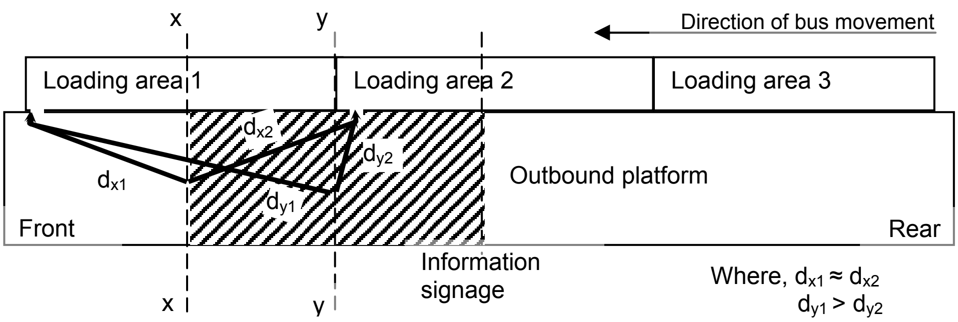


Figure 5 – Distance to loading areas from the waiting area on the platform

On occasions during the pilot study period the crowd at the platform increased. The additional passengers tended to spread toward the front end of the platform, which is the left side of the shaded area in Figure 4, causing the centroid of the crowd to drift nearer to the loading area 1's bus door position y'-y' (Figure 6). Hence, as the crowd density increased the distance $d_{y'1}$ became less than d_{y1} whereas the distance $d_{y'2}$ became greater than d_{y2}.

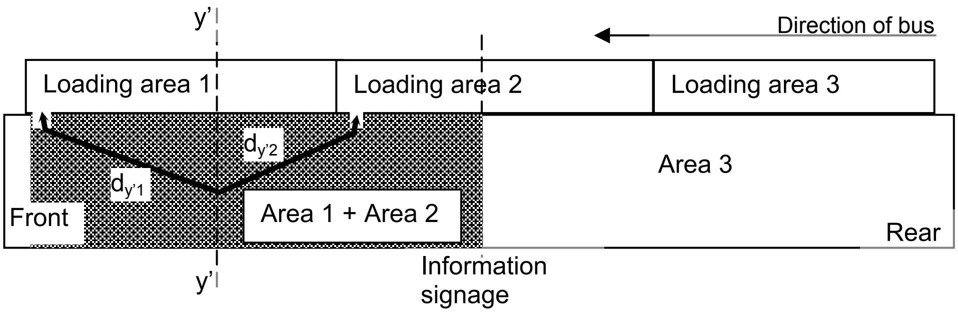


Figure 6 – Changed waiting area space on the outbound platform under increased crowding

5.2 Effects of platform crowding and passengers encountered

Figure 7 illustrates the duration of interface against platform crowding. Following the discussion above, for loading area 1 the duration of interface tends to reduce with increasing crowd due to the phenomenon discussed above with respect to Figures 5 and 6. For the same reasons, the duration of interface tends to increase with loading area 2. As the pilot analysis was during an off-peak period, loading areas 1 and 2 were mostly available for incoming buses; so loading area 3 was used rarely by buses. However, it was found that with the increase in crowding the interface time for loading area 3 increased slightly.

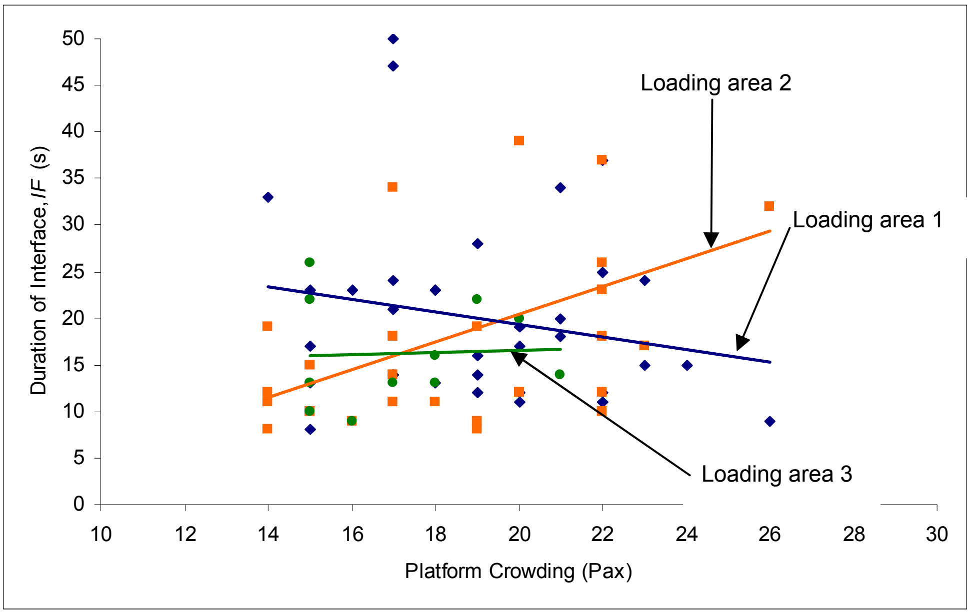


Figure 7 – Effect of platform crowding on duration of interface

However this analysis did not establish any clear statistically significant relationship between duration of interface and level of platform crowding. Alternatively, therefore, duration of interface was analysed against the number of passengers encountered en route to the bus entry door from the waiting potion. The number of passengers encountered in the walking path increases with an increase in the platform crowding level. From the analysis, it was found that the duration of interface tends to increase with the number of passengers on the platform encountered in the path (Figure 8). This is because, as the number of standing persons in the path increases, the passenger's walking speed decreases. The passenger can no longer use the straight path between the waiting point and bus door but is forced to use a zig-zag manoeuvre to complete the path. This increases the distance and thereby increases the walking time.

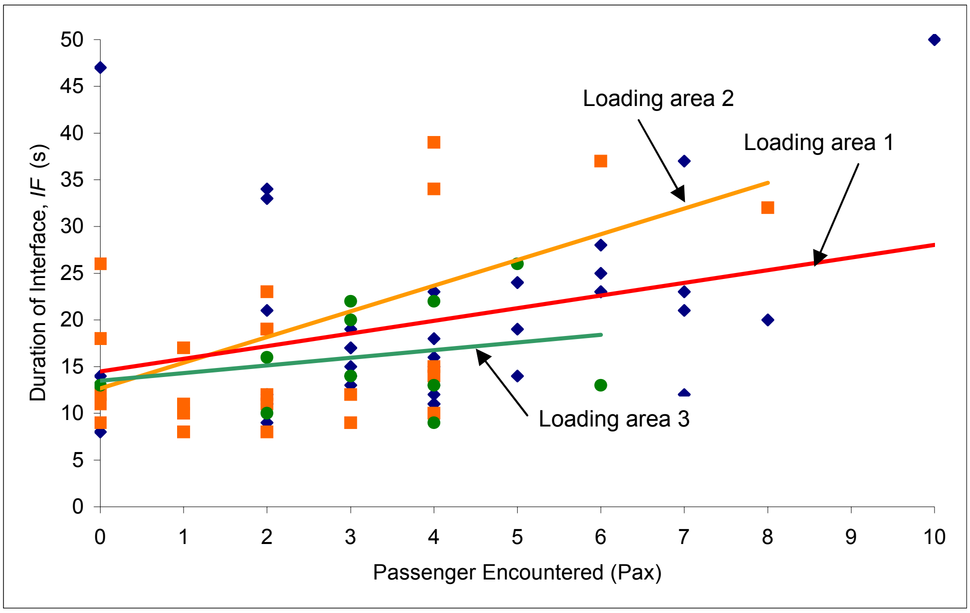


Figure 8 – Effect of passengers encountered on platform on duration of interface

This analysis was made by simple linear regression. The following predictive equations were developed to estimate the duration of interface as a function of the number of passengers encountered between W and D:

The duration of interface for loading area 1, IF_{la1}, is given by Equation 4.

$$IF_{la1} = 1.35P_e + 14.5 \qquad R^2 = 0.19,\ n = 38 \qquad \text{Equation 4}$$

Similarly, duration of interface for loading area 2, IF_{la2} is given by Equation 5.

$$IF_{la2} = 2.75P_e + 12.7 \qquad R^2 = 0.21,\ n = 31 \qquad \text{Equation 5}$$

Similarly, duration of interface for loading area 3, IF_{la3} is given by Equation 6.

$$IF_{la3} = 0.82P_e + 13.5 \qquad R^2 = 0.09,\ n = 11 \qquad \text{Equation 6}$$

where:

P_e is the number of passengers encountered on the platform on the walking path to the bus door, and

IF_{la1}, IF_{la2}, and IF_{la3} are the duration of passenger-bus interface (seconds) for loading areas 1, 2 and 3, respectively.

However, the regression returned very low R square values, due to the large spread in duration of interface for a given number of encountered passengers.

Figure 8 and these equations do demonstrate that the impact of passengers encountered between W and D varied with the loading area. A person in the walking path to loading area 1 had an average impact of 1.35 seconds, whereas the average impact of a person to the walking path to loading area 2 was 2.75 seconds. This may be because the passenger density, the number of passenger per unit area, was observed to be higher adjacent to loading area 2, giving less manoeuvrability. Similarly, each passenger en-route to the bus entry at loading area 3 impacted the duration of interface by an average of 0.82 seconds.

The constants in Equations 4, 5 and 6 represent much of the clear walking time for the passenger to reach the bus entry door plus any queuing time at the bus entry door, which is a function of boarding demand. The value of constant for the passenger-bus interface for loading area 1 was found as 14.5 seconds, as against the 12.7 seconds for loading area 2, which indicates that passengers tend to wait slightly closer to the loading area 2 bus entry door position than the loading area 1 bus entry door position, assuming bus boarding queuing is random between loading areas. Similarly, the constant for loading area 3 was found to be 13.5 seconds which is 0.8 seconds larger than that of loading area 2.

5.3 Influences of loading area on bus dwell times

Table 2 shows the variation in bus dwell times with the loading area on the station platform. Due to the analysis period being an off-peak period, loading area 3 was used less than loading area 1 and 2. During the off peak period of this study, It was found that the dwell times for the buses serving on loading area 1 are higher than those for buses serving on loading area 2. However, Jaiswal *et al*. (2007) found that during the peak period the dwell times for the loading area 1 were less than the dwell times for the loading area 2. This is likely because passengers, with increase in crowding, shift towards the loading area side of the platform in general, and specifically towards loading area 1 as explained above.

Table 2 – Bus dwell times at Mater Hill busway station

	Loading area 1	*Loading area 2*	*Loading area 3*
Average bus dwell times during off-peak period (s)	32	23	-
Average bus dwell times during peak period (s) (Jaiswal *et al*. 2007)	38	49	50

The variation in passenger walking time to the bus entry door with respect to the loading area is given in Table 3. The walking time of the passenger to the bus entry door is the interface time less the boarding queuing time. As expected, the average walking time to loading area 2 is less than that to loading area 1 or loading area 3 because of the closer proximity of the waiting position to the bus entry door. Interestingly, the average walking time to loading area 3 is lower than that to loading area 1, which may be because the reduced level of crowding towards the rear of the platform allows for more manoeuvrability and a higher walking speed. The maximum walking times reflect a similar pattern, while there is little difference in the minimum walking times.

Table 3 – Passenger walking times at Mater Hill busway station during off-peak period

	Loading Area 1	*Loading Area 2*	*Loading Area 3*
Minimum walking time for passengers (s)	8	7	7
Average walking time for passenger (s)	**17**	**12**	**15**
Maximum walking time for passengers (s)	33	19	22

6 Proposed form of bus dwell time model for busway stations

The newly developed approach of passenger-bus interface can be applied to existing dwell time models which may make the calculation of delays to buses and platform bus capacities at busway stations more robust. This section discussed a proposed approach to incorporate the passenger-bus interface within the current available dwell time model, which will be studied further in future research.

This research considers the dwell time equation given by TCQSM (Kittelson, 2003) as the base model. Therefore, the equation 2 can be represented mathematically as:

$$DwellTime = fn(P_a; P_b; T_a; T_b; O_c) \quad \text{Equation 7}$$

The proposed revised form of dwell time model which will also account for the platform crowd density and walking distance is given as:

$$DwellTime = fn(P_a; P_b; T_a; T_b; C_d; W_d; O_c) \quad \text{Equation 8}$$

where,

P_a = Number of alighting passengers

P_b = Number of boarding passengers

T_a = Alighting passenger service time

T_b = Boarding passenger service time

O_c = Operational constant, account for door opening and door closing time

C_d = Crowd density on the platform

W_d = Walking distance to reach bus entry door from waiting point

Representing the duration of service time to passengers boarding and alighting as passenger-bus interaction, and crowd density and walking distance on platform as passenger-bus interface, the proposed dwell time model for busway station can be expressed as:

$$DwellTime = fn\,(\text{passenger-bus interaction; passenger-bus interface; operational constant})$$

Equation 9

Future research will further develop the form of Equation 9. The models developed through Equations 4 to 6 will be used to inform the development of the component of Equation 9 that represents passenger-bus interaction. This can first be carried out for the off peak conditions of this pilot study, but will then need to be generalised for conditions at other times of day such as the afternoon and evening peak periods.

7 Conclusions

This study explores the crowd phenomenon and its effects on the operation on the operation of the busway station platform. This pilot study confirms that the passenger(s) encountered en route to the bus entry door affects the walking time. The paper illustrates the patterns in passengers' choice for waiting location with changing level of platform crowd. Additionally, this pilot study proposed a new form for the dwell time equation, which would account for the platform crowd and passenger – bus interface in bus dwell time estimation for busway stations, for further investigation.

To improve the bus dwell time efficiency it is necessary to minimise the amount of time wasted by the buses at the station platform. A proper understanding of crowd phenomena at the busway station is therefore very crucial. It may be possible to reduce the bus dwell times and hence the delay at stations by providing conditions favourable to organised and structured interaction between passengers and buses. It is equally important that the reliability of service and hassle free boarding and alighting at the station should be maintained. The new approach, presented in this paper, to classifying the activities of passengers and buses into passenger-bus interface and passenger-bus interaction, occurring within the platform space, therefore, could prove useful in developing a more robust bus dwell time model for busway stations. A passenger-bus interface variable could be incorporated with the traditional dwell time models to account for the platform crowding effect.

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References

Guenther, R P and Sinha, K C (1983) Modeling bus delays due to passenger boarding and alighting, *Transportation Research Record 915*, 7-13.

Jaiswal, S., Bunker, J. and Ferreira, L (2007). *Operating characteristics and performance of a busway transit station*. 30th Australasian Transport Research Forum (ATRF), 25-27 September: Melbourne.

Kittelson and Associates, Inc. (2003). *Transit Capacity and Quality of Service Manual* (TCQSM), *2nd edition*. Prepared for Transit Cooperative Research Program, Transportation Research Board: Washington, DC, United States.

Levinson, H S (1983). Analyzing transit travel time performance, *Transportation Research Record,* 915, 1-6.

Puong, A. (2000). Dwell *time model and analysis for the MBTA red line*. Open courseware project, Massachusetts institute of Technology. http://www.myoops.org/

Vuchic, V. (2005). *Urban Transit: Operation, Planning and Economics.* John Wiley & Sons, Inc. New Jersey.