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A Microscopic Simulation Model to Estimate Bus Rapid Transit Station Bus Capacity

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Abstract

The Bus Rapid Transit (BRT) station is the interface between passengers and services. The station is crucial to line operation as it is typically the only location where buses can pass each other. Congestion may occur here when buses maneuvering into and out of the platform lane interfere with bus flow, or when a queue of buses forms upstream of the platform lane blocking the passing lane. Further, some systems include operation where express buses do not observe the station, resulting in a proportion of non-stopping buses. It is important to understand the operation of the station under this type of operation and its effect on BRT line capacity.

This study uses microscopic traffic simulation modeling to treat the BRT station operation and to analyze the relationship between station bus capacity and BRT line bus capacity. First, the simulation model is developed for the limit state scenario and then a statistical model is defined and calibrated for a specified range of controlled scenarios of dwell time characteristics. A field survey was conducted to verify the parameters such as dwell time, clearance time and coefficient of variation of dwell time to obtain relevant station bus capacity. The proposed model for BRT bus capacity provides a better understanding of BRT line capacity and is useful to transit authorities in BRT planning, design and operation.

Key words: Bus Rapid Transit, busway, microscopic traffic simulation, capacity

1. Introduction

Bus Rapid Transit (BRT) is an integrated system of facilities, service, and amenities that collectively improves the speed, reliability, efficiency and identity of bus (TRB, 2003b). Many forms of BRT systems are in operation worldwide. Those most common incorporate either priority on-road infrastructure including exclusive bus lanes, facilities completely segregated from general traffic which are commonly referred to as busways, or a combination of the two. Dedicated busways in particular provide greater improvement in speed and reliability than exclusive bus lanes (TRB, 2003b).

BRT line service capacity (bus/h or p/h) is dependent on the bus capacity of its critical segment. In turn, critical segment capacity is controlled by one of its two adjacent nodes, which may take the form of a controlled intersection or a station, acting as a bottleneck (TRB, 2003a, Levinson and Jacques, 1998). Station bus capacity may be influenced by factors including spacing, location, design and operation. Accordingly the analyst requires a robust methodology in order to estimate bus capacity considering these potential bottlenecks.

The procedure for estimating BRT line service capacity is defined by the US Transit Capacity and Quality Service Manual (TCQSM) (TRB, 2003b) where line service capacity is controlled by capacity of buses through the busiest stop. This method is suitable when the system is operating under its capacity and all the buses are stopping at that critical station. However, some systems include operation where express buses pass the critical station, resulting in a proportion of non-stopping buses. It is important to understand the operation of the critical busway station under this type of operation, as it affects busway line capacity. However, research on such busway lane capacity of BRT operation is scarce. Therefore, this research was designed to respond to this question by using microscopic simulation.

2. Common Definitions

Bus Rapid Transit (BRT) is defined by the US Transit Capacity and Quality of Service Manual (TCQSM) (TRB, 2003b) as a flexible, rubber-tired rapid transit mode that incorporates stations, vehicles, services, running-ways and Intelligent Transportation System (ITS) elements into integrated system with a strong positive identity that evokes a unique image.

A *BRT line* or *busway* is defined as a linear corridor containing multiple segments, which carries one or more bus routes (Widanapathiranage et al., 2013). A *segment* is defined as a section of BRT line between two nodes that influence the traffic operation of the BRT line. Examples of a *node* include a BRT station, signalized intersection, unsignalized intersection, on-ramp and off-ramp. A *station* is defined as a node on a BRT line where buses are able to stop and dwell to serve passenger exchange (boardings and/or alightings). A BRT station may have various configurations. In this study, a station is defined to be directionally separated such that buses cannot overtake across the oncoming side of the roadway. It has a linear platform in each direction to serve passenger exchange. The platform contains multiple, off-line linear loading areas. In each direction, the roadway contains a platform stopping lane with an upstream pullout taper and a downstream merge taper, plus an adjacent passing lane. A *loading area* is defined as a portion of the platform stopping lane, either marked or unmarked, which is designated for bus stopping and dwelling to serve passenger exchange.

Transit line service capacity (veh/h) is that achievable under stipulated repeatable, safe working conditions resulting in a maximum achievable frequency. TCQSM (TRB, 2003b) defines it as “the maximum number of transit vehicles that can pass a given location during a given time period” based on a minimum headway. The given location is usually the busiest stop which causes the greatest constriction to throughput. The given time period is usually a peak hour for the peak travel direction. The minimum headway is usually a design value that incorporates a buffer to avoid congested operation.

3. Existing BRT Station and Bus Stop Capacity Models

The standard procedure for estimating BRT line service capacity is prescribed in TCQSM (TRB, 2003b). This procedure is a simplified version of a more complex deterministic procedure to estimate bus stop design capacity, which is applicable to a range of facilities including mixed traffic streets. The procedure stipulates that line service capacity is controlled by capacity of buses through the busiest stop. The remainder of this paper implies a busiest stop, or in this case BRT station capacity analysis.

For BRT facilities the procedure simplifies when the absence of immediately adjacent signalized intersections removes the need to apply a green time ratio. The design capacity is based on applying an operating margin to average dwell time that corresponds to a desired failure rate, which is defined as the probability of a bus queue waiting to access a loading area occupied by a dwelling bus.

One drawback of the TCQSM procedure is that it does not explicitly address bus queuing upstream of the platform area at a BRT station, where queues have been observed in this study to form rather than at each loading area along the station platform. Further, the actual length of bus queues cannot be readily estimated using the existing procedure. However actual queue lengths are useful when undertaking traffic engineering for a BRT facility, for instance in addressing queue spillback to other features on the line.

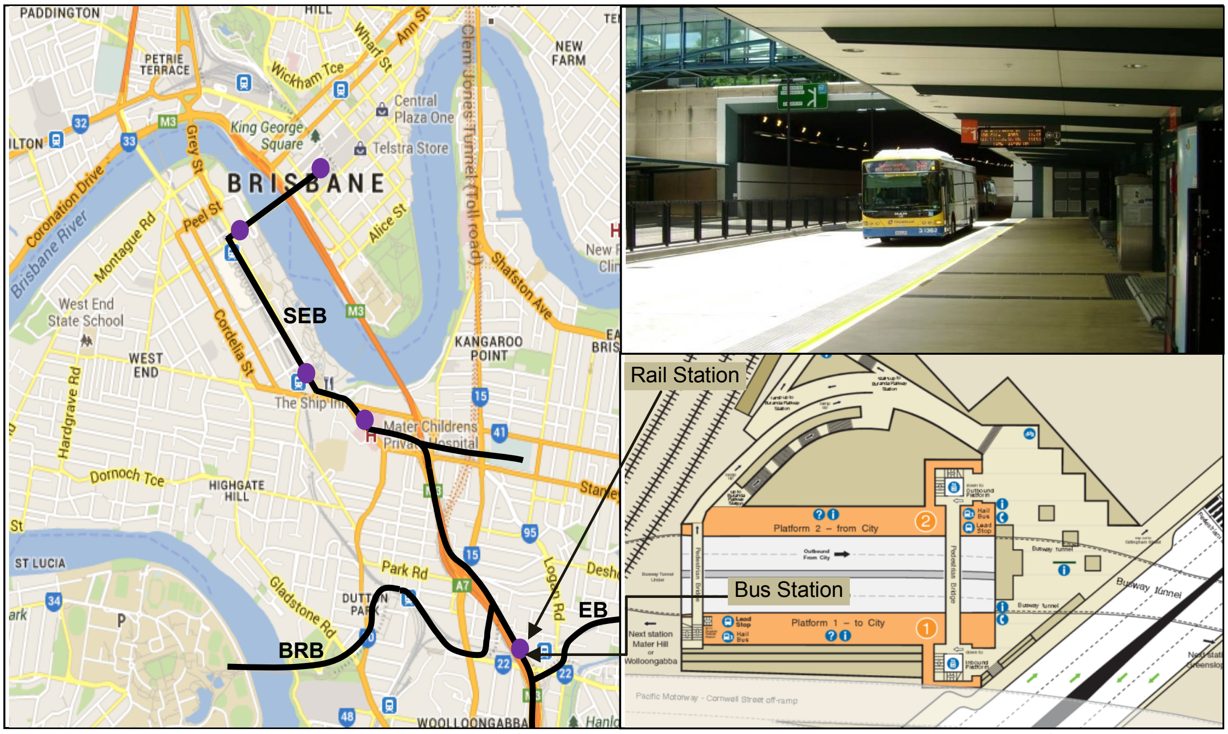
Fernández (2007) introduced the concept called capacity of divided bus stops. A divided bus stop contains berths that are separated to reduce bus interference and concequently increase bus capacity. It was found that weaving distance between nearby stop points should be designed by considering the influence of downstream stop queue length and the combination of passenger demand of stopping points (Fernández, 2007). Jaiswal et al. introduced bus lost time as an additional component of the minimum headway to calculate bus platform capacity (Jaiswal et al., 2009). Accordingly a Busway Loading Bus Capacity Model (BSLC) was introduced with lost time variables. Results showed that TCQSM model gives higher values than BSLC as BSLC model accounts lost time variable which accounts higher delay time for buses (Jaiswal et al., 2010).

The simulation modelling approach can be used to measure stop/station capacity as well as other performance measures. Fernández modelled bus stops and a light rail station using the PASSION microscopic model under mixed traffic conditions (Fernández, 2010). It was found that the stop cannot operate at its absolute capacity because upstream bus queuing developed even at a low degree of saturation, suggesting that no more than one vehicle queue would be acceptable during a short period of time.

4. Case Study Description

The simulation model is developed by considering Buranda busway station's configuration and operation. This station is the fourth of 10 stations along the 16km South East Busway (SEB) and is 4.4km south of Brisbane CBD's hub Queen Street Bus Station (Bitzios et al., 2009).

Figure 1: Buranda Busway Station Map



Note: Black line indicates the sections of SEB, EB and BRB and purple dots indicate Queens Street, Cultural Center, South Bank, Mater hill and Buranda stations from top to bottom of the figure (Source: www.translink.com.au, www.google.com.au).

Buranda station has one platform in each direction, and on each platform three off-line linear loading areas and a passing lane (Widanapathiranage et al., 2013). With a suburban railway station situated on ground level above (Translink, 2012), Buranda is an important bus/rail interchange. Furthermore, it is a junction station between the north-south SEB, the 4km Boggo Road Busway (BRB) which connects to the SEB via a signalized T intersection to the north, and the 1.0km Eastern Busway (EB) which connects to the SEB via a signalized T intersection to the south. BRB contains four stations with its western terminus station of University of Queensland being one of Brisbane's major transit destinations. EB contains two stations and at its eastern end connects to the high volume Old Cleveland Road on-street bus commuter corridor *(Translink, 2011)*. All buses through Buranda station are managed by Queensland Government's TransLink Division, which uses smart card fare technology for efficient passenger exchange and seamless multi-modal transit system operation.

Buranda station experiences high passenger exchange and some bus queuing on the inbound platform during the morning peak period and outbound platform during the peak period. Although there are three loading areas on the platform, a fourth itinerant loading area is created in peak periods when bus drivers are able to pull into it and dwell using only the front door to serve passengers.

4.1 Field Surveys

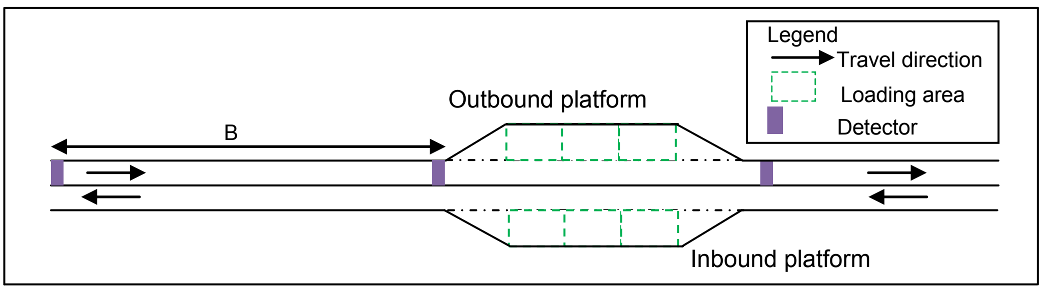
A manual counting method was used to count boarding and alighting passengers to minimize error and abide by TransLink's observation policy. A field survey was conducted in May 2011, which is one of the busiest months of passenger demand for Brisbane. Clearance time and dwell time data were collected by the survey team. The average dwell time, clearance time and coefficient of variation of dwell time (or dwell time coefficient) were computed as 18s, 16s and 0.52 respectively. The loading area efficiency was estimated using TCQSM method and was observed as 80%, 90% and 100% for first, second and third loading area, respectively (The fourth itinerant loading area efficiency was observed to be only 2%) which equates to 2.7 effective loading area. These values are within range of TCQSM. A second field survey was conducted in April 2013 to verify the distribution of dwell time and headways in order to develop the simulation model which described in next section.

5. Busway Station Simulation Model Development

Traffic simulation can efficiently represent the real world situation and reproduce its behaviour under a controlled environment and hence has widespread use in developing and testing scenarios (Fernández, 2010). The model proposed in this research is based on simulation, where for realistic representation of the network and reproduction of the network behaviour, the parameters for the simulation model are calibrated with the real data collected via field survey and validated against standard values given in TCQSM. Thereafter, different scenarios are simulated and the data obtained is used to develop the model.

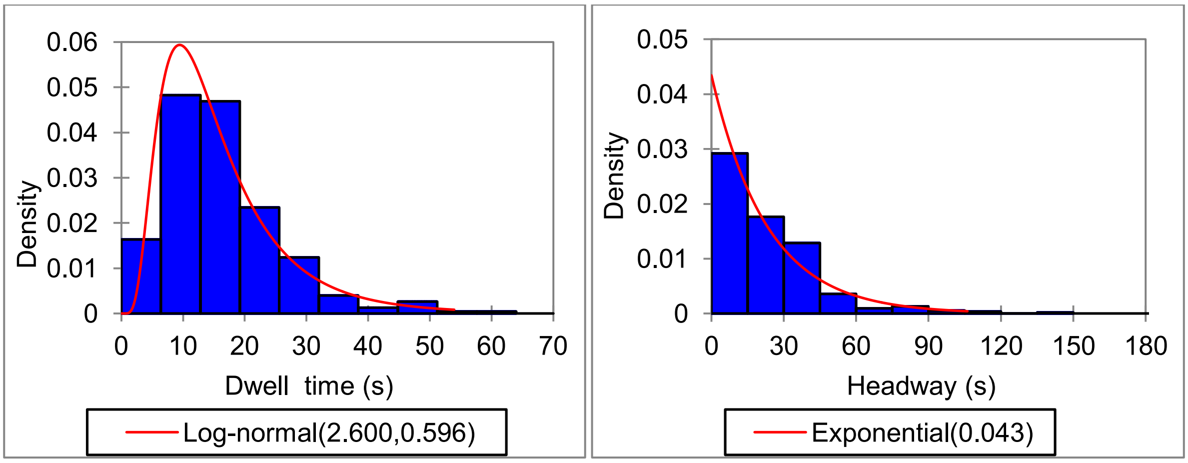
A microscopic busway simulation model was developed in AIMSUN 6.1 (TSS, 2010), where the bus station has three linear off line loading areas reflective of Buranda station. The simulated buses follow car-following model and during the bus pulling out manoeuvre, AIMSUN applies the lane changing considering zone 3 (TSS, 2010).

Figure 2: Cross Section of the Busway Station Model



The standard way of generating public transport vehicles (buses) in AIMSUN follows the normal distribution for a given mean headway and its deviation. Similarly, stochastic dwell time at a stop is defined using the normal distribution. However, analysis of the real data obtained from the Buranda field surveys indicate that bus headway and dwell time follow exponential and lognormal distributions respectively. Bus transactional data and survey data was analysed to define a proxy for dwell time and headway at Buranda. Figure 3 shows the dwell time headway distribution at Buranda station for the inbound direction obtained from field surveys at Buranda on 16/04/2013. Dwell time shows a log-normal distribution with μ equal to 2.6 and sigma equal to 0.6 (Figure 3*(b)*). The average dwell time was 15.9s and standard deviation was 6.3s which gives the coefficient variation of dwell time of 0.4. Figure 3*(b)* shows the headway distribution as exponential with λ equal to 0.04.This is consistent with the lognormal distribution of dwell time reported in literature (Li et al., 2012).

Figure 3: Dwell time and Headway distribution at Buranda



(a) (b)

An AIMSUN Application Programming Interface (API) was used to generate vehicles with headway following an exponential distribution and dwell time following a lognormal distribution. Even though dwell time follows a lognormal distribution, the data set was generated with required standard deviations to achieve relevant coefficient of variation of dwell times (c_v).

The drivers' reaction time during vehicle movement was assigned to be 0.75s and drivers' reaction time from stationary position considered as 1.35s. Simulation was performed using a simulation time step of 0.15s to ensure each driver's behaviour could be accurately discretized (TSS, 2010). For this study a basic model of operation was prescribed in order to develop the fundamental empirical relationships described later. It was therefore assumed that all buses are standard 12m rigid, all buses stop at the station, and that the station is saturated with buses in order to achieve a limit state capacity outflow condition. The objective of the simulation model was to empirically determine station limit state capacity for different flow, dwell time and its coefficient of variation and then extend the model for operation including proportions of non-stopping buses. The station limit state capacity and total bus capacity were measured just downstream of the station (Detector in right of Figure 2). Queue length just upstream of the platform (see section B in the) was measured using two upstream detectors. The upstream section (section B) was extended up to 13km to avoid any virtual queue being created at the upstream section.

5.1 All-Stopping-Buses (ASB) Potential Capacity Model Development

BRT station All-Stopping-Buses Potential Capacity $B_{asb|p}$ (bus/h) is defined here as the maximum potential average outflow of buses from the station area. This marks the region of the queue versus degree of saturation relationship where the queue length becomes unstable. Steady conditions occur when inflow to the station is less than the achievable outflow, conversely unsteady condition occurs when the inflow to the station equals or exceeds the achievable outflow such that a queue of buses immediately upstream of the station area perpetuates.

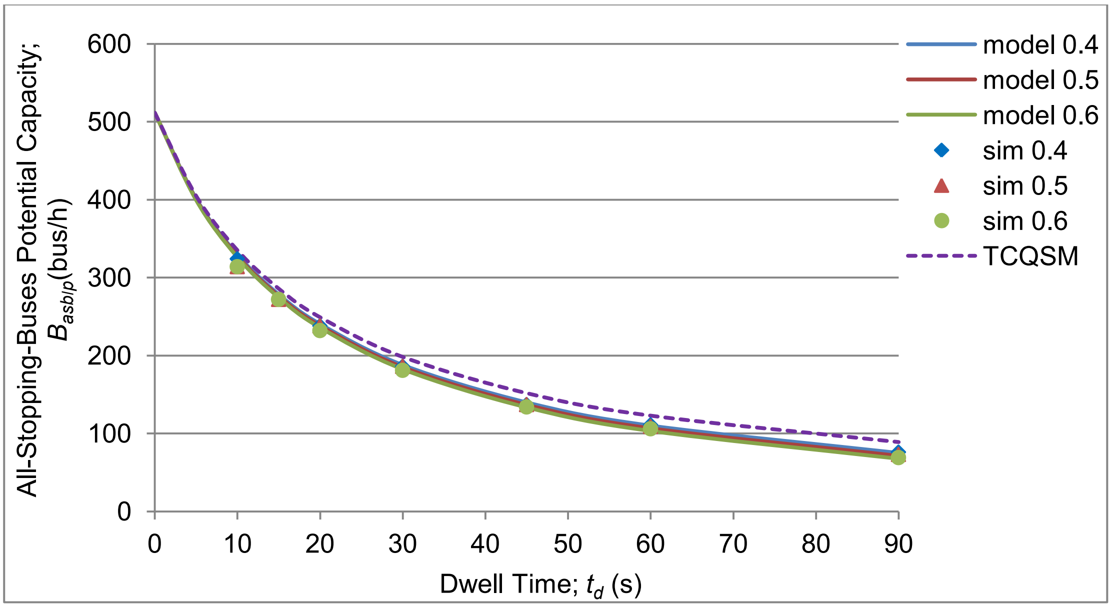
The simulation model was used to model conditions of perpetual upstream bus queuing approaching unsteady conditions to empirically determine $B_{asb|p}$ for a range of conditions of average dwell time, t_d (s) and coefficient of variation of dwell times, c_v. In all cases, all buses stopped on the off-line linear platform lane use one of three loading areas such that there are no through buses in the passing lane. For each scenario, average dwell time and dwell time coefficient were assigned as constants consistently to all three loading areas.

The smallest average dwell time simulated was 5s, which may just enough time for a bus to pull up, open and close its doors and depart. Although improbable on a real BRT station, this value was used in order to estimate the highest feasible limit state capacity. The largest average dwell time simulated was 90s. In all field observations at Buranda station no dwell times of this size were observed. However it was considered necessary to simulate this value to establish the lower magnitude of limit state capacity under adverse conditions. Average dwell times in the normal range of station operations of 10s, 15s, 20s, 30s, 45s as well as 60s were simulated to ascertain limit state capacities.

For each average dwell time, three values of dwell time coefficient of variation were simulated; 0.4, 0.5 and 0.6. The TCQSM (TRB, 2003b) specifies in the absence of field data the upper value for on street bus operations and the lower value for light rail operations. It is considered that BRT station bus operations would realistically lay within this range. Data collected on the outbound platform at Buranda station on May 2011 revealed a dwell time coefficient of 0.52 (Widanapathiranage et al., 2013).

Figure 4 illustrates icons showing the $B_{asb|p}$ values determined from simulation across the ranges of average dwell time and dwell time coefficient. As expected ASB potential capacity decreases with dwell time. It also decreases very marginally with increasing dwell time coefficient, which is attributed to the asynchronous conditions generated between buses as their dwell times vary. Capacities diverge marginally between dwell time coefficients with increasing average dwell time.

Figure 4: BRT Station All-Stopping-Buses Potential Capacity versus Average Dwell Time with Dwell Time Coefficient



Note: model 0.4 indicates $B_{asb|p}$ capacity from model for 0.4 of C_v and sim 0.4 indicates $B_{asb|p}$ capacity from simulation for 0.4 of C_v. TCQSM represents the $B_{asb|p}$ capacity by using TCQSM method.

Equation1 (TRB, 2003b) provides the TCQSM deterministic relationship for BRT station design capacity:

$$B = \frac{3{,}600}{(t_d + t_c + t_{om})} N_{EL} \qquad \textbf{Equation 1}$$

Where:

B = design bus capacity (bus/h)
t_d = average bus dwell time on a loading area (s)
t_c = average clearance time between buses using a loading area(s)
t_{om} = operating margin $= Z t_d c_v$
N_{EL} = number of effective loading areas
Z = variate corresponding to a prescribed failure rate
c_v = coefficient of variation of dwell time

The off-line loading area efficiency factors given in TCQSM and used to determine $N_{EL}$are based on observed experience at facilities in New York and New Jersey. The value of N_{EL} prescribed for a three loading area, off-line BRT station in TCQSM is 2.65. Figure 4 illustrates for this value the bus capacity calculated using Equation 1 as a function of dwell time, when no operating margin on dwell time is included. Inclusion of an operating margin represents a design case, whereas its omission results in a theoretical bus capacity reflective of maximum potential conditions. The curve representing capacity lies slightly above the data points, which can be explained by synchronous conditions improving capacity when no variation in dwell time exists.

Given that Equation 1 does not model dwell time variability, a function was sought to model the simulated conditions illustrated by the icons in Figure 4. The best function determined in this study to estimate potential capacity$B_{asb|p}$ (bus/h) is given by:

$$B_{asb|p} = \frac{3{,}600}{(t_d + t_c)} N_{la} f_{bbi} \qquad \textbf{Equation 2}$$

Where:

$B_{asb|p}$ = all-stopping-buses potential capacity (bus/h)
t_d = average bus dwell time on a loading area (s)
t_c = average clearance time between buses using a loading area(s)
N_{la} = number of actual loading areas on BRT station platform, equal to 3 in this study
f_{bbi} = capacity reduction factor due to bus-bus interference within BRT station area

The model was fitted with R^2 equal to 0.99. Equation 1 reduces to the form of Equation 2 when the operating margin on dwell time is omitted in the denominator, and the number of effective loading areas N_{EL} is replaced by $N_{la} f_{bbi}$.

Subsequently the simulation data were scrutinized to establish a model to estimate bus-bus interference factor (f_{bbi}) as a function of average dwell time (t_d) and dwell time coefficient (c_v). The best function was found to be of the following form; its coefficients determined with the average loading area bus clearance time t_c using ordinary least squares regression optimization:

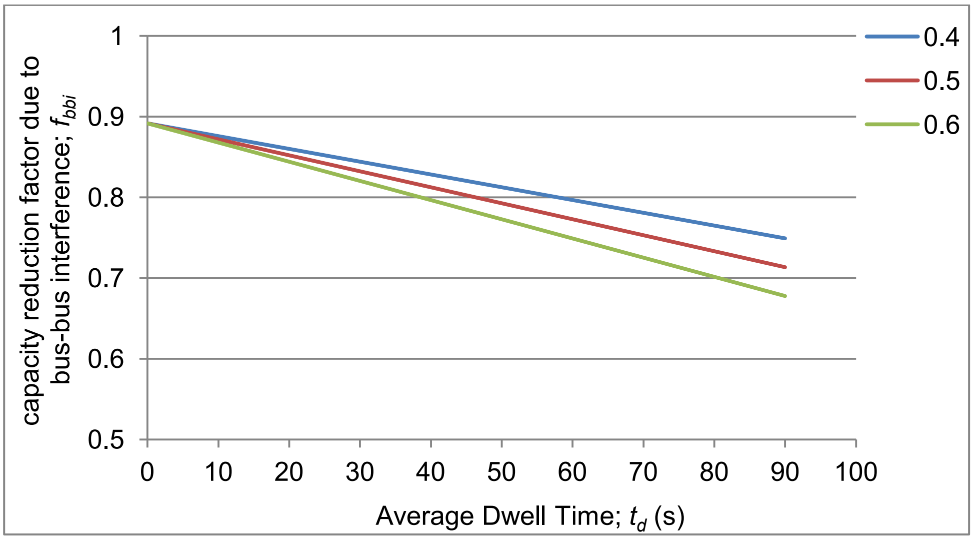
$$f_{bbi} = 0.90 - 0.004\, c_v t_d \qquad \textbf{Equation 3}$$

Where:

c_v = coefficient variation of dwell time
t_d = average bus dwell time (s)

As shown in Figure 5 f_{bbi} decreases when each of the coefficient of variations and average dwell time increase, which means the efficiencies of a busway loading area decreases under high average dwell time and high dwell time coefficients. This is intuitively reasonable because higher average dwell times relative to clearance times should result in more blockages to the front and middle loading areas, as would verities in dwell times. However, for the field data acquisition to measure f_{bbi} values is required to substantiate this postulation.

Figure 5: Bus-Bus Interference Factor vs.Average Dwell time and Dwell Time Coefficient



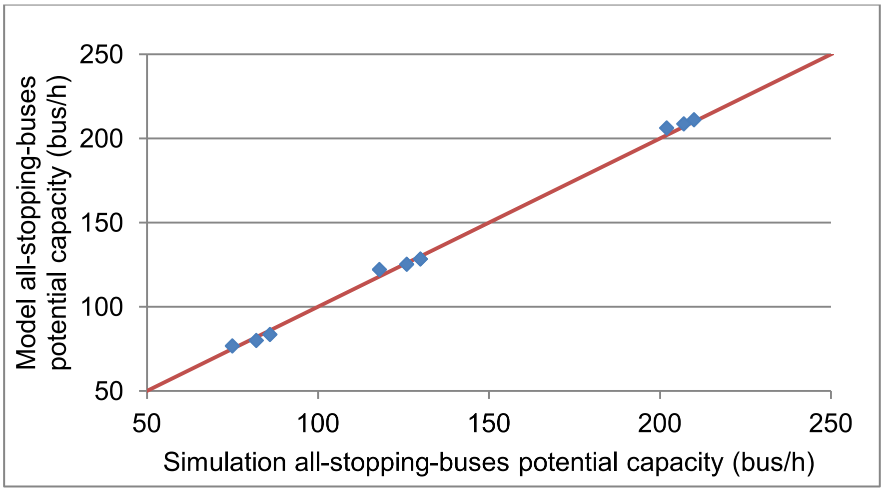
The value of N_{EL} in Equation 1 equal to 2.65 under the conditions of this study implies a value of bus-bus interference factor (f_{bbi}) equal to 0.88. This values lies in the range of the refined model of Equation 3.

Average clearance time determined from simulation model observations was 19s, which corresponds to observed values at the study station and lies within TCQSM's observed range of between 10s and 20s (TRB, 2003b).

Figure 4 also illustrates the model of Equations 2 and 3 to estimate ASB potential capacity across the simulated ranges of average dwell time and dwell time coefficient listed above. The equations provide a very close fit with a RMS error in potential capacity of between 2 and 3bus/h as dwell time coefficient varies.

Equation 1 was developed using average dwell times of 5, 10, 15, 20, 30, 45, 60 and 90s. The model was cross validated by comparing it with data obtained from simulations using 25, 50 and 75s average dwell times and concluded that these values fit well with the Equation 2 model with R^2 equal to 0.99 as presented in Figure 6.

Figure 6: Simulation vs. Model All-Stopping-Buses Potential Capacity



5.1.1 Parametric Considerations

The largest ASB potential capacity from Equation 1 and 3 is 512 bus/h which corresponds to a zero average dwell time, 19s average clearance time and 0.9 bus-bus interference capacity reduction factor. In this case all buses come to a stop on a loading area and depart immediately. Despite this case being unrealistic, it is an important limiting parameter of the model.

Equations 2 and 3 are asymptotic towards an ABS potential capacity of zero as average dwell time becomes very large, beyond the realm of the real system. For the largest average dwell times of one minute to which the function was fitted, potential capacity is very small, varying between 111bus/h and 106bus/h as dwell time coefficient varies between 0.4 and 0.6. In this case with each of the three loading areas occupied by successive buses each for an average of one minute, the potential outflow is substantially less than the 137 bus/h which would be the case if these three servers were located in parallel with no bus-bus interference. Potential outflow with three parallel loading areas is calculated when the number of effective loading area becomes 3 with 19s clearance time and 60s dwell time by using Equation1 without operating margin.

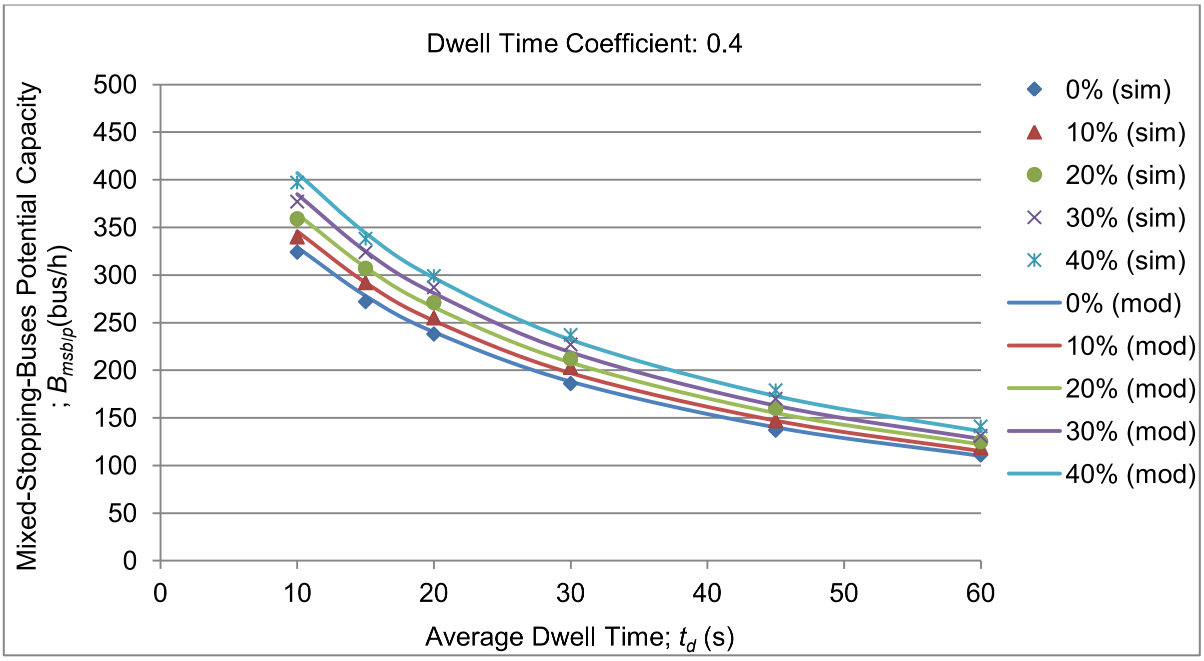
5.2 Mixed-Stopping-Bus Potential Capacity Model Development

As described earlier, stations on BRT lines may operate with a mixture of stopping and non-stopping buses. Total Mixed-Stopping-Buses (MSB) potential capacity, $B_{msb|p}$, will be greater than ABS potential capacity under this operation. However the TCQSM model of Equation 1 does not explicitly account for such operation. The analyst would need to apply the shared lane general traffic adjustment factor in the TCQSM methodology to attempt to account for non-stopping buses. No other methodology to explicitly account for non-stopping buses on BRT facilities could be found in the literature.

In order to fill this knowledge gap in BRT capacity estimation, this research enhanced the simulation model described above to incorporate non-stopping buses through the station to accurately estimate MSB potential capacity. Proportions of non-stopping buses equal to 0.1, 0.2, 0.3, and 0.4 were applied in this research. It would be considered unusual for 50% or more of all buses past a critical BRT station to be either scheduled so as not to observe it, or not to receive stopping requests or flag-falls during a peak period. For reference, the proportion of non-stopping buses past Buranda station during the peak periods was measured to be 0.3.

As with the ASB simulation model, a range of average dwell time between 10s and 60s was simulated, along with dwell time coefficients of 0.4, 0.5 and 0.6. Figure 7 illustrates the for dwell time coefficient equal to 0.4 icons showing the $B_{msb|p}$ values determined from simulation across the ranges of average dwell time and percentage of non-stopping buses.

Figure 7: Mixed-Stopping-Buses Potential Capacity vs. Average Dwell Time with 0.4 Dwell Time Coefficient



Note: 10% (mod) indicates 10% of non stopping buses $B_{msb|p}$ capacity from model for 0.4 of C_v and 10% (sim) 10% of non stopping buses $B_{msb|p}$ capacity from simulation.

The best model determined to estimate MSB potential capacity across the ranges of average dwell time, dwell time coefficient, and proportion of non-stopping-buses was found to be:

$$B_{msb|p} = \frac{B_{asb|p}}{(1 - 0.48\, P_{nsb})}$$ **Equation 4**

Where:

$B_{asb|p}$ = all-stopping-buses potential capacity (bus/h)

P_{nsb} = proportion of non-stopping buses

This model was fitted using Ordinary Least Squares regression with R^2 equal to 0.98.Based on Equation 4 the additional total station potential capacity under mixed-stopping-buses conditions compared to all-stopping-buses conditions is approximately 0.6 times the proportion of non-stopping buses.

From Equation 4, under conditions with a mixture of stopping and non-stopping buses, the station's potential capacity of stopping buses is equal to:

$$B_{sb|p} = \frac{B_{asb|p}(1 - P_{nsb})}{(1 - 0.48\, P_{nsb})}$$ **Equation 5**

The presence of non-stopping buses therefore impedes the station's potential capacity for stopping buses by approximately 0.65 times the proportion of non-stopping buses.

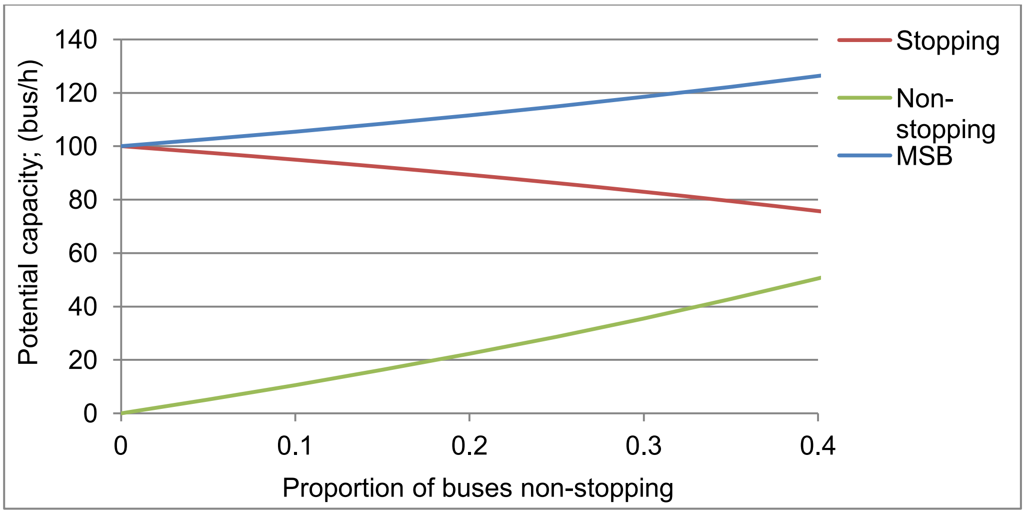
From Equation 4, under conditions with a mixture of stopping and non-stopping buses, the station's potential capacity of non-stopping buses is equal to:

$$B_{nsb|p} = \frac{B_{asb|p} P_{nsb}}{(1 - 0.48\, P_{nsb})}$$ **Equation 6**

Therefore the station potential capacity of non-stopping buses compared to all-stopping-buses is approximately 1.23 times the proportion of non-stopping buses.

Figure 8 illustrates the variation in potential capacities based on Equations 4, 5 and 6 as proportion of non-stopping buses varies between 0 and 0.4, with a reference ASB potential capacity equal to 100 bus/h. It can be seen that despite a reduction in stopping bus capacity with increasing proportion of non-stopping buses, the MSB total capacity increases moderately.

Figure 8: Mixed-Stopping-Buses (MSB) capacity variation with non-stopping buses



6. Conclusion

This study demonstrated that micro simulation model can be used to study and analyse operating characteristics of the BRT station to determine potential capacity. A mathematical model was proposed to estimate All-Stopping-Bus potential capacity $(B_{asb|p})$ using empirical data from simulation and found to complement theory of the Transit Capacity and Quality of Service Manual (TRB, 2003b).

Existing theory does not explicitly model conditions when some buses pass through the BRT station without stopping. Therefore a model was proposed to estimate potential capacity under Mixed-Stopping-Bus conditions as a function of proportion of non-stopping buses.

Mixed-Stopping-Buses Potential Capacity $(B_{msb|p})$ and Non-Stopping Buses Capacity $(B_{nsb|p})$ were introduced which gives the Mixed-Stopping-Buses Potential Capacity and Non-Stopping Buses Capacity with respect to all-stopping-buses potential capacity. Proposed model can be used to better understand BRT line service capacity of the corridor due to various mixtures of stopping and non-stopping buses proportions at stations. This will be helpful to agencies in bus route and schedule planning as well as capacity analysis.

7.0 Further Research

Similar to a queuing system such as a minor stream on an unsignalized intersection, when bus stop capacity just exceeds the steady state, queuing will increase in greater rate. Therefore potential capacity of a BRT station reflects conditions approaching steady state and is consequently not sustainable or acceptable for BRT station operation. A *practical bus capacity* will be defined, which corresponds to an acceptable level of bus queuing or delay immediately upstream of the station. This means a bus stop can achieve its *practical bus capacity* with respect to the degree of saturation and *practical upstream design queue length*.

The base simulation model for this research was developed consistent with the current deterministic procedure of TCQSM. However, it has been observed that Buranda station is served by a mixture of 12m rigid buses (88%), and the remaining 12% a combination of 18m articulated (2-3 doors) buses and 14.5m three-axle two door buses (2011). Those High Capacity Buses (HCB) occasionally need to occupy more than one loading area to serve passengers. Therefore a future stage of this research will be to further develop these equations for different bus configurations and operation and achieve a more robust practical bus capacity estimation model including upstream queue length estimation.

The second field survey in 2013 revealed more use of an iterant fourth loading area than the first field survey in 2011, which is attributed to increased bus volumes now scheduled through Buranda during peak periods. Therefore this model will be further validated according to current operation at Buranda.

8. Acknowledgements

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