Analyzing busway Station Potential Capacity under Mixed and Non-Stopping Operation

**Corresponding Author:**
Rakkitha Widanapathiranage
Civil Engineering and Built Environment School
Science and Engineering Faculty
Queensland University of Technology
Phone No: +61 7 31384186
Fax No: +61 7 31381170
Email: rakkitha.widanapathiranage@student.qut.edu.au

**1st Co-author:**
Assoc Prof. Jonathan M Bunker
Associate Professor
Civil Engineering and Built Environment School
Science and Engineering Faculty
Queensland University of Technology
Phone No: +61 7 31385086
Fax No: +61 7 31381170
Email: j.bunker@qut.edu.au

**2nd Co-author:**
Dr. Ashish Bhaskar
Lecturer
Civil Engineering and Built Environment School
Science and Engineering Faculty
Queensland University of Technology
Phone No: +61 7 31389985
Fax No: +61 7 31381170
Email: ashish.bhaskar@qut.edu.au

Submission date: 08.01.2014

<table>
<thead>
<tr>
<th>Word count</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>264</td>
</tr>
<tr>
<td>Main text</td>
<td>4342</td>
</tr>
<tr>
<td>Figures and tables (11 x 250)</td>
<td>2750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7356</strong></td>
</tr>
</tbody>
</table>
ABSTRACT

Busway stations are 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 busway capacity.

This study uses microscopic simulation to treat the busway station operation and to analyze the relationship between station potential capacity where all buses stop, and Mixed Potential Capacity where there is a mixture of stopping and non-stopping buses. First, the microsimulation technique is used to analyze the All Stopping Buses (ASB) scenario and then a statistical model is tuned and calibrated for a specified range of controlled scenarios of dwell time characteristics. The marginal difference between Transit Capacity and Quality of Service Manual (TCQSM) and ASB potential capacities is caused due to bus-bus interference proposed in this research which depends on average dwell time and coefficient of variation of dwell time. Subsequently, a mathematical model is developed for Mixed Stopping Buses (MSB) Potential Capacity by introducing different proportions of express (or non-stopping) buses.

The proposed models for a busway station bus capacity provide a better understanding of operation and are useful to transit agencies in busway planning, design and operation.

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

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 (1). 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 (1). For this study only segregated busways are selected.

BRT line service capacity (bus/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 (2, 3). 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.

A station is defined as a node on a BRT line where buses are able to stop and dwell to serve passengers. A busway station may have various configurations. In this study, a station is defined to be directionally separated whereby buses cannot overtake across the oncoming side of the roadway. It includes a linear platform in each direction to serve passengers. Each platform contains multiple, off-line linear loading areas. In each direction, the roadway contains a platform stopping lane with upstream pullout taper and 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 passengers FIGURE 3.
Transit line service capacity (veh/h) is that achievable under stipulated repeatable, safe working conditions resulting in a maximum achievable frequency. TCQSM (1) 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.

Other Existing Busway Station and Bus Stop Capacity Models

There are important busway station and bus stop capacity models available in literature. Some of them are opt for a different approach than the conventional TCQSM 2013 method to estimate design stop capacity depending on different operation procedures.

Fernández, (2007) (4) introduced the concept called capacity of divided bus stops. A divided bus stop contains berths that are separated to reduce bus interference and consequently 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.

Kwami et al., (2009) (5) investigated the quantitative impact of bus bays on curb lanes capacity of roadway. They introduced new concepts of bus impact time occupancy ratio and bus impact times. Relationships among bus deceleration time, bus acceleration time and bus impact time were established when buses maneuver to pull into and out of the bays. They found that bus bays have significant impact on curb lanes capacity. As well as with the increase in bus arrival frequency, the actual curb lane traffic capacity decreases showing that both bus impact time and bus arrival frequency affect curb lane capacity.

Jaiswal et al., (2009) (1, 6) introduced Busway Loading Bus Capacity Model (BSLC) with lost time variables. Results showed that TCQSM 2013 model gives higher values than BSLC as the introduced model accounts lost time variable which accounts higher delay time for buses.

Hidalgo et al., (2013) (7) introduced a method to estimate theoretical maximum number of passengers in bus lanes where maximum capacity per hour equals to maximum buses per hour per lane in to passenger per bus multiply with bus degree of saturation in to number of lanes. Further, they introduced a method to estimate maximum theoretical passenger capacity as a multiple of maximum buses per hour per platform, number of platforms per express buses and passenger per bus. However, this method is not considering the efficiency of platform area and limited for maximum of 60 buses per hour per platform. In a real BRT station operation with multiple loading areas this amount is far greater.

Moreover, the procedure for estimating BRT line service capacity is defined by the US Transit Capacity and Quality Service Manual (TCQSM) (1) 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 (7, 8). Therefore this research addresses mixed stopping operation and then estimate station potential capacity.
METHODOLOGY

Busway Station Microscopic Simulation Modelling Approach and Definitions

Traffic simulation can efficiently represent a real world situation and reproduce its behaviour under a controlled environment and hence has widespread use in developing and testing scenarios (9). 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 of the simulation model are tuned with the real data collected via field survey and compared against standard values given in the Transit Capacity and Quality Service Manual (TCQSM) (1).

A base scenario where all buses which pass through the subject station stop to serve passenger exchange was defined as ASB operation. However, of the buses that pass through the study busway station of Buranda, some stop to serve passenger exchange, while others do not due to express operation. Therefore, we defined a second scenario for simulation model development defined above as MSB operation.

Maximum potential capacity achievable under ASB operation is defined here as ASB potential capacity and maximum capacity under MSB operation defined here as MSB potential capacity.

Methodological Approach

The methodology of this paper is shown in FIGURE 1. The paper consists of three specific sections. The first section develops a microscopic simulation model of the study station. Field surveys were conducted to identify capacity related measures that are relevant to microscopic simulation model development. The simulation model is tuned against the deterministic capacity model of TCQSM (2013) assuming the case of constant dwell time, whereby coefficient of variation of dwell times is equal to zero.

During the second phase, the ASB potential capacity from microscopic simulation model is compared with TCQSM theory for different coefficients variations of dwell time (0.4, 0.5 and 0.6). Again, additional relevant parameters were collected using field surveys. The third section is focused on developing the empirical equation on estimating MSB potential capacity model by including some non-stopping buses.
**BUSWAY STATION SIMULATION MODEL DEVELOPMENT**

Busway station microscopic simulation model development was carried out by first selecting a study busway station, then introducing variation in input parameters, and finally extraction of data that enabled estimation of potential capacity.

**Selection of Busway Station**

We developed the simulation model for Buranda busway station in Brisbane, Australia. This station is the fourth of 10 stations along the 16 km (10 mi) South East Busway (SEB) and is 4.4 km (2.8 mi) south of the CBD hub Queen Street Bus Station (10).
Buranda station experiences high passenger exchange and some bus queuing on the inbound platform during the morning peak period and on the outbound platform during the peak period.

**Parameters Input and Model Development**

A microscopic busway simulation model was developed using AIMSUN 6.1.6, which is a proprietary traffic microscopic simulation platform (11). The test bed station has three linear off line loading areas reflective of Buranda station FIGURE 3. The simulated buses follow a car-following model, and during the bus merging manoeuvre, AIMSUN applies gap acceptance logic (11).

AIMSUN in its standard manner stochastically generates public transport vehicles (buses) according to a normal distribution defined by mean headway and standard deviation of headway.
FIGURE 4 shows headway and dwell time distributions measured on 03/17/2013. Field surveys at Buranda station during April 2013 and February 2014 indicate that the headway distribution is actually best described using the negative exponential distribution, with a flow rate parameter ($\lambda$) varying between 0.045 - 0.055 bus/h. Dwell time follows a log-normal distribution with mean ($\mu$) varying between 2.6 - 2.8 and $\sigma$ varying between 0.49 - 0.62.

AIMSUN in its standard manner also stochastically generates dwell time at a stop using a normal distribution. As a consequence of the observed distributions differing from the AIMSUN assumptions of normal distributions, we elected to use an AIMSUN Application Programme Interface (API) to generate bus arrivals onto the test bed according to a negative exponential distribution, and bus dwell times on the loading areas according to a lognormal distribution. Even though dwell time follows a lognormal distribution, we still maintained the required average dwell times and coefficient of variation of dwell times ($c_v$) during model development phase.

AIMSUN requires estimation of the driver’s performance characteristic of reaction time. Summala (12) identified that driver reaction time varies between 0.75 s and 1.5 s. Therefore the reaction time during vehicle movement was assigned to be 0.75 s and from stationary position was assigned to be 1.35 s.

Simulation was performed using a simulation time step of 0.15 s to ensure accurate discretization of each driver’s behaviour (11). therefore reaction time during vehicle movement equals five time steps while that from a stationary position equals nine time steps. For this study a basic system of operation was prescribed in order to develop fundamental empirical relationships.

**Capacity Estimation**

Potential capacity of buses was measured as outflow from the test bed just downstream of the station platform merging taper (detector marked as A - FIGURE 3). The upstream section was extended 13 km to avoid any virtual queue being created beyond the test bed.

**SIMULATION MODEL TUNING WITH DETERMINISTIC MODEL WITH NO DWELL TIME VARIATION**

The potential capacity of a busway station, presuming no variation in dwell time, can be quantified deterministically according to Equation 1:

$$B = \frac{3,600}{(t_d + t_c)} N$$  \hspace{1cm} \text{Equation 1}$$

where:
$B = \text{Design bus capacity (bus/h)}$
$t_d = \text{Average bus dwell time}$
$t_c = \text{Average clearance time}$
$N = \text{Number of loading areas, equal to 3 in the case of Buranda}$

Equation 1 is a simplified form of the TCQSM (2013) capacity equation, where an empirical term for number of effective loading areas is replaced by the actual number of loading areas. Widanapathiranage, et al., (2014) argued that the number of effective loading areas, which is ordinarily less than the actual number of loading areas, implies effects of variation in dwell time that leads to asynchronous operation of buses between loading area/s, and therefore less efficiency of the front loading areas due to intermittent blockages by buses dwelling on the rear loading area/s (13).

Table 1 shows the experiment scenarios considered in this paper. Scenario 1 in Table 1 displays the details of the simulation model development with zero coefficient of variation of dwell time. All scenarios were performed with 100 replications each of one hour duration.

Table 1: Description simulation model development scenarios

<table>
<thead>
<tr>
<th>Simulation model developed</th>
<th>Experimental Values</th>
<th>Average dwell time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_v$</td>
<td>NS (%)</td>
</tr>
<tr>
<td>1) All-Stopping Buses</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Deterministic Capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) All-Stopping Buses</td>
<td>0.4, 0.5, 0.6</td>
<td>0</td>
</tr>
<tr>
<td>Potential Capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Mixed-Stopping Buses</td>
<td>0.4, 0.5, 0.6</td>
<td>10, 20, 30, 40</td>
</tr>
<tr>
<td>Potential Capacity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

note: $c_v$: coefficient of variation of dwell time
NS%: non-stopping bus percentage
DoS: Degree of saturation

FIGURE 5 illustrates the results of simulation by way of measured ASB potential capacity, as dwell time ranges between 5 s and 90 s (scenario 1: Table 1).

![Graph showing simulation results](image-url)

note: dwell time coefficient represents the coefficient of variation of dwell time
**FIGURE 5** Bus station ASB potential capacity with no variation in dwell time, as dwell time varies

FIGURE 5 shows that the simulation provides identical results to the deterministic model of Equation 1. The coefficient of determination between the simulated data against the deterministic equation is equal to 0.99, which is a near perfect fit. These results are as expected and verify that the simulation model accurately models the most basic mode of operation of Scenario 1.

**EMPIRICAL ALL-STOPPING BUSES (ASB) POTENTIAL CAPACITY MODEL**

Busway station ASB potential capacity $B_{asbp}$ (bus/h) is defined here as the average maximum potential 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. Stable conditions occur when inflow to the station is less than the achievable outflow, conversely unstable 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 and therefore unstable conditions to empirically estimate $B_{asbp}$ for a range of experiments mentioned in Table 1 under scenario 2.

In all cases, all buses stopped on the off-line linear platform lane of the test bed using one of three loading areas, such that there were no through buses in the passing lane. Average dwell time and coefficient of variation of dwell time were assigned as constants across all three loading areas (scenario 2: Table 1).

The smallest average dwell time simulated was 5 s, which may be just enough time for a bus to pull up, open and close its doors and depart. Although improbable on a real busway station, this value was used in order to estimate the highest feasible potential capacity. The largest average dwell time simulated was 90 s. 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 potential capacity under adverse conditions.

For each average dwell time, three values of coefficient of variation of dwell time were simulated; 0.4, 0.5 and 0.6. TCQSM specifies values in the absence of field data the upper value for on street bus operations and the lower value for light rail operations (1). Data collected on the outbound platform at Buranda station on April 2013 and February 2014 revealed a coefficient of variation of dwell time varying between 0.45 and 0.60. **FIGURE 6** illustrates icons showing the $B_{asbp}$ values determined from simulation across the ranges of average dwell time and coefficient of variation of dwell time. We excluded the operating margin in TCQSM capacity method in order to find the potential capacity and compare the potential capacity from simulation model.

As expected, ASB potential capacity decreases within decreasing dwell time. It also decreases very marginally with increasing coefficient of variation of dwell time, which is attributed to the asynchronous conditions generated between buses as their dwell times vary. Capacities differ only marginally, as coefficient of variation of dwell time varies, with increasing average dwell time.
note: dwell time coefficient represents the coefficient of variation of dwell time.

FIGURE 6 Busway station All-Stopping Buses potential capacity versus average dwell time
with coefficient of variation of dwell time

Busway station capacity can be estimated using Equation 2 when dwell time is variable. The original TCQSM equation includes an operating margin term in the denominator; however, this term is excluded here because that parameter is intended as a buffer added to the original equation for purposes of determining a design capacity, rather than the maximum potential value.

\[
B = \frac{3,600}{(t_d + t_c)} N_{EL}
\]

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)
- \( N_{EL} \) = Empirical factor reflecting number of effective loading areas

The off-line loading area efficiency factors given in TCQSM and factors used to determine \( N_{EL} \) are based on observed experience at facilities in New York and New Jersey and which is confirmed with field observations elsewhere in the world.\(^1\).

The value of \( N_{EL} \) prescribed for a three loading area, off-line busway station in TCQSM is 2.65. FIGURE 6 illustrates for this value the ASB potential bus capacity calculated using Equation 2 as a function of dwell time. The TCQSM equation closely follows the simulation data results. However, slightly lower capacities result according to the simulation model, which is attributed to pronounced variation in dwell time.

An enhancement to Equation 1 to incorporate dwell time variation, as evident from simulation icons in FIGURE 6, was sought. The empirical equation determined in this study that best estimates potential capacity is given by:

\[
B_{asblp} = \frac{3,600}{(t_d + t_c)} N_{la} f_{bi}
\]

where:

- \( B_{asblp} \) = All-stopping-buses potential capacity (bus/h)
- \( t_d \) = Average bus dwell time on a loading area (s)
\[ t_c = \text{Average clearance time between buses using a loading area(s)} \]
\[ N_{la} = \text{Actual number of loading areas on platform, equal to 3 for study station} \]
\[ f_{bbi} = \text{Empirical capacity reduction factor due to bus-bus interference within station area} \]

Equation 3 was fitted with \( R^2 \) equal to 0.99. Comparison of Equation 2 and Equation 3 shows that the effect of variation in dwell time on potential capacity is more explicit by including a bus-bus interference factor than by presumed overall loading area effectiveness.

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 coefficient of variation of dwell time \( (c_v) \). The best empirical equation was found to be of the following form; its coefficients determined with the average loading area bus clearance time using ordinary least squares regression optimization:

\[ f_{bbi} = 0.90 - 0.004 c_v t_d \quad \text{Equation 4} \]

where:
\[ c_v = \text{Coefficient of variation of dwell time (0.4, 0.5, 0.6)} \]
\[ t_d = \text{Average bus dwell time (s) (5 s} \leq t_d \leq 90 \text{ s)} \]

0.90 and 0.004 are curve fitting constants

As shown in FIGURE 6, \( f_{bbi} \) and therefore loading area efficiency decreases when either coefficient of variation of dwell time or average dwell time increases. 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. However, more field data acquisition to measure \( f_{bbi} \) values is required to substantiate this position.

\[ \text{FIGURE 7 Bus-Bus interference factor vs. average dwell time and coefficient of variation of dwell time} \]

The value of \( N_{EL} \) in Equation 2 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 empirical Equation 3.

Average clearance time determined from simulation model observations was 19 s, which corresponds to observed values at the study station and lies within TCQSM’s observed range of between 10 s and 20 s (1). FIGURE 6 also illustrates the use of Equation 3 and Equation 4 to estimate ASB potential capacity across the simulated ranges of average dwell time and coefficient of variation of dwell time listed above. The equations provide a very close fit with
a Root Mean Square (RMS) error in potential capacity of between 2 and 3 bus/h, across the
range of coefficient of variation of dwell time.

Equation 3 was developed using average dwell times of 5, 10, 15, 20, 30, 45, 60 and 90 s.
The equation was tested further by comparing it with data obtained from simulations using
25, 50 and 75 s average dwell times and concluded that these values fit well with R² equal to
0.99 as presented in FIGURE 8.

**FIGURE 8**: All-Stopping Buses potential capacity; simulation versus empirical equation

### Parametric Considerations

The largest ASB potential capacity from Equation 3 and Equation 4 is 512 bus/h, which
corresponds to a zero average dwell time, 19 s 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 empirical equations.

Equation 3 and Equation 4 are asymptotic towards an ABS potential capacity of zero as
average dwell time becomes very large, beyond the realm of the system. For the largest
average dwell times of 90 s to which the equation was fitted, potential capacity is very small,
varying between 111 bus/h and 106 bus/h as coefficient of variation of dwell time 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 90 s, the potential outflow is substantially less than the 137
bus/h which would be the case if these three loading areas 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 three, with 19 s clearance time and 60 s dwell
time by using Equation 2.

### MIXED-STOPPING BUS POTENTIAL CAPACITY

When busway lines operate with a mixture of stopping and non-stopping buses,
Mixed-Stopping Buses (MSB) potential capacity ($B_{msbp}$), becomes greater than ABS
potential capacity. However, the TCQSM model of Equation 2 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 busway facilities is evident in
the literature.
In order to fill this knowledge gap in busway 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 (scenario 3: Table 1). It would be considered unusual for 50% (0.5) or more of all buses past a critical busway 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 10 s and 60s was simulated, along with coefficient of variation of dwell times of 0.4, 0.5 and 0.6. FIGURE 9 illustrates the MSB potential capacity versus average dwell time for different proportions of non-stopping buses with 0.4 coefficient of variation of dwell time. For an instance, 10% (mod) indicates the MSB potential capacity from Equation 5 model and 10% (sim) indicates the MSB potential capacity from simulation model for 10% of non-stopping buses.

![Graph showing MSB potential capacity versus average dwell time with 0.4 coefficient of variation of dwell time](image)

**FIGURE 9** Busway station Mixed-Stopping Buses potential capacity versus average dwell time with 0.4 coefficient of variation of dwell time

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

\[
B_{msb|p} = \frac{B_{asb|p}}{(1 - 0.48P_{nsb})}
\]

*Equation 5*

where:

- \(B_{asb|p}\) = ASB 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. From Equation 5, under conditions with a mixture of stopping and non-stopping buses, the station’s potential capacity of stopping buses is equal to:

$$B_{sb|p} = \frac{B_{asb|p}(1 - P_{nsb})}{(1 - 0.48P_{nsb})}$$ \hspace{1cm} \text{Equation 6}

where:

- $B_{sb|p}$ = Stopping Buses (SB) potential capacity under MSB operation (bus/h)

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 5, under conditions with a mixture of stopping and non-stopping buses, the station’s potential capacity of non-stopping buses is equal to:

$$B_{nsb|p} = \frac{B_{asb|p}P_{nsb}}{(1 - 0.48P_{nsb})}$$ \hspace{1cm} \text{Equation 7}

where:

- $B_{nsb|p}$ = Non-stopping Buses (NSB) potential capacity under MSB operation (bus/h)

FIGURE 10 illustrates the variation in potential capacities based on Equation 5, Equation 6 and Equation 7 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 10** Mixed-Stopping Buses (MSB) capacity variation with non-stopping buses

**CONCLUSION**

This paper highlighted that microscopic simulation model can be a valuable tool to study and analyse operating characteristics of the busway station to determine potential capacity. A mathematical equation was proposed to estimate All-Stopping Bus (ASB) potential capacity using data from simulation and found to complement theory of the Transit Capacity and Quality of Service Manual (TRB, 2013). The difference between TCQSM and ASB potential capacities is attributed to the effect of bus-bus interference on the loading area efficiency. It is observed that bus-bus interference depends on average dwell time and coefficient of variation of dwell time.
Existing theory does not explicitly model conditions when some buses pass through the busway 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. Empirical equations for Mixed-Stopping Buses Potential Capacity (MSB) and Non-Stopping Buses Capacity (NSB) were developed. These can be used to better understand facility capacity under 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.

**FURTHER RESEARCH**

Models proposed here will be further validated using field data under mixed and non-stopping operation. Series of surveys will be conducted to account potential capacity state at Mater Hill and Buranda stations.

Similar to a queuing system such as a minor stream on an unsignalised 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.

**ACKNOWLEDGEMENTS**

We would like to acknowledge the support of TransLink Division, Department of Transport and Main Roads, Queensland. Further, the support of Mr. Hao Guo to develop a smart phone survey application is highly appreciated. Finally, the support of survey team and Queensland University of Technology, Australia is gratefully acknowledged.

**REFERENCES**


