Capacities of Exclusive Bus Lanes with On-Line Linear Bus Stops on Urban Arterials

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Abstract: Because of right-of-way constraints and safety concerns, on-line linear bus stops with no provisions for buses to pass each other can become the only practical means for passenger services in exclusive bus lanes on urban arterials. How to improve the capacities of bus lanes with this type of stops and accommodate demands by bus companies for a greater access to bus lanes is a pressing issue for the transit authority in Taipei, Taiwan. To provide a decision-support tool to address these issues, field data were collected and used to calibrate a simulation model. The model was then used to examine the relationships between capacity and its influencing factors. This paper discusses the findings of the simulation analysis. It also presents an easy-to-use tool that can enhance transportation professionals’ capabilities for capacity and level-of-service analysis.

Key Words: exclusive bus lane, capacity, simulation

1. INTRODUCTION

Exclusive bus lanes on arterial streets are deployed in many cities to improve the quality of bus transit service. Such bus lanes may use various types of bus stops for loading and unloading passengers. When right-of-way is severely restricted, linear on-line bus stops as defined in the Highway Capacity Manual of Transportation Research Board (2000) are often a practical choice. A linear on-line bus stop does not have an auxiliary off-line bay for buses to load and unload passengers. As a result, buses have to stop in the bus lane to serve passengers. Furthermore, out of safety concerns, buses are prohibited from changing lane even if the bus lane is not physically divided from adjacent lanes with barriers. This means a bus may be blocked by the buses that are stopped at a bus stop. Because of these limitations, linear on-line bus stops are not very efficient.
Provision of off-line loading bays at bus stops to minimize blockage, however, is often not a practical alternative.

A case in point is the bus transit system in Taipei, Taiwan. This system has 301 bus lines run by 10 companies. Many of these lines share 11 routes of exclusive bus lanes that total 59 lane-km. Because each bus stop is usually shared by many bus lines, some stops have heavy congestions during peak hours. Most bus lanes in Taipei are the inside lanes of streets that have express lanes and mixed-vehicle lanes, as shown in Fig. 1. These lanes are divided from opposing lanes with median barriers and there are no spaces available for off-line loading bays. Reducing service frequency or synchronizing dispatch headway to avoid buses from blocking each other at a bus stop is not practical. One reason is that the arrival time of a bus at a stop is governed not only by dispatch headway but also by the upstream traffic and the signal conditions. This means it is difficult to control the arrival time of a bus at a bus stop. To reduce the chance of a bus being blocked by the buses that are already at a bus stop would require very long dispatch headway. This, in turn, will cause unacceptably long waits for passengers at the upstream bus stops and diminish the appeal of bus transit service.

To aggravate the aforementioned dilemma, bus companies in Taipei have been demanding a greater access to the exclusive bus lanes in the form of an increase in service frequency or a license to expand their operations to other routes. How existing bus lanes can be made more efficient and how best to address the demand for a greater access to bus lanes are pressing issues. Resolving these issues requires finding cost-effective ways of improving the capacities of existing bus lanes. There is also a need to assess how best a given capacity should be utilized to provide a reasonable level of service.

In response to these needs, the Institute of Transportation (IOT) in Taiwan initiated a study to collect and use field data to calibrate the *Highway Traffic Systems Simulation (HTSS) Model* that is being used in Taiwan to support highway capacity analysis (Institute of Transportation, 2001). The calibrated model was then used to examine how the capacities of the bus lanes with linear on-line bus stops in Taipei may be improved. Capacity affects the operating efficiency of a bus stop, but it is not the only concern in the planning, design, and operation of exclusive bus lanes.
A typical capacity analysis of a bus lane also includes an assessment of the related level of service in terms of a set of measures of effectiveness. Such a task often has to rely on computer simulation because of complex interactions between the performance of a bus lane and prevailing traffic, design, and control conditions. Like most microscopic simulation models, the HTSS model requires a substantial effort on the part of users in preparing input data files. This tends to discourage potential users. To alleviate this problem, the IOT has provided a simplified simulation package that enables Taiwan’s transit authorities to conveniently estimate capacities and evaluate alternative designs and operating strategies for bus lines.

The primary purposes of this paper are twofold. The first is to describe current practices in estimating the capacities of bus lanes with linear on-line bus stops, the observed traffic characteristics that were used to calibrate the HTSS model, and the nature of the capacities of bus lanes with linear on-line bus stops as revealed by simulation. The second is to introduce the simplified simulation package made available by the IOT. Along with several recommendations for future studies, this paper points out potential changes that may be made to improve the capacities of the bus lanes in Taipei.

2. EXISTING PRACTICES

In general, the capacity of a bus lane between two signalized intersections is the maximum flow rate at which buses reasonably can be expected to enter the downstream intersection under prevailing roadway, traffic, and control conditions. Based on the conditions used to define capacity, bus-lane capacity may be further classified into block capacity and service capacity. Block capacity refers to the maximum bus departure rate from a street block when there is a constant presence of queuing buses waiting to enter a bus stop. Service capacity is expected maximum departure rate that reasonably can be expected, when the rate at which buses are allowed to enter a street block is limited to a fraction of the block capacity in order to maintain a desirable level of service. Both block capacity and service capacity are affected by the unconstrained capacity of the bus stops in a bus lane and the signal control at the downstream end of the lane.

Unconstrained capacity is expected maximum flow rate at which buses reasonably can be expected to depart from a bus stop, provided that there is a continuous presence of queuing buses waiting to enter the stop and that the departure of buses from the stop is not affected by the downstream intersection. When the distance between a bus stop and the downstream intersection increases, the downstream signal control becomes less likely to interfere with the departure of buses from the stop, and the block capacity will approach the unconstrained capacity of the bus stop.

Service capacity is constrained by the traffic and signal control conditions at the upstream intersection. It also depends on the desired level of service that should be maintained. Level of service may be assessed in terms of a variety of measures of effectiveness such as delays and average travel speed. Based on a study by St. Jacques and Levinson (1997), the Highway Capacity Manual and the Transit Capacity and Quality of Service Manual (TCQSM) published by the Transportation Research Board (2000; 2003) use the probability that queues will form
behind a bus stop to assess level of service. This probability is also referred to as failure rate. The model adopted in these manuals for estimating service capacity is as follows:

\[ B = \frac{3600(g/C)N_e}{t_c + (g/C)t_d + Z_aC_vt_d} \]  

where

- \( B \) = service capacity (buses/h),
- \( g/C \) = effective green g to cycle length C ratio,
- \( N_e \) = number of effective loading berths,
- \( t_c \) = clearance time between successive buses (s),
- \( t_d \) = average dwell time (s),
- \( Z_a \) = one-tail normal variate corresponding to probability that queues will form behind bus stop, and
- \( C_v \) = coefficient of variation of dwell times.

The effective number of loading areas of a bus stop is determined as the ratio of bus stop capacity to single-berth capacity. For on-line bus stops, simulations performed by Levinson and St. Jacques (1998) show that \( N_e \) varies from 1.26 to 2.18 for 2-berth bus stops and from 1.66 to 3.42 for 3-berth stops. The TCQSM recommends that a constant \( N_e \) be used for a given bus stop. The recommended values for 2-berth and 3-berth bus stops with platoon arrivals of buses are respectively 1.85 and 2.65. The value of \( Z_a \) is 2.330 for a 1.0% failure rate and 0.000 for a failure rate of at least 50%.

Equation 1 may also be used to estimate block capacity and unconstrained capacity. For example, if queuing buses waiting to enter a bus are always present, then the value of \( Z_a \) is 0.0 and Equation 1 can be reduced to the following form for estimating block capacity:

\[ B = \frac{3600(g/C)N_e}{t_c + (g/C)t_d} \]  

When the downstream intersections are too far away to affect the departure of buses from a bus stop, then the \( g/C \) ratio in Equation 2 can be set to 1.0. In such a case, Equation 2 can be simplified as follows to estimate unconstrained capacity:

\[ B = \frac{3600N_e}{t_c + t_d} \]  

Many factors affect the capacity and the level of service of an exclusive bus line with linear on-line bus stops. Commonly considered factors include number of loading berths, dwell time, clearance time, signal control, and operator policy (Atkinson, 1993; Chira-Chavala and Coifman, 1996; Cuntill and Watts, 1973; Dueker, et al., 2004; Levinson, 1982; Levinson and St. Jacques, 1998; Milkovits, 2008; Marshall, et al., 1990; Transportation Research Board, 2000; Transportation Research Board, 2003). The interactions between bus-lane capacity and its influencing factors are very complex. Under the circumstance, Equation 1 has serious limitations
because it is only a crude approximation of the relationships between capacity and its influencing factors.

For example, the probability of having queuing buses waiting to enter a bus stop is affected not only by the bus stop design, downstream traffic signal, the operating characteristics of buses but also by the arrival pattern and the upstream signal control. Equation 1 does not have explicit treatment of the effects of upstream traffic and signal control conditions. For the same reason, the use of constant effective number of berths for a given bus stop can also induce significant errors. Equation 2 also lacks a solid theoretical ground. For example, if a bus stop is moved away from the downstream intersection, the impact of the downstream signal control can be expected to diminish and the block capacity will approach the unconstrained capacity. But Equation 2 does not consider bus-stop location as an influencing factor.

Because of the difficulties in developing a reliable analytical model, computer simulation is often used to analyze bus transit capacities and operations. Bowes and Van der Mark (1977), for example, used computer simulation to investigate the potential capacities of downtown bus lanes in Ottawa, Canada. They found that a bus flow rate of 150 to 170 buses/h could be achieved. Other researchers (Misener, et al., 2002; Siddique and Khan, 2006; Stirzajer and Dia, 2007) have also used simulation tools to assess various bus transit services. And St. Jacques and Levinson (1997) relied on simulation to develop an analytical procedure that is based on Equation 1.

In light of the limitations of analytical models, the IOT has developed and made the HTSS model available to the transportation professional in Taiwan to support highway capacity analysis. The HTSS model is a microscopic, stochastic model. It was originally developed for analysis of individual intersections, arterials, and networks. This model can also simulate bus lane operations with either linear on-line bus stops or off-line bus stops. Each simulated intersection is represented by a node, and the highway or street between two nodes are represented by unidirectional links. Each simulated vehicle has its own attributes that are assigned according to observed or calibrated probability functions. The location, speed, and acceleration of a simulated vehicle are updated once per second according to algorithms that simulate lane-change behavior, the interactions between vehicles, and the interactions between control devices and vehicles. The outputs of the model depend on the subject of simulation. Common outputs include departure flow rate, delays, average travel speed, and maximum queue length for each link.

The HTSS model is being updated continually to enhance its functionalities. To ensure reliably simulation of the operations of bus lanes in Taipei, operating characteristics at bus stops and at signalized intersections were observed and used to calibrate the model. These characteristics are described in the next section.

3. OBSERVED OPERATING CHARACTERISTICS

The bus lanes in Taipei have widths of 3.6 m and each bus stop has a 15-cm to 20-cm high platform. The platform lengths are mostly 45 m to 50 m. Passengers have to use crosswalks at intersections to reach the bus stops. The leading edge of practically every bus stop platform is located at the stop line of the downstream intersection to minimize walking distances. During peak hours, departure flow rates at bus stops can reach approximately 135 buses/h, and a signal
cycle of 180 s is usually used to coordinate pretimed signals. Nearly all passengers use noncontact smart cards to pay for the rides. A small number of passengers pay with exact changes. Approximately 91 percent of the buses traveling in bus lanes are 11.5 m in length. Another 7.5 percent and 1.5 percent are respectively 9-m and 7.5-m long. All 11.5-m buses have double doors. As a result, a typical platform in Taipei can provide up to four loading berths for 11.5-m long buses.

The operating efficiency of a bus stop is mainly affected by bus dwell time, platform space utilization, clearance time, and move-up time at the bus stop. It can also be affected by the free-flow speeds of buses and the queue discharge characteristics at the stop line of the downstream signalized intersection. Data relating to these characteristics were collected from seven bus stops and the stop lines of two signalized intersections. All the data were collected during peak hours over a two-week period. In addition, queue discharge data were collected from two mixed-vehicle lanes that were shared by cars and buses to supplement the data collected from the bus lanes. Electronic stopwatches were used to measure queue discharge headways, clearance time, and move-up time. For investigating platform space utilization, the edges of platforms were marked at 1 m intervals for observers to estimate the stopped location of each bus and the space headway between two successive buses. A laser gun was used to measure the free-flow speeds of buses at mid-blocks.

3.1 Dwell Time

Dwell time refers to the time a bus stopped at a bus stop for passenger service. It does not include the delays caused by the downstream traffic signal after the passenger service is completed. Nor does it include delays caused by blockage. The mean peak-hour dwell times observed at seven bus stops in exclusive bus lanes range from 5.3 s to 15.6 s. Figure 2A shows that the cumulative distributions of the normalized dwell times (i.e., individual dwell time to mean dwell time ratios) at these bus stops are similar. And individual dwell times are mostly between 20% and 400% of their average. The coefficient of variation of each distribution of dwell times varies from 0.53 to 0.83. Figure 2B shows the cumulative distributions respectively associated with the lower bound and the upper bound of this coefficient.

The cumulative distributions of the normalized dwell times are represented by the following distribution in the HTSS model for simulating individual dwell times:

\[
\begin{align*}
\text{If } t_n < 0.20, & \quad F(t_n) = 0.0 \\
\text{If } 0.20 \leq t_n < 3.3, & \quad F(t_n) = -0.255 + \frac{1.253}{1 + e^{t_n/0.433}} - t_n/0.697 \\
\text{If } 3.3 \leq t_n < 4.0, & \quad F(t_n) = 0.973 + 6.655 \times 10^{-3} t_n \\
\text{If } t_n \geq 4.0, & \quad F(t_n) = 1.0
\end{align*}
\]

where

- \( t_n \) = normalized dwell time, and
- \( F(t_n) \) = proportion of normalized dwell times less than or equal to \( t_n \).
3.2 Platform Space Utilization

Figure 3A shows that in Taipei the stopped location of a lead bus can be 3 m downstream (negative distances in the figure) of the stop line or more than 8 m upstream. Figure 3B shows that the space headways between successive stopped buses (rear end to front end), which average 2 m, vary from approximately 0.5 m to 6 m. These characteristics can be attributable to the tendency of some drivers to stop near passengers who wave to draw attention. The large random variation in space utilization reduces the maximum number of buses that can simultaneously use a platform. Consequently, it can lower the capacity of a bus stop. As in the case of dwell time, the observed distributions shown in Figure 3 are represented by mathematical functions and used in the HTSS model to simulate the platform utilization characteristics in Taipei.
3.3 Clearance Time and Move-up Time

Measured from the moment a free-flow bus starts accelerating to the moment that bus has traveled a distance equal to its length (11.5 m), the average observed clearance time is approximately 4.7 s. Clearance time measured in this manner is useful for calibrating a microscopic simulation model but not as meaningful as move-up time for analyzing bus stop operation. Move-up time refers to the time interval between the moment the last bus at a stop starts accelerating and the moment a bus waiting outside the stop moves into and stops in the loading zone. The move-up distances in Taipei can be as short as one bus length and as long as 60 m or more for a platform of 45 m to 50 m in length. Figure 4 shows that move-up time is more or less a linear function of the move-up distance. For a given move-up distance, individual move-up times are largely within 2 s of their mean move-up time. This phenomenon is reproduced by the HTSS model through the inherent variations in vehicle acceleration and deceleration rates.

![Figure 4 Move-up time at exclusive bus-lane stop](image)

3.4 Queue Discharge Headway

Queue discharge characteristics affect the maximum flow rate at which vehicles can be discharged into an intersection. They can restrict the capacity of a bus lane. The buses in a bus lane in Taipei can only go straight-through or make left turns at an intersection. Right-turn buses have to move into a downstream mixed-vehicle lane first. Because a bus stop in a bus lane can accommodate up to four large buses at a time and has a setback of 0 m from the stop line of the downstream intersection, buses exit a bus stop after the green light is turned on rarely form a moving queue of more than 5 buses. To provide a basis for simulating the discharge of long queues, queue discharge data were also collected from lanes shared by buses and cars.

Figure 5 shows the nature of observed straight-through average queue discharge headways. For buses in the first five queue positions, average queue discharge headways in bus lanes are mostly 0.1 s or less shorter than those in shared lanes. Therefore, it was assumed that, for queues longer than five buses in a bus lanes, their discharge headways will be only slightly shorter than those
observed in shared lanes. A car-following logic imbedded in the HTSS model was calibrated to enable the model to produce queue discharge characteristics that are compatible with the aforementioned queue discharge characteristics. The passenger car equivalents (pce) of simulated straight-through buses are in the range of 1.6 to 1.8. This compares with a pce of 2 suggested in Chapter 16 of the Highway Capacity Manual of Transportation Research Board (2000).

![Figure 5 Characteristics of queue discharge headways of buses](image)

**3.5 Free-Flow Speed**

The speed limit of urban transit buses in Taipei is 40 km/h. The average free-flow speeds measured at mid-blocks are 39 km/h. Individual free-flow speeds vary from 70% to 120% of the mean free-flow speed. The HTSS model uses a representative cumulative distribution of normalized free-flow speeds for simulation.

**4. SIMULATION ANALYSES**

To explore ways of improving the design and operation of the bus lanes in Taipei, the calibrated HTSS model was used to examine the nature of unconstrained capacities and block capacities of such bus lanes. Service capacity is sensitive to site-specific conditions and its nature is too complex to be discussed in this paper. Therefore, only unconstrained capacity and block capacity are discussed herein.

The capacity of a bus lane can be estimated in a simulation run by allowing buses to reach the bus stop at a rate that produces continuous presence of queuing buses waiting to enter the bus stop. The rate at which buses can enter the downstream intersection under such a condition represents the capacity of the bus lane. More than eight thousand scenarios of bus lane operation between two signalized intersections were analyzed through simulation. Each scenario dealt with
one bus stop in combination with various conditions of signal control, number of loading berths, dwell time, and bus stop setback from the stop line of the downstream intersection. All the analyses were based on 11.5-m straight-through buses, pretimed signal control, and 4-s signal change intervals. In Taipei the last bus at a stop would need at least 9 m of platform length to begin passenger service. Therefore, loading platform lengths of 14 m, 25 m, 38 m, 53 m, and 65 m were used to simulate bus stops with 1, 2, 3, 4, and 5 berths, respectively. Simulated signal cycle lengths range from 60 s to 240 s. For each cycle length, the green intervals available to buses were simulated at 30%, 45%, 60%, and 75% of the cycle length. Simulated bus stop setbacks range from 0 m to 140 m. And average dwell times vary from 5 s to 90 s.

As mentioned previously, the HTSS model uses the distributions shown in Figure 3 to simulate the characteristics of platform utilization. To examine the potential effect of altering the platform utilization behavior, the HTSS model was modified to allow the simulation of constant space headway at a bus stop. This modified version of the HTSS model forces every simulated lead bus to stop within 1 m of the leading edge of a platform and the rest of the buses at the same stop to maintain a constant headway of 2 m. The simulation results presented below in Sections 4.1 and 4.2.1 through 4.2.3 are based on this constant-headway utilization of a platform. The effect of the random utilization observed in Taipei is discussed in Section 4.2.4.

4.1 Unconstrained Capacity

Figure 6 shows that, for a given number of loading berths, the unconstrained capacity of a bus stop is more or less a negative exponential function of average dwell time. The average departure headway at capacity, however, is a linear function of average dwell time. Based on this characteristic, unconstrained capacity can be estimated as:

\[ Q_u = \frac{3600}{\alpha + \beta D} \]  

where

- \( Q_u \) = unconstrained capacity (buses/h),
- \( \alpha = 3.572 + 2.838e^{-0.4(N-1)/2.231} \),
- \( \beta = 0.296 + 0.704e^{-0.4(N-1)/1.493} \),
- \( D \) = average dwell time (s), and
- \( N \) = number of berths.

In Equation 3, \( \alpha + \beta D \) represents the average departure headway when a bus stop is operating at capacity. For N=1, the values of \( \alpha \) and \( \beta \) are respectively 6.4 s and 1.0, where 6.4 s is approximately the average move-up time observed in Taipei when a waiting bus has to move up by one bus length to occupy the berth ahead. These values agree with theoretical expectations.

4.2 Block Capacity

Block capacity is bound by the unconstrained capacity and the ability of queuing buses in utilizing the green intervals provided by the downstream signal control. Its relationships with major influencing factors vary with specific bus stop design features and operating conditions. Nevertheless, such relationships follow certain patterns that point out ways of improving the
capacities of the bus lanes in Taipei. Such patterns of relationships are described below based on samples of simulation results.

![Graph showing variation of unconstrained capacity and departure headway with number of berths and average dwell time]

Figure 6 Variation of unconstrained capacity and departure headway with number of berths and average dwell time

4.2.1 Effects of Bus Stop Setback

The leading edge of a typical bus stop platform in Taipei is at the stop line of the downstream intersection. This setup prevents a bus, which has completed passenger service, to vacate a loading berth if the red signal light is on. Figure 7 shows moving a bus stop away from the downstream stop line may increase block capacity. Once the setback exceeds a certain distance, the flow rate departing from a bus stop approaches the unconstrained capacity of the bus stop and thus further increases in setback cannot improve block capacity. The effects of bus-stop setback are more prominent when the dwell time is shorter. The average dwell times at various bus stops in Taipei are short; moving these bus stops upstream by 40 m may increase the block capacities by about 20 percent.

4.2.2 Effects of Signal Control

Figure 8 shows that, for a given cycle length, the effects of green interval to cycle length ratio (G/C) depends on dwell time and bus-stop setback. Once the setback exceeds a certain distance, the impact of G/C becomes negligible as long as the stop line capacity is greater than the flow released from the bus stop. Longer dwell times reduce unconstrained capacity and thus diminish the impact of G/C ratio.

The signal cycle lengths in Taipei are usually 180 s during peak hours. Figure 9 shows that, for a given G/C ratio, cycle length can affect block capacity. In general, shorter cycles yield greater capacities. This is because longer cycles tend to have longer red intervals. Longer red intervals, in turn, increase the chance that a departing bus will be blocked by a red light. This can reduce
the utilization efficiency of a platform. The impact of cycle length, however, diminishes with increased setback and dwell time.

Figure 7 Variations of block capacity with average dwell time and stop setback \( (C = 90 \text{ s}; G/C = 0.5) \)

Figure 8 Effects of green interval to cycle length \((G/C)\) ratio on block capacity for \(C = 90 \text{ s}\)
4.2.3 Effects of Number of Berths

Because a bus that has completed passenger service may be blocked by the buses ahead, lengthening the platform of a bus stop to provide additional loading berths has a diminishing return in capacity improvement. The effectiveness of a bus stop may be measured in terms of the effective number of berths of the stop. This parameter can be defined as the ratio of the capacity of a bus stop to that of a single-berth bus stop. Figure 10 shows that the effective number of berths for a bus stop depends on bus stop setback and signal control. Each berth of a two-berth stop is equivalent to approximately 0.6 to 0.8 berth of a single-berth stop, and each berth of a five-berth stop is equivalent to 0.36 to 0.55 berth of a single-berth stop.

Figure 10 Effective number of berth for average dwell times of 20 s or 40 s and G/C of 0.4, 0.5, or 0.7
4.2.4 Effects of Other Factors

There are other factors that can affect the capacity of a bus stop. In general, an increase in the variability of dwell times could reduce block capacity. Refer to the two distributions shown in Figure 2B for example. When the dwell time distribution is characterized by the one with a coefficient of variation $C_v$ of 0.83, simulated block capacities are 0% to 15% lower than when the dwell time distribution has a $C_v$ of 0.53. The extent of capacity reduction depends on average dwell time and number of berths. The platform utilization behavior also can impact capacity. In comparison with a bus stop where buses maintain a constant headway of 2 m, variable headways characterized by the distributions shown in Figure 3 can reduce block capacities by as much as 15%. The average reduction for all the scenarios examined in this study is approximately 10%.

5. A SIMPLIFIED TOOL FOR ANALYSIS

The simulation results presented in the previous section provide some insights into potential ways of improving the capacities of the bus lanes in Taipei. How a given capacity should be used to provide a desirable level of service, however, requires the consideration of the local traffic conditions (e.g., demand flow rate and arrival pattern) and the signal control upstream of a bus stop. Because of the need to consider upstream traffic and signal control conditions, the level-of-service analysis of a bus lane is much more complicated than estimating capacity.

The HTSS model is available to the transportation professionals and researchers in Taiwan to support both capacity estimation and level-of-service analysis. When used for analyzing urban arterials or networks with exclusive bus lanes, the HTSS model generates the following estimates as outputs: (1) departure flow rate, average stopped delay, average total delay and mean speed for each lane of every simulated street block; (2) the failure rate of each bus stop; (3) the maximum queue of buses waiting to enter each bus stop; and (4) average speed along a specified route. Total delay estimated by the HTSS model for each lane includes stopped delay and additional travel time owing to acceleration and deceleration. And the failure rate of a bus stop refers to the percentage of buses that have to wait for vacant loading berths. These estimates not only allow transit authorities to evaluate alternative bus stop designs, dispatch headways, and signal control but also help in determining how best to allocate bus lanes to bus operators.

One stumbling block in using the HTSS model is the substantial effort that is needed to prepare input data files. Even with graphic-user-interface software, users of the model still need to read a lengthy user manual before embarking on the task of developing an input file. On the other hand, many planning, design, and operating decisions in Taiwan require detailed analyses only at street-block level. This means many analyses require the consideration of at most two adjacent signalized intersections at a time. Under the circumstances, standard input files can be developed to serve as templates for simplifying input file development. Therefore, the IOT has posted a simulation software package with standard input files at its website (http://www.iot.gov.tw/english/mp.asp) for free download. This package includes the HTSS model executable file (htss-v3.exe), two standard input files (busiso2p.txt and artbus.txt), and short instructions (ReadBus.pdf). The instructions and the outputs are in English.
The busiso2p.txt file can be used to simulate the operation of bus stop when it is not necessary to consider the impact of upstream intersection. The other file (artbus.txt) is set up to simulate the operation of a bus lane under the influence of: (1) upstream and downstream signal controls; and (2) bus lane operations in two upstream street blocks. These files can be easily modified by users to prepare an input file according to the conditions to be simulated. Primary input data that users may have to modify concern type of bus stop (on-line or off-line), number of berths, bus stop setback, average dwell time, scheduled flow rate of bus line, signal phase intervals, and street block length.

6. CONCLUSIONS AND RECOMMENDATIONS

The linear on-line bus stops in Taipei are not as efficient as those bus stops that have off-line loading bays. The installation of off-line loading bays is usually impractical in Taipei. Therefore, there is a need to explore how the existing rights-of-way along various routes of exclusive bus lanes can be better utilized. The simulation analysis performed in this study reveals several potentially viable ways of improving capacity.

First, existing bus stops may be moved upstream to allow more buses to move out of the stops when the downstream traffic signals are in red. This has the potential to increase capacities by up to 20%. Second, long signal cycle lengths tend to reduce bus-lane capacities. The signal cycle length of 180 s commonly used in Taipei during peak hours is very long. Whether a shorter cycle length can be used to accommodate both vehicular and pedestrian traffic should be investigated. Preemption of signals to give buses priority treatments should also be considered. And finally, instructing lead bus drivers to always stop near the leading edge of a platform and other drivers to always maintain space headways of about 2 m can increase bus stop capacities by about 10%.

To identify the most desirable changes to design elements and operating strategies requires the assessment of the impacts of such changes on not only capacity but also level of service. To be meaningful, this task should use site-specific conditions for analysis. To facilitate this undertaking, the IOT has provided the public with an easy-to-use software package.

Moving existing bus stops upstream will increase the walking distances of passengers. An attitudinal survey of passengers may be conducted as an extension of the current study to determine an acceptable bus-stop setback. The implementation of exclusive bus lanes on an urban arterial usually requires the allocation of an existing lane for the exclusive use by buses. This has a negative impact on non-users of bus lanes. The transit authorities in Taiwan can benefit from the development of warrants that should be met before giving serious considerations to the implementation of exclusive bus lanes.

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