DETERMINING IMPACT OF BUS-STOPs ON ROADWAY CAPACITY

Dr Johnnie Ben-Edigbe
Associate Professor
University of Technology, Malaysia

Mrs Nordiana Mashros
Lecturer
University of Technology, Malaysia

Abstract
Roadway capacity is a quantitative assessment of traffic stream properties. It is based on relationship between flow, speed and density. A bus stop is a designated place where buses stop for passengers to board or alight. Bus stops are normally positioned on the highway and the bays are either located on or off the road carriageway lane to reflect the level of usage. The study is aimed at determining capacity loss and traffic shockwaves associated with bus stop locations along the carriageway lane of a single lane highway. The off-peak hour study was carried out in Skudai Town, Malaysia. An average dwell time of 50s was recorded. The roadway was divided into three sections (A-downstream, B-transit, and C-upstream). Bus stops are located at section C. Based on the hypotheses that on street bus stops would lead to roadway level of service reduction, volumes, speeds and vehicle types were surveyed for 4 weeks. Bearing in the mind that surveys were carried out different locations, volume and speeds relationships were used to compute roadway capacities for the different scenarios. Roadway capacities were computed using quadratic relationship between flows and densities. Results and analyses showed significant differences in roadway capacities for the on and off street bus stops. Roadway capacity loss of 23.4 per cent was recorded, and 25km/h propagation of velocity shockwaves. Ideally, the survey should have been carried out at the same location for different scenarios, but this is not practicable as it would have required the construction and reconstruction of bus stops. Notwithstanding, the study concluded that on-street bus stops have significant impact on roadway capacity loss.

Keywords: Bus-stops, capacity, shockwaves, flowrate, roadway

1. INTRODUCTION
Traffic theory is concerned with the movement of discrete objects in real time over a finite network in 2Dimensions. It is compatible with or dependent on fundamental diagram of traffic stream properties (flow, speed and density). Roadway capacity is a quantitative assessment of traffic stream. It is based on relationship between flow, speed and density. Headways, traffic volumes, flow and speed as well as fundamental relationships of speed, flow and density are known empirical methods employed to estimate roadway capacity. However, lack of a clear definition of roadway capacity poise itself as the main hindrance in understanding and tackling roadway capacity robustly. The choice of a particular method clearly depends on the data available and degree of certainty ascribed to the study being carried out. Notwithstanding, roadway capacity is a central concept to roadway design and traffic management. In general it is defined as the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a carriageway lane per time period under prevailing roadway, traffic and ambient conditions.

In this study, the primary concern is bus stop locations on the highways and the consequences for traffic stream properties. The location of bus stops along a road carriageway lane is the main condition in this study. A bus stop is a designated place where
buses stop for passengers to board or leave a bus. The number and type of bus stops provided on a road significantly influence the flow characteristics of traffic on the road. So, it can be postulated that any change to the prevailing location of a bus stop could trigger a change in the capacity of the highway.

The construction of bus stops is often tied to the level of usage. Bus stops infrastructure ranges from a simple pole and sign, to a rudimentary shelter, to sophisticated structures. Bus stop shelters may have a full or partial roof [4]. The stop may include separate street furniture such as a bench, lighting and a garbage receptacle. Individual bus stops may simply be placed on the sidewalk next to the roadway, although they can also be placed to facilitate use of a bus way. More complex installations can include construction of a bus turnout or a bus bulb, for traffic management reasons, although use of a bus lane can make these unnecessary [4]. Several bus stops may be grouped together to facilitate easy transfer between routes. These may be arranged in a simple row along the street, or in parallel or diagonal rows of multiple stops. For operational purposes there are three main kinds of stops: Scheduled stops, at which the bus should stop irrespective of demand; request stops (or flag stop) where the vehicle will only stop on requested and hail and ride stops where a vehicle will stop anywhere along the designated section of road on request [4]. In cases where bus stops are located off the carriageway lane, often bus drivers have difficulty in joining the traffic stream. The gap acceptance time inevitably lead to increase in bus turnaround time. However, when bus stops are located on the carriageway lane, their dominant presence presents problem for follow up traffic stream. The roadway would experience bottlenecks, queues and delays especially at peak period. Bottlenecks, queues and delays on highway link will often lead to capacity loss. The study is aimed at determining capacity loss associated with bus stops locations along the carriageway lane. It was carried out in Skudai Town, Malaysia [5].

Figure 1 Typical Bus/Coach

2. LITERATURE REVIEW

Highway capacity is significant because it’s an important indicator of road performance and can point road managers in the right road maintenance and traffic management direction. Determination of road capacity is one of the main outputs in traffic studies and traffic theory analysis. Its value is a key input for facility selection, design and rehabilitation. It is used to determine the number of design lanes required on a new facility as well as assess the performance of an existing highway section to see if it can cope with the current traffic demand as well as the expected demand in the future. As mentioned in previous studies, [1, 2, 3, and 7] and rightly so, three parameters namely: speed, flow and density are often employed to describe the operational state of any given traffic stream.

Bus-stop markings allow buses to arrive at a stop, but it does not impede the flow of traffic on the roadway, therefore they are of little concern, what is important is the location of the bus stop as shown below in figures 2 and 3. The siting of bus bay is important because bus driver would have to content with the probability of increase in dwelling and clearance (time it takes bus to re-enter the traffic stream) times if the bus bays are located off-carriageway lane. Dwell time is the scheduled time a bus is allowed to discharge and take on passengers at a stop, including opening and closing doors. Should the marking be placed on-carriageway lane, bus drivers will have quicker clearance times, even though other road users’ especially follow-up vehicles would have their flow disturbed. So, it can be postulated that an abrupt slowdown in concentrated traffic stream can trigger shock wave along the line of cars, either downstream (in the traffic direction) or upstream, or it can be stationary. Often the consequence of traffic shock wave is roadway capacity loss. So what are shock waves? Where traffic stream is moving at a speed in close proximity and lead vehicle driver step on
the brake, if the follow up driver should lose his/her nerves on sighting the brake lights abrupt braking will trigger shock waves.

Propagation velocity of shock wave in highway traffic theory is concerned with the movement of discrete objects in real time over a finite network in 2 Dimensions. The shock wave propagates along a line of vehicles in response to changing conditions at the front of the line. Shock waves can also be generated by collisions, sudden increases in speed caused by entering free flow conditions, or by a number of other means. Basically, shock wave is a temporary, physical condition that occurs whenever the traffic conditions change. It is a temporary, physical condition. Shock waves equation that is used to estimate the propagation velocity of shock waves is given below.

\[
u_w = \frac{q_b - q_d}{k_b - k_d}
\]

Where:
- \(u_w\) = propagation velocity of shock wave (km/h);
- \(q_b\) = flow prior to change in conditions (veh/h);
- \(q_d\) = flow after change in conditions (veh/h);
- \(k_b\) = traffic density prior to change in conditions (veh/km);
- \(k_d\) = traffic density after change in conditions (veh/km);

It should be noted that when \(v_w\) is positive, the shock wave moves downstream with respect to the roadway and vice versa. Differential in flow conditions upstream and downstream of a point does not imply that a shock wave is present. As shown below in figure 4, traffic shock wave has a triangular shape ‘abd’. Traffic shock is a resultant of highway capacity loss. In order words, highway capacity loss irrespective of the causation would trigger traffic shockwaves. The most widely known high order models of traffic shock waves still require speed-density equilibrium relationship shown below:
Figure 4 Hypothetical Flow-Density Curves

\[ uf \] represents the free flow speed and \( kj \) the jam density

Roadway capacity is the apex point of an asymmetric flow and density curve shown above in figure 4. Clearly, the flow and density curve has 2 chambers (constrained (C) and unconstrained (U)). The constraint is capacity. Highway capacity loss occurs when the available road space is oversubscribed. The flow density curves are peculiar to highway traffic. It has 4 basic boundary conditions: i, flow equals zero when density is zero; ii, flow equals zero when density is at jam, iii, speed equals zero at jam density, iv, speed equals free flow when density is zero. As flow approaches maximum flowrate dynamics of traffic flow and shock waves may cause capacity to be reduced below maximum flowrate with speeds corresponding to the right chamber of the curve. As shown in figure 4, points ‘abd’ is the shock wave triangle whereas ‘cdef’ is the capacity loss envelope. In order to estimate capacity and shock waves associated with bus stops, the study relied on fundamental diagrams of traffic stream where flow is a function of speed multiply by density. Speed and density as contained in many literature has been shown to have a linear relationship shown below in equation 3, where speed \( (\ ) \):

\[ \text{Equation 3} \]

Since flow, speed and density are related; if equation 3 is plugged into the relationship, then flow \( (q) \) could be written as:

\[ \text{Equation 4} \]

In theory, where the flow / density relationship has been used to compute roadway capacity [1, 6] the critical density is reached at the apex point. Up till that point, traffic stream is operating under free flow as often mentioned in many studies. When the volume/capacity ratio critical point of 0.85 is reached, traffic flow is now under capacity constrained condition. Beyond the apex point, traffic stream is at capacity. Consider Equation 4 again, for maximum flow:

Then, optimum density \( k_o \)

\[ \text{Equation 4} \]

If \( k_o \) is plugged into equation 3 highway capacity \( (Q) \) can be estimated,

\[ \text{Equation 4} \]

As often found in many studies, it may be the case that such calculated capacities are unrealistically high and questionable. It can even be argued that capacities derived in such a way may have very little resemblance to traffic stream actuality. That may be so. Since our interest is in estimating the capacity change due to bus stop locations, the choice of precise value of critical density need not be very critical to the outcome of this study. In many Chinese cities [7], ‘traffic conditions are classified into two types: no stopped bus and presence of stopped bus at the kerb stop the presence of a stopped bus creates a temporary conflict between bicycles and cars, reducing road capacity. Thus, a road capacity model based on gap acceptance theory and queuing theory is used for mixed traffic flow at the kerb.
stop. The probabilities of no bus and presence of bus at a stop can be obtained by using the queuing model of bus streams. Capacity can be derived through gap acceptance theory. Car capacity at the kerb stop is taken as a function of three types of traffic stream—buses, cars, and bicycles—and it may be applicable in traffic analysis and the design of bus stops in other developing Asian cities [2, 7]. This is not the case in Malaysia where motorcycles are very popular and studies have shown that motorcycles have insignificant impact on roadway capacity [1].

3. FIELD STUDY AND DATA COLLECTION
The road section used for the study was not a bottleneck; hence extrapolation of the free flow part of the fundamental diagram representing flowrate and density was used. Dynamic passenger car equivalent (PCE) values were relied upon when converting volume to flow for carriageway lane with and without bus stops. Obviously, changes to road conditions will adversely affect vehicle performance and their interactions, hence the application of dynamic passenger car equivalent values. Notwithstanding, the method adopted in estimating PCE will have no effect on the outcome of the study [1]. A simple headway method was used to derive PCE values. As illustrated below in figures 5 and 6, study sites were divided into three sections with Section 1 (S1) as the upstream end and Section 3 (S3) the downstream end, while Section 2 (S2) was the transition section. Bus stops are located at section 3. Based on the hypotheses that on street bus stops would lead to roadway level of service reduction, volumes, speeds and vehicle types were surveyed for 4 weeks. Bearing in the mind that surveys were carried out different locations, volume and speeds relationships were used to compute roadway capacities for the different scenarios. Roadway capacities were computed using quadratic relationship between flows and densities. Ideally, the survey should have been carried out at the same location for different scenarios, but this is not practicable as it would have required the construction and reconstruction of bus stops. Notwithstanding, the findings from the study will probably provoke debate on the merits and demerits of bus stop locations.

4. FINDINGS AND DISCUSSION
Baseline roadway capacity was first computed so as to establish the operational maximum volume of the roadway in the absence of bus-stops of any kind. Once the baseline roadway capacity was established, flow rates in the right chamber of the curves represent capacity loss whereas flows in the left chamber are either free or restrained flows. Restrained flows are flows greater or equal to 0.85 but less than 1. Note that 0.85 is the critical volume to flow ratio on a roadway. As shown below in figure 7 where flow = q and density = k, model equations for carriageway lane with and without bus stop are computed using equation 4 and bearing in mind that the coefficient for determination, $R^2$ is greater than 0.5, suggesting that the model equation in question can be relied upon for predicting:

Baseline roadway capacity model equation, $q_1 = -1.58k^2 + 113.79k - 80.1; \quad R^2=0.96$
Optimum density ($K_0$) = 36veh/km, Optimum speed ($U_0$) = 55km/h and
Baseline capacity ($Q_b$) = 1969pcu/h

Carriageway lane with bus stop; $q_2 = -0.75k^2 + 67.88k - 28.9; \quad R^2=0.89$
Optimum density ($K_0$) = 45veh/km, Optimum speed, ($U_0$) = 33km/h and
Carriageway lane with Bus-stop capacity ($Q_s$) = 1509pcu/h

Carriageway lane without bus stop; $q_3 = -1.88k^2 + 119.6k - 63.5; \quad R^2=0.85$
Optimum density ($K_0$) = 32veh/km, Optimum speed, $U_0= 57km/h$ and
Carriageway lane without Bus-stop capacity ($Q_p$) = 1833pcu/h

Roadway Capacity loss = 23.4%.

Using equation 1; propagation of shock wave = -25km/h

5. CONCLUSIONS
Findings showed significant differences in roadway capacities for the on and off street bus stops. Because, roadway capacity loss of 23.4 per cent and -25km/h propagation velocity of shock wave were recorded for carriageway lane with bus stops. The study concluded that on-street bus stops though useful in minimising turnaround and gap acceptance times have significant impact on roadway capacity loss and would propagate traffic shock waves in circumstances where the vehicle following a bus perceived abrupt bus stopping on carriageway lane.

REFERENCES