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Effect of Bus Bays on Capacity of Curb Lanes

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ABSTRACT: Bus bays have a significant influence on the capacity of curb lanes because they interfere with passing vehicles primarily while buses maneuver to pull into and out of the bus bays. The studies of bus stops influence on capacity of signalized intersections have been attempted by several Researchers and Scholars from both home and abroad. However, the studies of bus bays' impact on capacity of curb lanes are found to be very few. The objective of this study is to investigate the quantitative impact of bus bays on curb lanes capacity of roadways in Beijing. New concepts of bus impact time occupancy ratio and bus impact time were introduced in the study. 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. A statistical relationship between average bus impact times and average bus arrival frequencies was established using Statistical Program for Social Sciences (SPSS 13) for Windows. A model was calibrated for bus parameters (bus impact time and bus arrival frequency) using the collected data from fifteen bus bays on the expressways in Beijing. This model is very useful and can be used as a tool for analysis by Engineers and Planners of traffic and transportation professions to provide technically-sound advice to Public Transport Operators, Traffic Management Department and Department of Urban Planning and Design. [Journal of American Science 2009:5(2) 107-118] (ISSN: 1545-1003)

Index Terms: Capacity, Beijing, Bus Bays, Bus Impact Time Occupancy Ratio, Curb Lanes, Bus Arrival Frequency.

1. INTRODUCTION

1.1 Background of the Study

Traffic congestion at bus bay bus stops in Beijing is on the rise with increasing private automobiles on the roadways competing with public transports for the limited roadway spaces. The efficiency of public transportation buses is declining considerably. Commuters have to waist a lot of time at bus stops and also in the bus in order to get to their destination. The purpose of this study is to model the relationship between bus impact time as bus main parameter at the bus bay and the capacity of the curb lanes. The results of this study can be used for Public Transport Operators to take necessary measures to optimize bus dispatching plans and increase the operation efficiency of public transport buses. On the other hand, the results will help traffic engineers and traffic management department to better understand the performances of traffic flow at the bus bays in order to take necessary steps to increase the capacity of the bus bays by way of reorganizing and redesigning of the bus bays.

These days, bus bays types of bus stops have been brought into wide use in many big cities of China. Bus bays primarily conflict with other passing vehicles when buses maneuver to pull into and out of the stop. Bus bay bus stops will also interfere with vehicles movement if bus demand exceeds the bus bay's capacity, resulting in some buses waiting in the travel lane until the buses occupying the bay exit the bay. At certain situations, there can also be cases of buses blocking the curbside traffic lane during their bay occupancy period or bay dwell period, if they do not fit completely within the bay due to the reduced width of the available bay or due to erratic behavior of drivers. Bus bays may also present problems to bus drivers when attempting to re-enter traffic, especially during periods of high roadway traffic volumes. The typical bus bay is illustrated in figure 1 below.

There are many homes and abroad researches on bus stops influencing on capacity of signalized intersections, but scholars and researchers very few or seldom study bus bay influence on capacity of curb lanes or basic roadway links. Therefore, at times when bus bays are planned, designs are carried out and they are to be built, Engineers only rely on their own professional experiences and at times make references to scholars or researchers' qualitative recommendations or considerations and hence need for quantitative impact study of bus bays on curb lanes capacity.

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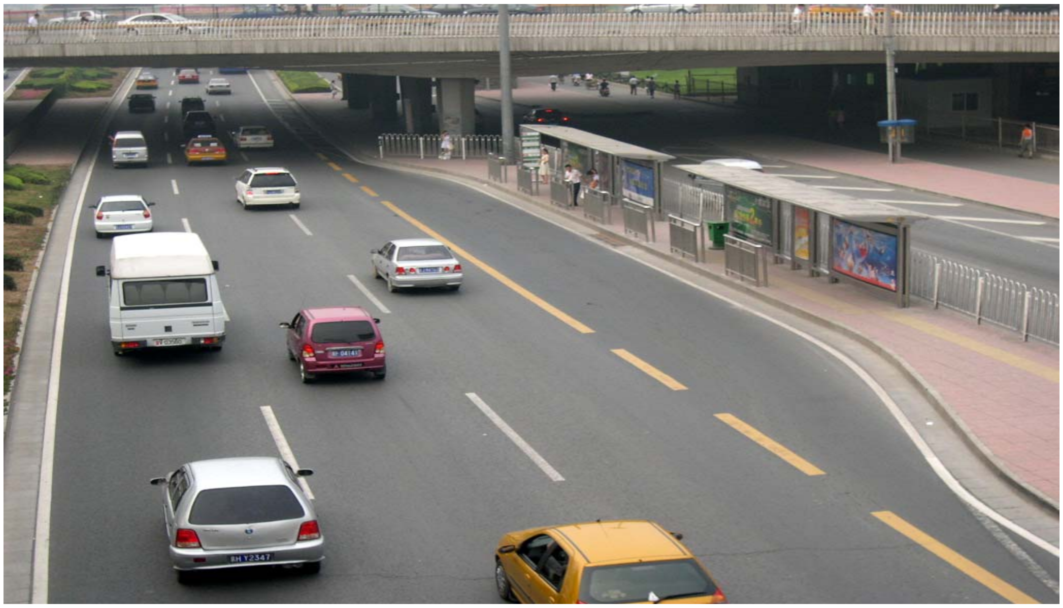

FIGURE 1: Typical Bus Bay

1.2 Literature Review

In the 2000 Highway Capacity Manual (HCM) [1], although there are some findings about the influence of bus stops on capacity

when buses pull in and out of the bus stops, when one applies these results, the parameters

one needs are the number of buses per hour at each bus stop and the average bus stopping time (average bus dwell time).The impact times for deceleration and acceleration by the buses into and out of the bus stops respectively are not taken into account or simply not considered by the HCM. Therefore, when the formula in the HCM is applied in this study it will not produce the desired results.

Reebu Zachariah Koshy and V. Thamizh Arasan (2005) analyzed the influence of bus stops on traffic flow under heterogeneous traffic conditions using a simulation technique. They examined the effects of variation of the basic parameters, such as bus dwell time, road width and traffic flow for both bus bays and curbside bus stops. However, they did not come up with a formula for calculating capacity of roads on which bus stops have influence on the traffic flow.

Bing Wu from Tongji University analyzed the delay of buses under mixed traffic conditions and found a way of calculating the capacity. He also analyzed the running characteristics while the buses are at the bus stops and their influence on capacity. He believed that buses have the same influence on the capacity when the bus stops are located at the far side of the intersection as when they are located at the nearside of the intersection. However, he did not build a quantitative model for calculating the influence which the bus stops have on the intersections' capacity.

Besides that, Pei Yu-long and Wu Shi-mei (2004) from Harbin Institute of Technology mainly analyzed the influence of bus stops located at or set near the unsignalized intersections on capacity, and built a theoretical model for it.

Wong S.C. and Hai Yang discussed the way of calculating the delay of signalized intersections when there are bus stops at farside of the intersection. They came up with (or drew) a conclusion that the delay is influenced by the distance between bus stops, traffic capacity of the road, the departure frequency of the buses, the average bus dwell time of buses and the signal index of the intersection. They also deduced a formula for calculating the capacity.

Wang Qian and Yang Xiao-guang (2003) from Tongji University made a quantitative analysis on the situation of which buses stop on the outer compound lanes of motor vehicles at signalized intersections and tried to establish the relationship between traffic delay, capacity and bus-stopping parameters, such delay, the location of bus berth and bus flow at shared approaches of signalized intersections mathematically. In the end, they built a model for the change of the intersection capacity caused by the buses stopping in order to provide analysis tools for bus operation and also for improvement of urban bus management.

Zhou Y. and Liu X. [1994] conducted a research study on traffic flow composition and road capacity. They used a multiple linear regression method to derive values of passenger car equivalents (pce) in China. Their research findings were used in assigning a value for pce for buses on Beijing roads.

2. OBJECTIVE OF THE STUDY

The objective of this study is to develop a model for determining the quantitative impact of bus bay on capacity of curb lanes. To reach this objective, it is necessary to find out the relationship between bus deceleration time, bus acceleration time, and bus impact time (main parameter), when buses maneuver to pull into and out of the bus bay.

In addition, the model is to seek to:

1. Establish a relationship between average bus impact time, T (bus main parameter) and the capacity of curb lane, C.
2. Find a statistical correlation between average bus impact time, T and average bus-arrival frequency, λ.

The results of this study can be used by Engineers and Planners of the traffic and transportation professions to provide useful advice to Public Transport Operators in the establishment of bus dispatching plans on the bus routes and also ensure to over reach capacity of bus routes or bus lines lines. Other, this study will be to enable traffic and transportation practitioners to provide expert advice to Public Transport Operators in dealing with spacing of bus stops and providing bus stations or bus terminals appropriately in order not to reach the over capacity at the bus bays and bus terminals. The procedures when developed will help provide theoretical model for quantitative impact analysis of bus bays on capacity of curb lanes and will go a long way to help Transit Agencies to know the grid frequency or bus lines frequency in order to serve as basis for planning. All these are objectives which the model seeks to achieve.

3. METHODOLOGY

The operation of a bus bay type of bus stop has its own peculiar characteristics other than the curbside type of bus stops. The components of bus impact time (bus main parameter) of a bus bay are different from that of curbside bus stop. With the bus bay, bus impact time includes only the summation of deceleration and acceleration times of a bus when it maneuvers to pull into the bay and pull out of the bus bay to re-enter the traffic stream to attain the normal speed of other vehicles in the curb lanes. While in the curbside bus stop, bus dwell time or bus stop occupancy time is included in the summation of bus deceleration and acceleration times to give bus impact time. To model the impact of bus bays on capacity of curb lanes, the following three steps have been taken:

3.1 Selection of Bus Bays of Interest

A total of fifteen bus bays were selected on second and third ring roads of expressways in Beijing for data collection. For the purpose of model building, one needs to collect bus deceleration times, bus acceleration times and bus arrival frequencies or volumes. The selected bus bays should satisfy the following conditions. First, there should be an area where a digital video camera can be mounted to tape the entire bus bay affected zone or the whole traffic influenced area, to ensure the video graphing and on-site observations. This will give valuable data covering all categories of buses on the road-site and the number of survey samples times to meet the demand of the study. Normally, overpass for pedestrians close to the bus bay, or high-rise building nearby, or flyovers close to the bus bays are good places to install video camera. Secondly, the traffic on the sections of roads, where bus bays sited to be investigated should be relatively high, but basically there should be no congestion at the bus bays. Thirdly, bus bays are selected along sections of the road where the road is typical, void of interference of basic at-grade intersections, larger roadway gradient, and entrances or exits from the main roads on which the bus bays are located. Fourthly, bus bays located at or near bus terminals of bus lines or bus routes are to be excluded. These could affect bus traffic flow and data collection. Lastly; the selection of the bus bay locations are to be carried out uniformly and equally in all directions as shown in figure 2. The collection of data from these locations serves as the data for building a model of objectivity and practical value.

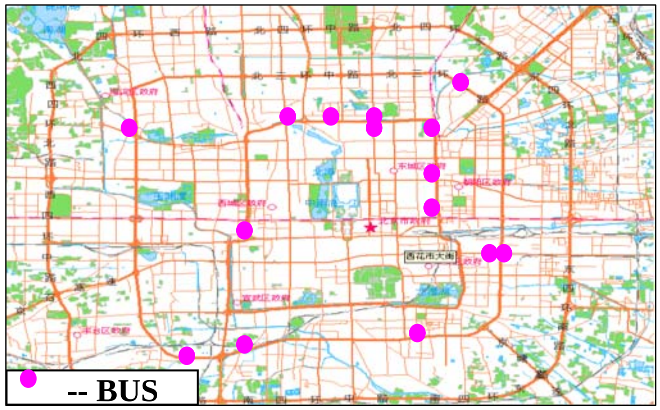

FIGURE 2: Geographical Locations of 15 Selected

3.2 Determination of Bus Impact Time and Bus Arrival Frequency

At the bus bay, bus impact times were observed during every 15 minutes interval within an hour. Their corresponding bus arrival volumes were also observed. To obtain the bus arrival frequency during the every 15 minutes interval was simply the counting of the buses that arrived within that 15 minutes period.

To determine the bus impact times in every 15 minutes within an hour when buses maneuver to pull into the bus bay and pull out the bay, we simply observed the bus deceleration time and acceleration time and sum up the two components to get the bus impact time for each bus arrival at the bus bay. This can be expressed mathematically as follows:

$$T = t_d + t_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Where: T -- bus impact time, (s).

t_d --time taken by the bus to decelerate to bus bay stop and stop, after perception reaction time to apply the brake, (s)

t_a -- time taken by the bus to accelerate to re-enter or join the traffic at the curb lane, (s)

3.3 Concept of Bus Impact Time Occupancy Ratio.

For the purpose of building a model to determine quantitative impacts of bus bays on capacity of curb lanes, a new concept of "Bus lmpact Time Occupancy Rate or Ratio (BlTOR) is introduced. The Bus lmpact Time Occupancy Rate can be defined as the ratio of the bus impact times within one hour at a bus stop to an hour; and its expression in mathematical equation is as follows:

$$k = \frac{T}{3600} \quad \ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Where: k --- Bus Impact Time Occupancy Ratio (Rate).

T --- Bus Impact Times within one hour at the bus bay, (s).

4. DATA COLLECTION AND REDUCTION

In order to build a model, it is necessary to collect field data. Instruments and equipments used for the data collection and reduction were: (1) Digital video cameras and Tripods. (2) Stopwatch. (3) Digital camera. (4) Videotape cassettes. (5) Measuring tape, and. (6) Computer. A total of fifteen bus bays on second and third ring roads in Beijing were chosen as locations for the study. All the investigated bus bays have locations or spots (pedestrian overpasses or high-rise buildings nearby) to allow the Surveyors or Investigators to install video camera. The distance from the installed digital video cameras to the bus bay ranges from 25 to 35 meters. Locations of these fifteen bus bays (as shown in figure 1) are in urban areas where there are relatively high volumes of traffic on the roads but no congestion at the bus bays.

Two to four hours were spent at each bus bay and another six to eight hours on data processing. Bus impact times and bus arrival volumes were retrieved from the video tapes for the fifteen bus bays, taking 15 minutes as an analysis interval. Table 1 at the end of the manuscript illustrates the results of data processing and reduction of one (Gulouqiaoxi bus bay) of the fifteen bus bays investigated. Microsoft Excel Software was used in data processing and reduction. Data collection and reduction for the fifteen bus bays were carried out as enumerated above. For each of the bus bay, bus impact times and bus arrival frequencies were retrieved from the video tapes, taking 15 minutes as an interval of analysis as shown in Table 1. After the data reduction using Microsoft Excel Software, the final data for average bus impact time per hour and average bus arrival frequency per hour for the model building and calibration of bus parameters were tabulated in Table 2 (end of the manuscript) for one of the fifteen bus bays. A Statistical Program for Social Sciences for Windows (SPSS 13) was employed in the calibration process using the full processed data for the fifteen bus bays in the same similar manner as described and shown in Table 2 at the end of the manuscript..

5. MODEL BUILT-UP

Before developing a model of quantitative impact of bus bays on capacity of curb lanes, some hypotheses were made and the model was based on them. First, it is assumed that all the buses run and stop normally without breaking traffic rules and regulations. Also provision of bus bays for public transportation vehicles conform to guidelines for location and design of bus stops and do not violate general design and traffic regulations. Secondly, it is assumed that before buses enter the bus bay, all the buses are running normally at the outermost lane or curb lane. Thirdly, all the bus bays are located on roads without any interference of at-grade intersections, entrances and exits to the roads on which bus bays are located. The fourth hypothesis is that the traffic flow at the bus bay is normal of no congestion, devoid of interferences from the pedestrians and other vehicular and social disruptions in the traffic flow. Fifthly, bus stops at /or near the bus terminals of the bus routes or bus lines are excluded, so as not to have impact on the study.

5.1 Theoretical Model

In building a model, consideration is given to a situation in which all the buses are contained in the bus bay without an overflow or spillover of buses onto the curb lane. A consideration is also given to a bus on arrival, or maybe more than one bus, and the buses stopping in line in the bays without taking up onto the curb lanes. Under this condition, buses stopped inside the bus bay and do not have any influence on the other vehicles in the curb lane. However, when buses decelerate to stop at the bus bay and pull out of the bus bay by accelerating to join the curb lane traffic stream, they have influence on the other vehicles following them and therefore decreasing the capacity of the curb lanes. Therefore, we only need to measure the times which the other vehicles got jammed by the buses, specifically to be the sum of impact times which buses decelerate to enter the bus bay and accelerate to pull off the bus bay to re-enter the traffic before and after they stop in the bay respectively. The bus bay occupancy time or bus dwell time is not included. The bus impact time T, is expressed in equation (1) of Methodology Section 3 above. Therefore, the mathematical formulation of bus bay impact model on curb lanes capacity is as follows:

$$C = C_p \times \left(1 - \frac{T}{3600}\right) + C_p \times \frac{T}{3600} \times f_{HV}$$

$$= C_p \times (1-k) + C_p \times k \times f_{HV} \quad ,$$

$$\Rightarrow k = \frac{T}{3600} \qquad \text{from equation (2)}$$

$$= C_p \times (1 - k + k \times f_{HV})$$

$$= C_p \times \left[1 - \frac{T}{3600} \times (1 - f_{HV})\right] \ldots\ldots (3)$$

Where: C --- Capacity of the curb lane under the influence of buses, (veh/h).

C_p ---Possible design capacity or base capacity of the curb lane before bus impact, (pce/h).

T ---Bus impact time of the public transport bus, which is the summation of bus impact times of deceleration and acceleration. Bus dwell time is not inclusive. (s)

f_{HV} ---Adjustment factor for heavy vehicle. In our case, it is the bus.

k --- Bus impact time occupancy ratio.

Recalling, for the relationship between adjustment factors for heavy vehicles, proportion of heavy vehicles in the traffic stream and the passenger car equivalent will be as follows:

$$f_{HV} = \frac{1}{\left[1 + P_{HV}(E_{HV} - 1)\right]} \quad \ldots\ldots\ldots\ldots (4)$$

Where: P_{HV} ---- Proportion or percentage of heavy vehicles (buses) in the traffic stream.

E_{HV} --- Passenger car equivalent for heavy vehicle (buses).

$E_{HV} = 3$ [from Zhou et al, (1994)] and $P_{HV} = 8\%$ for the second and third ring roads of the Expressways in Beijing based on the values derived in the other studies conducted in China.

5.2 Calibration of Parameters for Buses and a Model of Curb Lane Capacity

To carry out the calibration of parameters for the buses there is the conversion of all the 15-minutes bus impact time rates and the bus arrival frequency rates data into average hourly bus impact times and average hourly bus arrival frequencies respectively throughout the bus bay survey data. A Statistical Program for Social Sciences (SPSS 13) for Windows was employed by plotting average bus impact times against average bus arrival frequencies to obtain a scatter diagram (often called "scattergram" or "scatterplot"). Average bus arrival frequency, λ is the independent variable and average bus impact time, T is the dependent variable. A statistical correlation and its scatter plots and diagrams between average bus arrival frequency, λ and the average bus impact time, T was established by the use of SPSS 13 for Windows as shown in the figure 3, figure 4, figure 5 and table 3 below. After the employment of the SPSS 13, a scatter plot, various equations models curves fit for dependent variable (bus impact time), and SPSS scatter diagram with a curve of best fit (Power Model) were obtained and shown in figure 3, figure 4 and figure 5 respectively. The results of the statistical correlation (Model Summary and Parameter Estimates) as shown in Table 3, showed that the best fit curve is the power model because its correlation coefficient, R-square and F-statistics test (fit) values proved to be the highest among the values of other curve fits. Therefore, the correlation model for average bus impact time, T and average bus arrival volume, λ can be expressed as:

$$T = 22.698\lambda^{0.84} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

To obtain the calibrated formula for the capacity of curb lanes under the influence of public transport buses, equation (5) is substituted into equation (3) and the expression for the curb lane capacity formula is as follows:

$$C = C_p \times \left[1 - \frac{22.698\lambda^{0.84}}{3600} \times (1 - f_{HV})\right]$$

$$C = C_p \times \left[1 - 0.006305\lambda^{0.84} \times (1 - f_{HV})\right] \quad \ldots. (6)$$

Recalling for the expression of heavy vehicle adjustment factor, f_{HV} from equation (4) above, and substituting $E_{HV} = 3$, [from Zhou et al. (1994)], $P_{HV} = 8\%$ for the composition of buses in the traffic stream on 2nd and 3rd ring roads of expressways in Beijing based on earlier studies conducted,

$$f_{HV} = \frac{1}{[1 + P_{HV}(E_{HV} - 1)]} = \frac{1}{[1 + 0.08(3 - 1)]} =$$

$$= 0.862$$

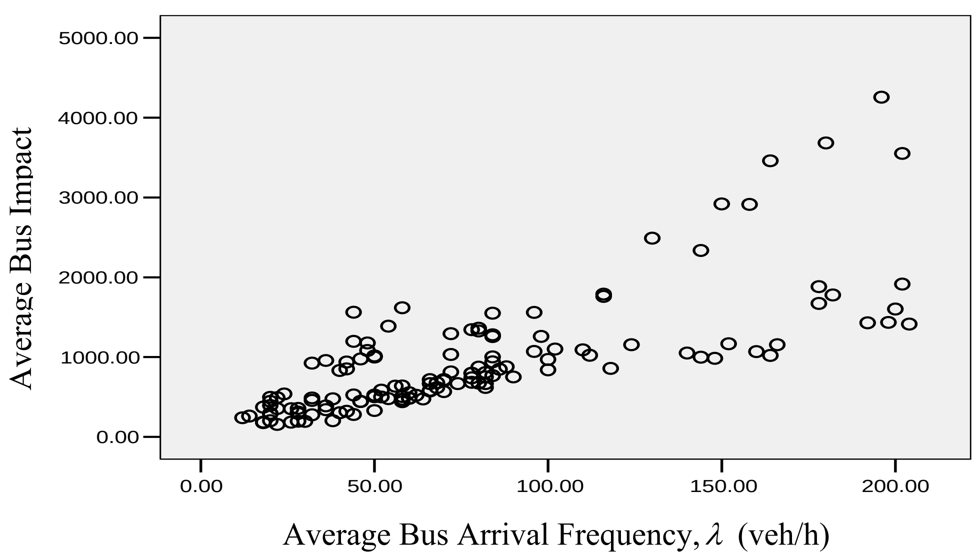

FIGURE 3: Scatter Plots of Bus Impact Time and Bus Arrival Frequency

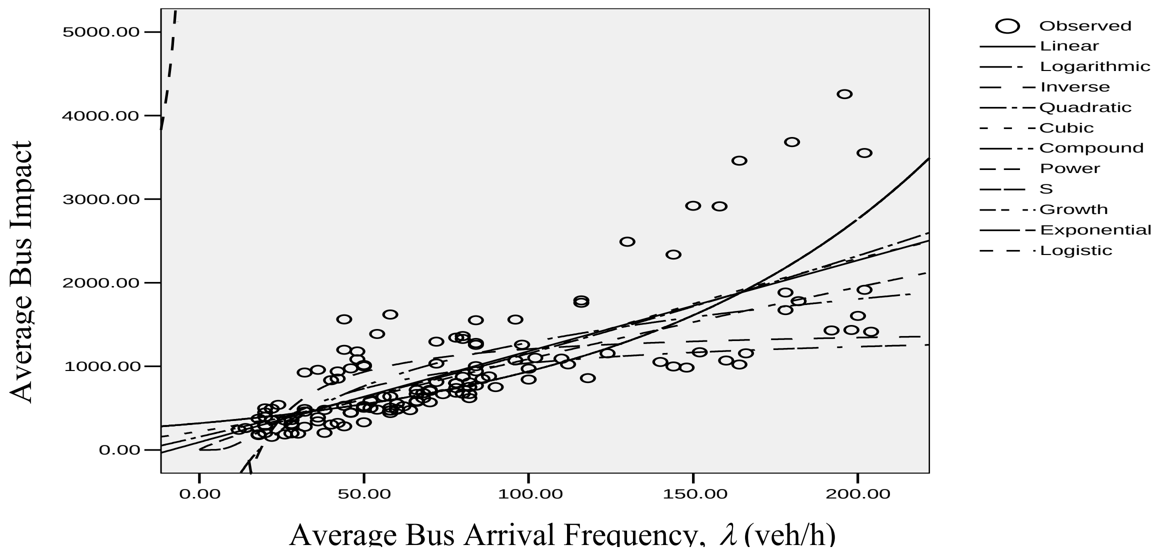

FIGURE 4: Various Equations Models Curves Fit for Dependent Variable (Bus Impact Time)

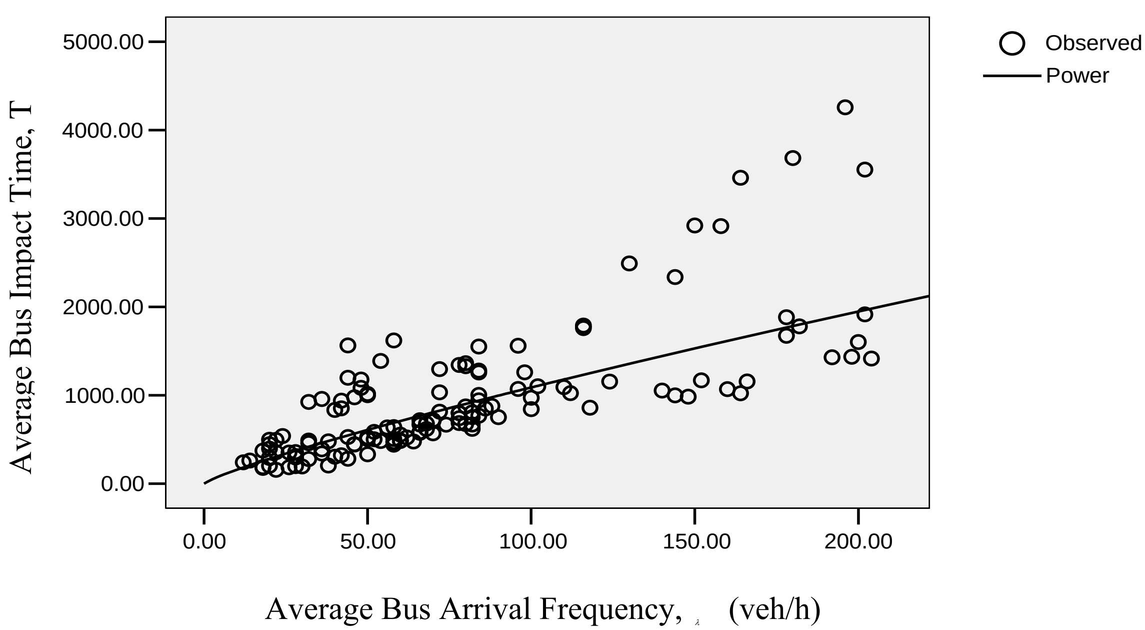

FIGURE 5: SPSS Scatter Diagram with a line of Best Fit (Power Model) for Bus Bay Survey Data

TABLE 1: Determination of Bus Impact Times and Bus Arrival Frequencies Data at GuLouQiaoXi Bus Bay.

No	Bus Arrival Frequency and Category of Buses	Bus Deceleration Time (s)	Bus Acceleration Time (s)	Bus Impact Time (s)
1	J1	6.5	10.3	16.8
2	J1	6.7	12.8	19.5
3	D1	9	8.8	17.8
4	J1	9.6	12.9	22.5
5	D1	8.5	8.7	17.2
6	J1	10.4	10.2	20.6
Sub Total.	8			114.4
END OF THE 1-ST 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
7	D1	7.9	10.2	18.1
8	J1	10.7	15.2	25.9
9	D1	8.3	12.9	21.2
Sub Total.	3.5			65.2
END OF THE 2-ND 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
10	J1	10.3	13.1	23.4
11	J1	8.8	14.8	23.6
12	J1	10.4	11.4	21.8
13	D1	10.5	9.4	19.9
Sub Total.	5.5			88.7
END OF THE 3-RD 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
14	D1	8.6	11.8	20.4
15	J1	9.6	11	20.6
16	J1	9.4	10.1	19.5
17	D1	8.5	13.1	21.6
18	J1	9.8	12.9	22.7
19	J1	8.4	8.9	17.3
Sub Total.	8			122.1
END OF THE 4-TH 15 MINUTES INTERVALBUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
20	D1	9.3	8.8	18.1
21	J1	9.3	8.8	18.1
22	J1	9.3	8.8	18.1
23	D1	9.3	8.8	18.1
Sub Total.	5			72.4
END OF THE 5-TH 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
24	J1	7.4	9.4	16.8
25	J1	7.2	9.1	16.3
26	J1	8.9	9.3	18.2
27	D1	8.7	12.2	20.9
28	D1	6.4	9.6	16
Sub Total.	6.5			88.2

END OF THE 6-TH 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
29	J1	8.9	8.9	17.8
30	D1	7.9	11	18.9
31	D1	7.7	10.9	18.6
33	J1	8.3	10.2	18.5
Sub Total.	5			73.8
END OF THE 7-TH 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				
34	J1	8.8	8	16.8
35	J1	11.6	8.2	19.8
36	J1	10.2	7	17.2
37	D1	9.9	10.3	20.2
38	J1	7	8.2	15.2
Sub Total.	7			89.2
END OF THE 8-TH 15 MINUTES INTERVAL BUS IMPACT TIMES AND BUS ARRIVAL FREQUENCIES OBSERVATION, RECORDING AND ESTIMATION.				

Notes: 1. D-- Normal Public Bus with Two Doors

2. J-- Big Articulated Public Bus with Three Doors = 1.5 Bus D
3. D1= one normal public bus, D2= two normal public buses and so on.
4. J1= one big articulated public bus, J2= two big articulated public buses and so on

.

TABLE 2: Final Data for Input into SPSS 13 for Windows on Average Bus Impact Time per Hour and Average Bus Arrival Frequency per Hour for Gulouqiaoxi Bus Bay.

No	Bus Arrival Volume/15 mins (vel/15 min)	Bus Impact Times/15 min. (seconds)	Bus Arrival Volume/one hr. (vel/hr)	Bus Impact Times/ one hour (seconds)
1	8	114.4	32	457.6
2	3.5	65.2	14	260.8
3	5.5	88.7	22	354.8
4	8	122.1	32	488.4
5	5	72.4	20	289.6
6	6.5	88.2	26	352.8
7	5	73.8	20	295.2
8	7	89.2	28	356.8

Note: This is one of the investigated fifteen bus bays final data after processing and reduction and to be used for the SPSS 13 for Windows in the calibration process. The remaining 14 bus bays data were also processed in the similar manner and used for the SPSS 13 for Windows.

TABLE 3: Model Summary and Parameter Estimates

Equation (Regression Model)	Model Summary		Parameter Estimates			
	R^2	F	$Constant(b_0)$	b_1	b_2	b_3
Linear: $T = b_0 + b_1\lambda$	0.565	174.370	92.341	10.883		
Logarithmic: $T = b_0 \log_{b_1} \lambda$	0.483	125.207	-2178.685	751.949		
Inverse: $T = b_0 e^{\lambda \ln b_1}$	0.306	59.088	1480.625	-27389.5		
Quadratic: $T = b_0 + b_1\lambda + b_2\lambda^2$	0.566	86.884	156.399	9.118	0.09	
Cubic: $T = b_0 + b_1\lambda + b_2\lambda^2 + b_3\lambda^3$	0.567	57.594	222.035	6.011	0.000	
Compound: $T = b_0\left(b_1{}^{\lambda}\right)$	0.607	206.809	319.259	1.011		
Power: $T = b_0\left(\lambda^{b_1}\right)$	**0.658**	**258.313**	**22.698**	**0.840**		
S: $T = e^{b_0 + b_1/\lambda}$	0.535	154.138	7.292	-34.661		
Growth: $T = b_0 e^{\lambda t}$	0.607	206.809	5.766	0.011		
Exponential: $T = b_0 e^{b_1\lambda}$	0.607	206.809	319.259	0.011		
Logistic: $T = \frac{1}{1+e^{-\lambda}}$, $\lambda = b_0 + b_1 x_1$	0.607	206.809	0.003	0.989		

Therefore, the final calibrated formula for capacity of bus bays curb lanes after substituting $f_{HV} = 0.862$ in equation (6) will be as follows:

$$C = \left(1 - 0.00087\lambda^{0.84}\right) \times C_p \quad \ldots\ldots\ldots.. (7)$$

The curb lanes traffic capacity formula for bus bays expressed in equation (7) was used to estimate the curb lane capacities for the bus bays on expressways of Beijing under various estimated bus impact times and various bus arrival frequencies. The results were tabulated and shown in table 4 below.

TABLE 4: Relationship between Bus Arrival Frequency and Actual Traffic Capacity of Curb Lane

Average Bus Arrival Frequency, λ (veh/h)	Average Bus Impact Time, T (seconds) $T = 22.698\lambda^{0.84}$	Actual Curb Lane Traffic Capacity, C (veh/h) $C = C_p \times (1 - 0.00087\lambda^{0.84})$
<10	---	2000
10	157.032	1988
20	281.095	1978
30	395.157	1970
40	503.174	1961
50	606.907	1953
60	707.350	1946
70	805.137	1938
80	900.706	1931
90	994.378	1924
100	1086.395	1917
110	1176.948	1910
120	1266.193	1903
130	1354.254	1896
140	1441.236	1890
150	1527.229	1883
>150	---	---

6. CONCLUSIONS AND FURTHER STUDY

From the analysis of the bus bays survey data by the employment of SPSS 13 for Windows and calibration of a model for bus bays it is concluded that bus bays have significant impact on curb lanes capacity as shown in Table 4. Through data collection, processing, reduction and analysis, functional relationship between bus arrival frequency and the bus impact time (bus main parameter) was established and used in calibration of the model for curb lane capacity. 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. The modeling of the relationship between bus arrival frequencies, bus impact times and curb lanes capacity will help traffic engineers and traffic management unit and Public Transport Operators to better understand the performances of traffic flow at the bus bays, especially buses impact on the curb lanes capacity. In this study a total of fifteen bus bays were selected to collect data including bus deceleration time, bus acceleration time and bus arrival frequency. A concept of bus impact time occupancy rate, k was proposed to facilitate the model building. This concept plays a key role in the model building.

From the videotaping it was observed that some aggressive drivers do not yield to buses when the buses were maneuvering to pull into the bay as well as pull out of the bay to re-enter the traffic stream of the curb lanes. This would affect the data collection process and reduce the sample size. The model built in this study applies to ideal situations of which no interference of other social vehicles taking up the curb lanes as well as passengers wishing to take the buses. The study of bus bays impact on capacity is very complicated. Even though this study is preliminary, the result from this study looks promising for future exploration of bus stops impact on capacity of curb lanes. For this reason the further study should be focused on impact of the following aspects on bus bays curb lanes capacity or other types of bus stops curb lanes capacity in general:

1. Bus driver's perception reaction time to start applying the brake to stop at the bay or bus stop in general.
2. The number of passengers getting on and/or off the bus since the longer dwell time on the bay will influence the deceleration time of the other buses if there is less space at the bus bay.

3. The time taken by the passengers to get off and /or get on board the bus, since the greater time taken will impact on the deceleration times of other buses wishing to stop at the bay, but due to limited space at the bay, they may choose to reduce their speeds.
4. Aggressive driver behavior impact on curb lanes capacity at the bus stops.

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