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Research Article

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Combination Effect of Bus Stop and Exit on Lane Flow Distribution of the Expressway

YAN Xingkui, Zhang Hongbin

School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo Shandong 255000, China
*Correspondence Author: Zhang Hongbin
School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo Shandong 255000, China

Abstract Understanding Longitudinal traffic dynamics helps highway operators to effectively manage traffic flow under various situations. This study particularly focuses on the changes in lane flow distribution due to the combined effect of a bus stop and an exit point. Depending on a bus stop location in the upstream or downstream of an exit, two cases are investigated. A series of models is developed to analyze the relationship between lane flow distribution and traffic density, bus arrival rate, diverging volume. The models could also predict lane flow distributions of individual lanes that can be used to monitor traffic flow conditions under proposed traffic control strategies. The results of study can be applied to traffic control optimization at locations near bus stops and exit points on urban express ways.

Keywords Bus stop, exit, lane flow distribution, traffic density

Introduction

Urban express beltway has become a common roadway facility in metropolitan areas in China to meet huge urban travel demand. These expressways often serve major public transit lines with bus stops throughout the beltway. Due to road space restrictions, off ramps from a beltway are commonly constructed close to a bus stop that serves at least two bus lines in Beijng. Mixing a bus stop with an expressway exit point certainly affect traffic flow patterns.

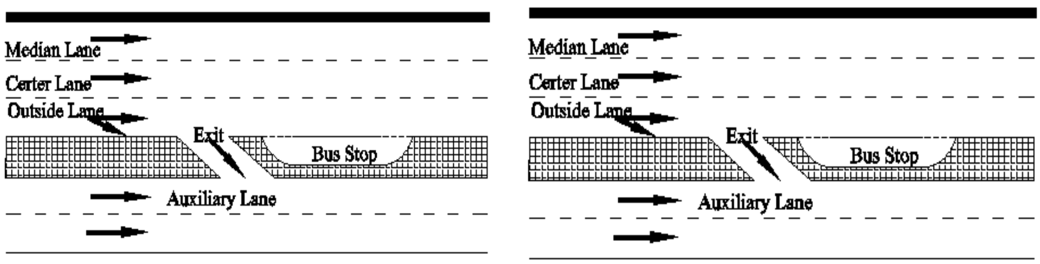
Longitudinal traffic dynamics often expressed by lane flow distributions (LFD) indicates the proportion of total traffic on each individual lane**.**LFD determines roadway lane utilization, thus is closely related to roadway capacity and safety. The Highway Capacity Manual suggested that, in general, lane utilization depends on many factors such as traffic regulation, traffic composition, speed and volume (flow rate), the number of and location of exit points, the origin-destination patterns of drivers, and drivers' behaviors [1].

Several past studies discovered that LFD affects the mechanism of traffic breakdown and amount of reduction in bottleneck discharge flow [2-4]. Several studies [5-6] stated that for motorway segments far away from merging or diverging sections, vehicles are mainly distributed uniformly. Locations of merging, diverging and weaving sections may affect lane utilization. Jin suggested that lane-changing patterns are different at such locations [7]. Nordaen, Rundmo and Özkan *et al*. suggested that drivers' behavior is significantly affected by cultural differences at different countries [8,9], which might explain the differences lane change patterns in different countries as reported by Ferrari [10]. Turner included the individual effect of heavy-goods vehicle (HGV) volume and total directional flow volume on HGV lane utilization [11]. Fwa and Li studied HGVs' Lane utilization in Singapore for the pavement design purposes [12]. The study from Yousif, Al-Obaedi and Henson revealed how HGVs distributed between motorway lanes under different flow conditions and the combined effect of HGV flow and total directional flow [13].

The past research efforts have provided the valuable insight on specific lane distribution patterns and key influential factors. But none of the previous researches investigated the combined impact of bus stops and exit points on lane distribution. Transit vehicles entering and leaving a bus stop is similar to the vehicle diverging and merging maneuver. Because of urban road resource restriction in Beijing, bus bay stops on the expressway are often close to exit points and vehicles diverge from directly the mainline without auxiliary lane. The combinations of bus stops and exites aggravate the effect on LFD. Traffic congestion often sets in near bus stops with exites because of different traffic flows interweaving. Drivers on the mainline are influenced by bus stops with exites and often decrease speed or change from the outside lane towards the center or median lanes, which results in the LFD changed. Yet, this has received no attention in previous research.

Traffic volume has been widely used as a practical measure explaining lane use distributions especially under uncongested traffic condition [14,15]. Unfortunately, traffic volume may not provide adequate information because the same traffic volume can be found at two different travel speeds corresponding to uncongested and congested conditions. Density can overcome this limitation because it has only one corresponding value to travel speed throughout all traffic conditions. In this paper, traffic density is applied as a measure explaining LFD for uncongested and congested conditions during the field data collected.

This paper investigates four cases differentiated by the configuration of a bus stop to the nearby exit point. Specifically, each case is defined by a bus stop location before or after (upstream or downstream) of an exit as shown in Figure 1. The far left lane is denoted as "median lane", middle lane as "center lane" and rightmost lane as "outside lane", which are also called lane 1, lane 2and lane 3, respectively in the analysis.



(a) Upstream bus stop to an exit (b) Downstream bus stop to an exit

Figure 1: Illustration of the Cases

Data Collection

To study the characteristics of lane distribution, massive imagery were collected from the so called the 3rd ring road in Beijing, China. The 3rd ring road, 48 kilometers long, is an important beltway about 6.5 kilometers from the city center. The Morning rush hour traffic volume on this expressway is 10,421 in September, 2018 [16]. There are three lanes in each direction and 68 bus stops on this divided urban expressway. Each bus stop serves many bus lines and there are 20 bus stops accommodating more than 15 bus lines. The busiest stop is located in LIULIQIAONAN with 29 bus lines. Totally there are 20 bus stops located near an exit point.

The data were collected from two selected segments that has bus stop but no vertical slope, no horizontal curvature and not under maintenance or incident at the time the data were collected. To ensure the good visibility, the data collection was conducted under good weather during day time. In order to capture detailed traffic flow characteristics, three video cameras were placed at three locations near a bus stop (ahead of, adjacent to, and after a bus stop). Every passing vehicle was observed as an analysis unit. The data was collected continuously for three and half hours covering both peak and off-peak hours at each camera location for each bus stop. About 14,000 observations were made at each location. The operating speed and flow density were estimated at every minute. The observed jam density on the ring road was about 125 vehicles per kilometer. Table 1 lists the summary of the data collection sites.

Table 1: Summary of Selected Data Collection Sites

Bus Stop Location	**Case Type (bus stop location)**	**Number of bus lines**	**Number of berths**
LIUJIAYAOQIAOXI	upstream of exit	15	2
YANGQIAOXI	downstream of exit	20	3

Lane Flow Distribution Analysis

Bus stop located upstream of an exit

For the next two cases where a bus stop is located close to an exit, the traffic congestion was too intense to estimate the flow rate at the time of data collection. The data analysis results for the bus stop located upstream of an exit is displayed in Figure 2.

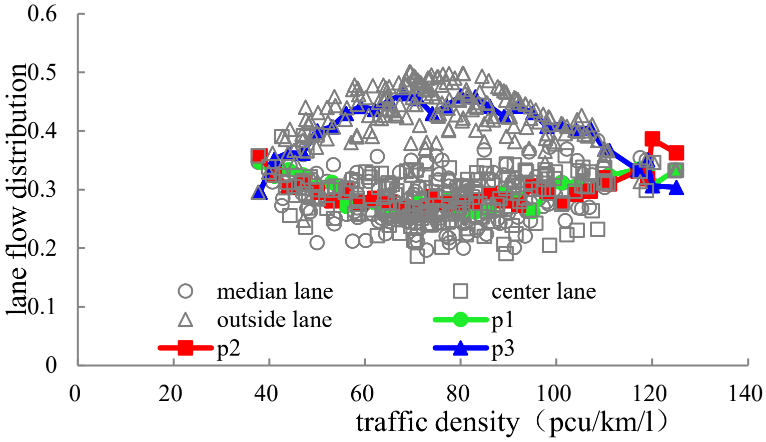


Figure 2: Lane flow distributions near upstream bus stop to exit

Figure 2 clearly shows that for the recorded average densities between 40pcu/km/lane and 110pcu/km/lane, the median and center lanes carry similar LFD, whereas the outside lane carries higher LFD rate than other two lanes do. All three lanes' traffic distribution rates converge to the average when the density reaches approximately 110veh/km.

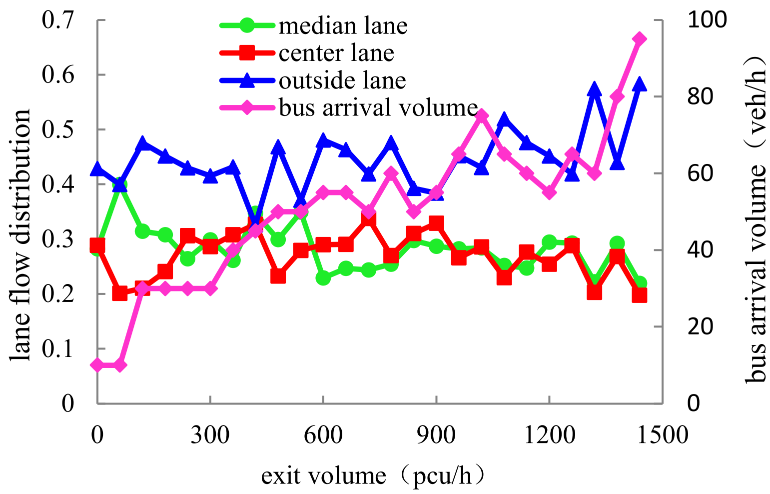


Figure 3: Relation between distribution and exit volume for upstream bus stop to exit

Although the diverging vehicles increase the lane distribution on the outside lane, its LFD decrease when the diverging percentage reaches some value. Because the outside lane becomes full of slower moving traffic as the exit struggles to cope with the higher diverging demand. The weaving interaction between diverging vehicles and buses leaving the bus stop aggravates this case, which also leads to LFD on the outside lane decreasing.

As shown in Figure 3, the LFD at the outside lane is higher than other two lanes when the exit volume and arrival bus rate increase. Based on the field observation, diverging vehicles have to depart from the mainline without other choices and bus drivers usually give way to diverging vehicles when in interweave conflicts, which leads to diverging vehicles and buses entering the stop occuping much high the LFD at the outside lane.

To estimate the relationship between LFD and its influential is done by a model with the collected data. The variables included in the model are traffic density, bus arrival rate, diverging flow. The models developed for the purpose is listed in Table2. Models are fitted well with the field data.

Table 2: Estimated models on LFD near upstream bus stop to exit

Lane	Estimated model	R^2
Median lane	$r_i = 0.467 * (\frac{K}{100})^2 - 0.736 * \frac{K}{100} - 1.569 * (\frac{q_b}{1000})^2 + 0.294 * (\frac{q_b}{1000}) + 0.013 * (\frac{q_d}{1000})^2 - 0.059 * \frac{q_d}{1000} + 0.582$	0.849
Center lane	$r_i = 0.368 * (\frac{K}{100})^2 - 0.593 * \frac{K}{100} - 0.930 * (\frac{q_b}{1000})^2 + 0.157 * (\frac{q_b}{1000}) + 0.001 * (\frac{q_d}{1000})^2 - 0.011 * \frac{q_d}{1000} + 0.515$	0.765
Outside lane	$r_i = -0.835 * (\frac{K}{100})^2 + 1.329 * \frac{K}{100} + 2.483 * (\frac{q_b}{1000})^2 - 0.448 * (\frac{q_b}{1000}) - 0.014 * (\frac{q_d}{1000})^2 + 0.070 * \frac{q_d}{1000} - 0.097$	0.927

Note: q_d=*diverging volume(pcu/min).*

Bus stop located downstream of an exit

There are no conflicts between buses entering the stop and diverging vehicles for bus stop located downstream of an exit. For safety and cooperative mechanism, vehicles on the outside lane usually switch to the center lane for giving away to buses entering the stop.

Figure 4 illustrates changes of LFD as a function of average density for a bus stop located after an exit.

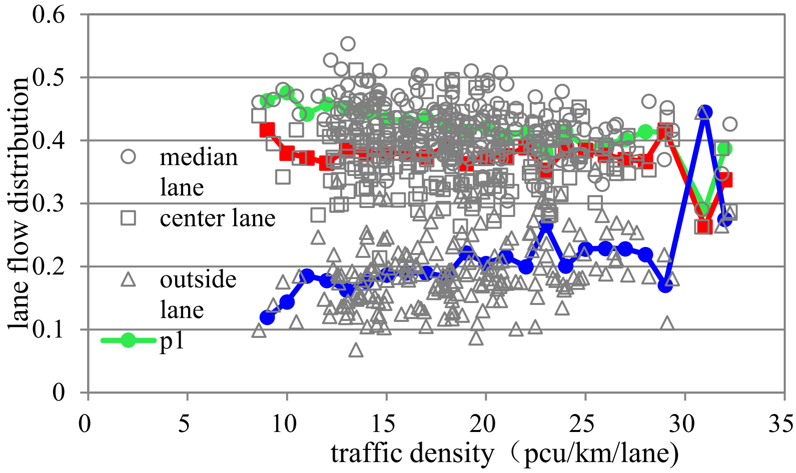


Figure 4: Lane flow distributions near downstream bus stop to exit

Figure 4 illustrates as the density increases, the traffic distribution on the outside lane increases, whereas the distributions decrease on the median and center lane. All three lanes converge to the same when the density reaches 30pcu/km/lane. The distribution on the median carries higher than other lanes. The distribution on the outside lane ranges from 10% to 22%. As the density increases, the differences between the outside lane and other lanes become narrow.

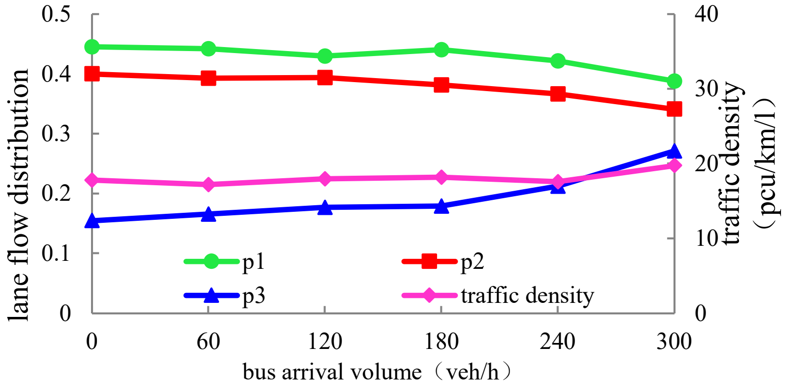


Figure 5: Relation between distribution and bus arrival rate near downstream bus stop to exit

Figure 5 shows that as the bus arrival rate increases, the distribution at the outside lane increases, whereas the median and center lane are slow down. The finding indicates the distribution at the outside lane is related to the bus arrival rate.

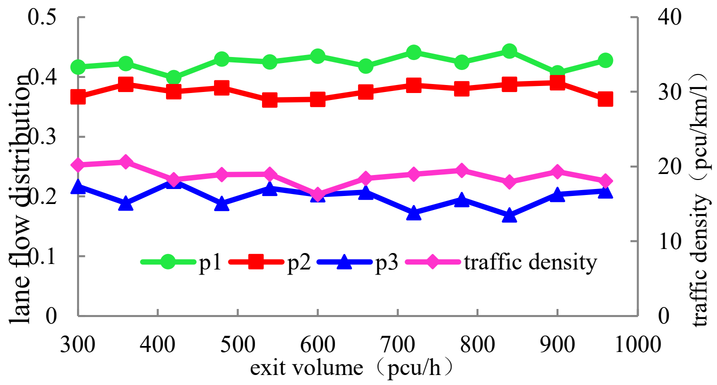


Figure 6: Relation between distribution and exit volume near downstream bus stop to exit

Figure 6 reveals as the exit volume increases, the distributions on all three lanes are no difference. The finding illustrates diverging vehicles have no effected on the distribution on lanes.

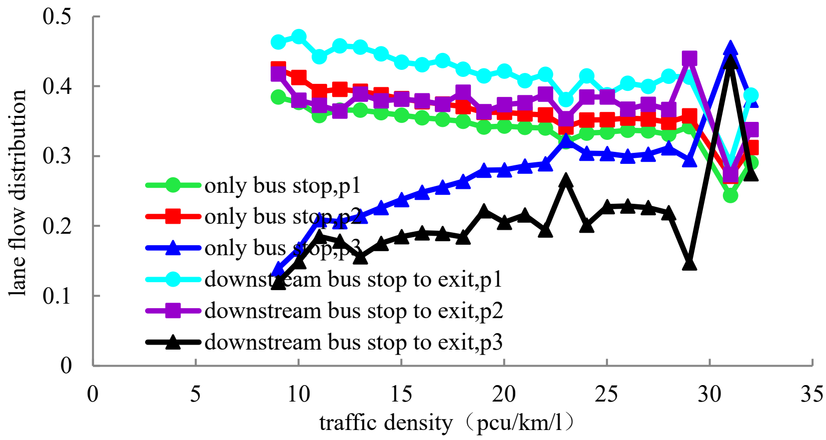


Figure 7: Comparison of lane flow distributions near bus stops with exit and without exit

To illustrate the finding from Figure 6, Figure 7 is given. Figure 7 shows that the trends of the distributions on three lanes are no difference.

To estimate the relationship between LFD and its influential is done by a model with the collected data. The variables included in the model are traffic density, bus arrival rate. The models developed for the purpose is listed in Table3. Models are fitted well with the field data.

Table 3: Estimated models on LFD near downstream bus stop to exit

Lane	Estimated model	R^2
Median lane	$r_i = 2.633*(\frac{K}{100})^2 - 1.311*\frac{K}{100} - 0.779*(\frac{q_b}{1000})^2 + 0.1227*(\frac{q_b}{1000}) + 0.557$	0.953
Center lane	$r_i = 0.606*(\frac{K}{100})^2 - 0.124*\frac{K}{100} - 0.107*(\frac{q_b}{1000})^2 - 0.259*(\frac{q_b}{1000}) + 0.429$	0.848
Outside lane	$r_i = -3.239*(\frac{K}{100})^2 + 1.435*\frac{K}{100} + 0.907*(\frac{q_b}{1000})^2 + 0.0329*(\frac{q_b}{1000}) + 0.013$	0.953

Models Verification

To verify the reliability and high portability of the developed models of LFD on four cases, date on the corresponding combination type of bus stop and exit is collected, such as FANGZHUANGQIAOXI bus stop location in the inner of the 3rd ring road, JIANGANZHUANG bus stop location in the inner of the 3rd ring road.

Figure 8 and Figure 9 give the estimated and observed results for four analysis cases, respectively. The differences between the estimated and observation average values of LFD for upstream bus stop to exit case are 6.4%, 5.2% and 4.8% respectively. The differences between the estimated and observation average values of LFD for downstream bus stop to exit case are 4.9%, 4.5% and 5.2% respectively. This shows that the proposed models can effectively reflect the traffic characteristics near a bus bay stop with an exit.

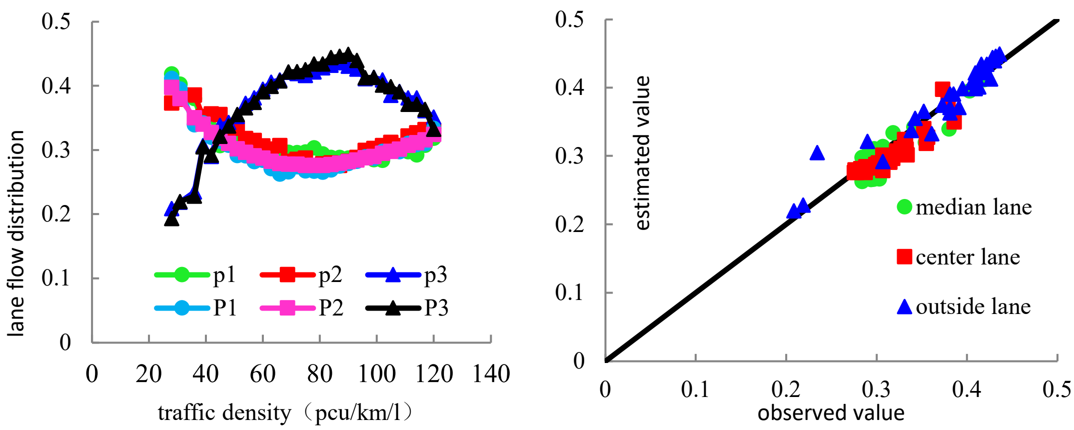


Figure 8: Validity of lane flow distribution near upstream bus stop to exit

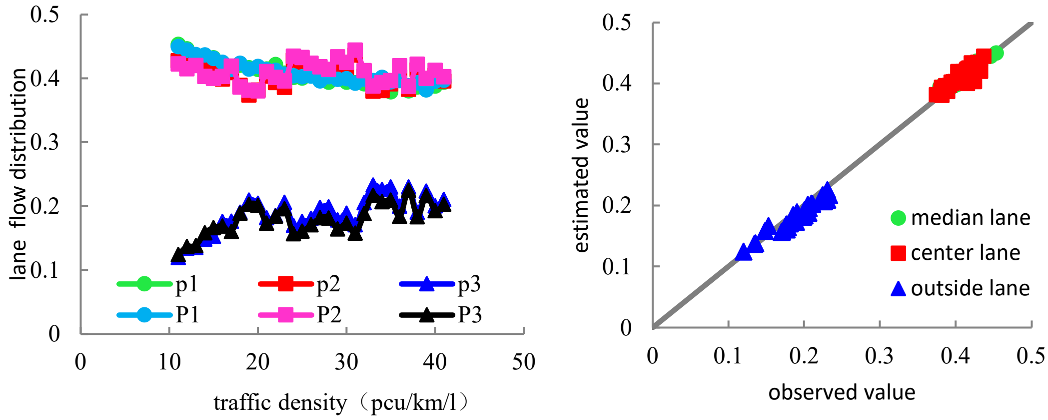


Figure 9: Validity of lane use distribution near downstream bus stop to exit on express way

Summary and Conclusions

This study investigates the combined effect of a bus stop and an exit on the LFD with the data collected from four different sites on one important expressway in Beijing. Depending on the location of a bus stop to the exit, two cases are analyzed. A series of models are developed to predict lane flow distributions as a function of several variables including bus arrival rate, traffic density, diverging volume. The developed models are fitted well with the field data.

The results show that the bus stop located to an exit has significant impact on the expressway LFD which lead to much difference between the outside lane and other lanes. The magnitude of impact depends on the configuration of bus stop and exit point (before or after). It is also closely related to traffic characteristics in terms of traffic density, bus arrival rate, diverging traffic.

Bus stop located upstream of an exit has a significant effect on the LFD. Particularly, the LFD on the outside lane increases sharply when diverging volume increases for a bus stop is located upstream of an exit, because both diverging vehicles and buses entering the stop occupy the outside lane and cause a congested area.

The proposed models could be useful in assessing lane flow distribution resulting from a buses entering and leaving the stop, vehicles diverging from the mainline. The study provides information for monitoring traffic conditions and optimizing traffic management near a bus stop close to an exit.

The results presented in this paper are guiding the future research in this area. One future work is intended to look at other expressways with varying degrees of bus arrival rate, diverging volume. The various traffic conditions (e.g., incident occurrences), environmental characteristics (e.g., weather, daylight vs. nighttime), roadway characteristics (e.g., vertical/horizontal curvature), and trip characteristics (e.g., origin/destination of trip) are already under study.

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