Hindawi
Journal of Advanced Transportation
Volume 2019, Article ID 5107327, 13 pages
https://doi.org/10.1155/2019/5107327

Research Article

Unbalanced Multiple Left Turn Lane Usage Modelling: From Individual Choice to Aggregate Volume

Li Li,[1] **Qing-Chang Lu**,[1] **Dong Zhang**,[2] **Ping Wang**,[1] **and Gui-Ping Wang**[1]

[1] *School of Electronics & Control Engineering, Chang'an University, China*
[2] *School of Transportation & Logistics, Dalian University of Technology, China*

Correspondence should be addressed to Qing-Chang Lu; qclu@chd.edu.cn

Received 6 June 2018; Revised 26 October 2018; Accepted 11 December 2018; Published 6 January 2019

Academic Editor: Rocío de Oña

Diverse lane preferences of left-turn drivers lead to unbalanced traffic distribution on multiple left-turn lanes. The preferences can be measured in terms of lane usage at macroscopic level and individual lane choice at microscopic level. The data of lane volume and individual lane choices are collected at eight dual or triple left-turn lanes equipped in signalized intersections in China. Linear regression model with dummy variables and discrete choice model were applied to analyse drivers' lane choosing patterns at macroscopic and microscopic levels, respectively, and results of the two studies are mutually verified and complemented. The drivers' lane preferences are found to vary with approach configurations, traffic control, and the number of lanes available. Static influential factors, such as turning radius inside the intersection, the design of shadowed lane, and intersection skewedness, as well as dynamic influential factors, including queue length, heavy vehicle in queue back and subject vehicle type, could affect the drivers' lane preferences. The findings of this study have important implications for intersection design and traffic control in practice.

1. Introduction

Multiple lanes serving the same direction traffic often appear at entrance approaches of urban arterial intersection. Capacity of the multilane infrastructure largely determines the approach capacity, so the operation performance of these multilane is always of traffic researchers and engineers' concern [1–3]. Underutilization is a phenomenon of unbalanced traffic distribution happened in many types of multilane infrastructures, including multiple left-turn lanes (MLTLs). The more unbalanced traffic distribution of the MLTLs is, the more its design capacity is degraded. Underutilized degree of the MLTLs' capacity can be measured in terms of some indicators. The indicator of saturation flow rate reflects the maximum traffic serving ability of an individual lane, which is the determinant of theoretical capacity of the MLTLs. The capacity is reduced to a more realistic value by an adjustment indicator of lane utilization to reflect the negative impact of unbalanced left-turn traffic distribution happened in the MLTLs on its capacity utilization [4]. But this indicator cannot tell the detailed volume proportion of each left-turn lane (LTL) with respect to the whole left-turn traffic, so the indicator of lane usages was defined and applied to meet this need [5, 6].

The calculation of abovementioned underutilization indicators counts on the data of LTL volumes; from individual perspective, the data also measure aggregate LTL choices of left-turn drivers within a given time. Owing to this connection, the drivers' LTL preferences can be inferred from the value of an indicator. If we can identify the influential factors of the value variance, it is reasonable to say that the factors also affect the drivers' LTL preferences. Proper settings of the factors can improve underutilization of the MLTLs which actually works by balancing the drivers' average LTL preferences. Some existing tools have the potential to conduct such intervene. The microscopic traffic simulation packages, SIDRA and VISSIM [7, 8], already support the design of lane-scaled timing scheme to meet specific lane traffic demand. Signal phase offset can be set lane by lane to rebalance the LTL utilizations. Such settings can get theoretical support from the lane-scaled signal timing optimization methods proposed recently. These methods integrate signal timing variables with the variables reflecting lane geometrics and lane traffic into one model and optimize them together. Wong and Heydecker found a way to optimize lane marking patterns and signal timings in simultaneously to improve the overall intersection capacity with better lane usages [9]. The method can fit for different junction geometries with asymmetrical and complex lane marking patterns. Zhao et al. proposed to open up exit lanes for left-turn traffic dynamically with the help of an additional traffic light to increases intersections capacity [10]. Other lane-scaled signal timing methods have been used to handle the travelling demand in heavily congested intersections with specific approach configurations [11, 12]. These studies have built a solid theoretical foundation for the application of lane-scaled signal timing method to improve the MLTLs underutilization. What we need to do urgently is to figure out the influential factors of LTL usages or, in other words, the factors affecting the drivers' LTL choices. Although LTL geometrics have been considered in left-turn signal plan where single LTL exists in some cases [13, 14], but the work has not been done at the MLTLs yet.

Previous studies have identified various factors probably influencing drivers' LTL preferences. Sando et al. investigated the operation performance of fifteen triple LTLs in Florida and found that inside shadowed LTL of the MLTLs could attract more drivers than outside unshadowed LTLs [5, 6]. Their study results also indicated that the different settings of geometrics of upstream approaches and intersections skewedness lead to variances of LTL saturation flows. Yu et al. found that downstream attraction sites of the MLTLs could affect drivers' LTL choices, as bus stops located at downstream of the intersection result in unbalanced traffic distribution on the upstream MLTLs [15]. Besides the static factors, some dynamic ones could affect the drivers' lane preferences at the MLTLs. Liu et al. found that the chance of a driver choosing the outside left-turn lane would increase with the queue length in the inside left-turn lane, and drivers of heavy vehicles were more likely to select outside left-turn lanes [16]. Cooner et al. found that driver's LTL choices could change with the switch of traffic signal [17]. Since there exist diverse influential factors of the drivers' LTL selections, it is not surprising to find that the rule of installation and operation of the MLTLs to improve the unbalanced left-turn traffic distribution is dependent on local circumstance [15, 18]. This application feature requires the adjustments of approach geometrics or traffic controls should be designed based on the data that can be collected easily and fast by traffic managers and engineers in field. The data of lane volumes and individual lane choices could meet this need. This is why the data are taken as the basis of this study. Note that the data cannot support the analysis of the decision-making mechanism of lane choosing drivers unless their personal characteristics are omitted.

This study conducts an empirical analysis of the influences of exogenous factors on left-turn drivers' lane preferences at the MLTLs. The main contributions of this study can be summarized as follows.

First, this study fills this research gap of underutilization of the MLTLs capacity being rarely investigated in China. The urbanization trend there started twenty years ago, and this trend is expected to continue in next decade. Unlike the cases of European or American cities, signalized intersections in big size are often seen in downtown area in China, and many of them are equipped with multiple LTLs. But their underutilization is rarely reported before. The investigation of this study provides the first-hand information of the infrastructure operation performance for roadway planners and managers in China.

The second contribution is that lane usage is used as the indicator of left-turn drivers' lane preferences in statistical model, unlike only being a descriptive statistic of multilane traffic distribution in previous studies. The connection of this indicator and the drivers' lane choices laid the realistic foundation of conducting this work.

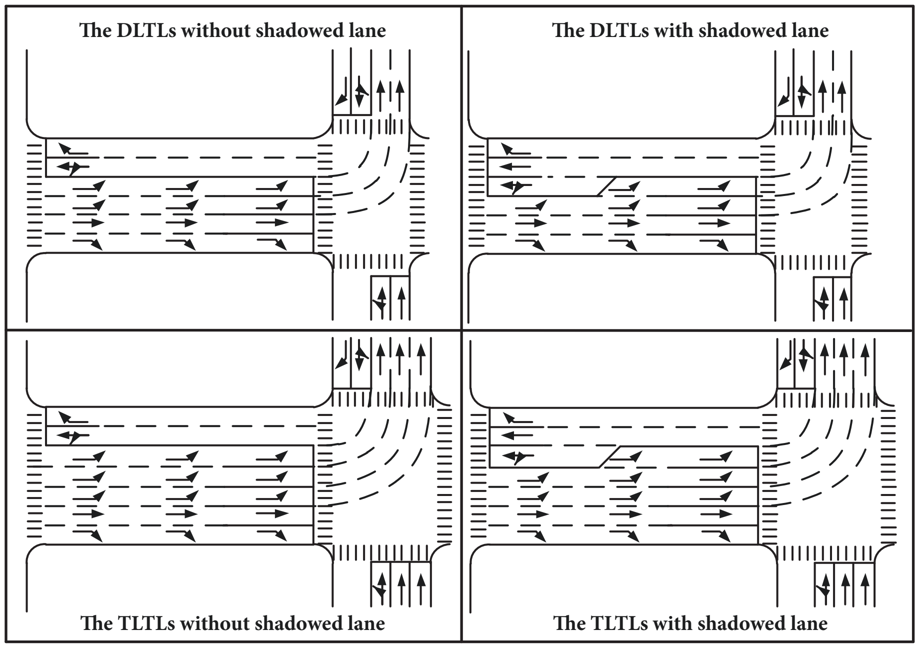
The third point is that both of static and dynamic influential factors of the drivers' LTL preferences are identified in this study. Since lane usage is calculated from the data of lane volume, its variance can be attributed to time-invariant influence of a static factor, such as roadway geometrics. Meanwhile, the drivers' lane choices could also be affected by time-variant exogenous influences. This study employs discrete choice model to capture the dynamic influences, and the investigated influencing patterns of static and dynamic factors are compared and discussed. Such comprehensive analysing approach help understand unbalanced left-turn traffic distribution on the MLTLs in a relatively complete view.

The remainder of this paper is organized as follows. Section 2 describes the scenarios considered in the study of left-turn drivers' lane preferences. The next two sections introduce statistical models and variables applied in the analysis, respectively. The data used in the model estimations are presented in Section 5. Section 6 reports the results and discusses their implications for engineering practices. Section 7 concludes major findings of this study and proposes recommendations for future work.

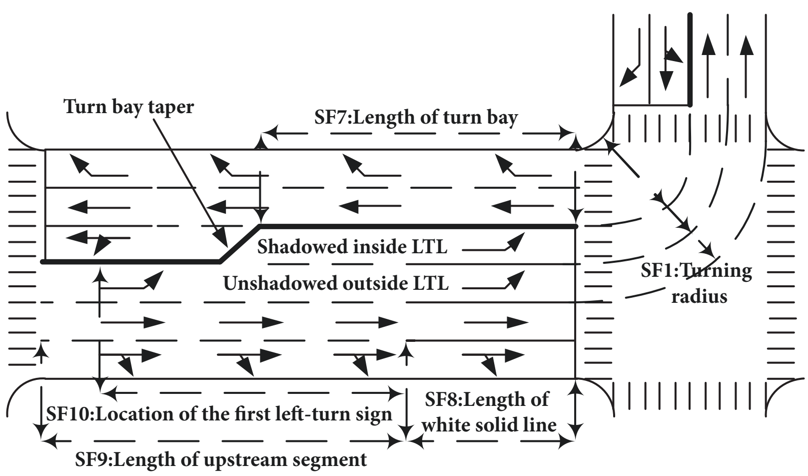
2. Study Scenarios

Triple LTLs (TLTLs) and dual LTLs (DLTLs) are two types of the MLTLs equipped at arterial intersections in China. Figure 1(a) illustrates four typical configurations of them: (1) two unshadowed LTLs; (2) one shadowed LTL and one unshadowed LTL; (3) three unshadowed LTLs; and (4) one shadowed LTL and two unshadowed LTLs. The shadowed lane (see Figure 1(b)) is set near the stop line to accommodate more left-turn vehicles. The notation of each lane within a MLTL is defined according to its location with respect to the road central line. The closest lane is inside LTL. The further and the furthest ones are median and outside LTLs.

The choice set of the left-turn drivers consists of the inside and outside LTLs at the DLTLs, or the inside, median, and outside LTLs at the TLTLs. Study scenarios listed in Table 1 are defined according to available lanes that a driver can choose. The scenarios are further divided according to traffic signal phase to investigate if the drivers' lane preferences could vary



(a)



(b)

Figure 1: (a) Typical configurations of the DLTLs and the TLTLs. (b) An example configuration of the DLTLs.

with the change of signal light. This influence is omitted in the scenario of signal cycle.

Study data are organized according to the scenarios defined in Table 1. Two lanes of the DLTLs are always available for left-turn drivers, so the data of individual LTL choices are spilt in the groups of red and green phases (scenarios 1.R and 1.G) or the one of signal cycle period (scenario 2). Similarly, the data of LTL volumes are organized according to signal phase or cycle. Lane choice scenario at the TLTLs is more complex than at the DLTLs. Crossing two lanes in one lane changing manoeuvre is strictly forbidden in China, so the outside lane of the TLTLs is unavailable for the drivers in inside LTL (scenarios 3.1.R, 3.1.G, and 4.1). Similarly, the inside LTL is unavailable for the drivers on the outside LTL (scenarios 3.2.R, 3.2.G, and 4.2). All of three LTLs are available only for the drivers on the median LTL (scenarios 3.3.R, 3.3.G, and 4.3). The drivers' lane choices collected at the three scenarios are combined into a full record and used in the analysis at scenarios 3.4.R, 3.4.G, and 4.4. The LTL volumes include all LTL choices in a given period, so the LTL volumes contain combined individual lane choices at the DLTLs (scenario 2) and the TLTLs (scenarios 3.4.R, 3.4.G, and 4.4).

3. Model

3.1. Model of Lane Usage Deviation. The volume of an LTL records its frequency being chosen by left-turn drivers in a

Table 1: Lane choosing scenarios at the DLTLs and the TLTLs.

Scenarios	Type	Available LTLs	Volume scale
1.R (red)/1.G (green)	DLTLs	Inside and outside LTL	Lane/phase
2 (cycle)	DLTLs	Inside and outside LTL	Lane/cycle
3.1.R (red)/3.1.G (green)	TLTLs	Inside and median LTL (for the drivers in inside LTL)	–
3.2.R (red)/3.2.G (green)	TLTLs	Median and outside LTL (for the drivers in outside LTL)	–
3.3.R (red)/3.3.G (green)	TLTLs	All LTLs (for the drivers in median LTL)	–
3.4.R (red)/3.4.G (green)	TLTLs	Mixture of scenario 3.1.R&3.2.R&3.3.R, or 3.1.G&3.2.G &3.3.G	Lane/phase
4.1 (cycle)	TLTLs	Inside and median LTL (for the drivers in inside LTL)	–
4.2 (cycle)	TLTLs	Median and outside LTL (for the drivers in outside LTL)	–
4.3 (cycle)	TLTLs	All LTLs (for the drivers in median LTL)	–
4.4 (cycle)	TLTLs	Mixture of scenario 4.1&4.2&4.3	Lane/cycle

given period. Its lane usage is the ratio of its volume to the total volume of the MLTLs. The usage of the ith LTL of the MLTLs, or $f_{usa\text{-}i}$, is defined as

$$f_{usa-i} = \frac{V_i}{V/N} \quad (1)$$

where V_i is the volume of the ith LTL and V/N is the average lane volume of the MLTLs. The usage of the LTL achieves its balanced state when the left-turn traffic evenly distributes on all LTLs. In that case, $f_{usa\text{-}i}$ equals 1. To measure the unbalanced degree of the lane usage of the ith LTL, its deviation to the balanced state, or $f_{dev\text{-}i}$, is calculated by $f_{usa\text{-}i}$-1. A positive $f_{dev\text{-}i}$ means that the ith LTL attracts more vehicles while the usages of other LTLs decrease correspondingly. Similarly, it is easy to understand the meaning of negative $f_{dev\text{-}i}$. The variance of $f_{dev\text{-}i}$ reflects aggregate change of left-turn drivers' preferences to the ith LTL, so the influential factors attributed to the variance can be considered to influence the drivers' LTL choices. Since the value of $f_{dev\text{-}i}$ is from LTL volumes, its variance can only result from the influences of the factors whose value are time-invariant in the volume counting period. Some of such static influential factors are selected and reported in Section 4. They will be taken as the categorical variables in statistical analysis. Hence, a linear regression model is developed to identify the significances of the variables by setting them as the dummy variables as follows:

$$f_{dev-i} = \alpha + \sum_{j}^{J} \sum_{k=1}^{K-1} \beta_{jk} d_{jk} + \sum_{l=1}^{L} \beta_l x_l + \varepsilon \quad (2)$$

where α is a constant parameter; d_{jk} is the kth dummy variable of the jth categorical factor, and β_{jk} is its coefficient; x_l is the lth influential factor, and β_l is its coefficient; J is the number of static factors, and K is the level number of each one at a study scenario; ε is the error term. To avoid multicollinearity of the dummy variables in the regression analysis, the number of dummy variables should be one less than the level number of a factor.

3.2. Model of Lane Choice. Individual driver's lane choice decision made at the MLTLs can be modelled under the framework of discrete choice model. The model can analyse the impact of a dynamic factor defined in Section 4 on a driver's lane choice. The utility of each LTL for the kth driver, or U_{ik}, assumes to be equal to the addictive influences of exogenous factors:

$$U_{ik} = \beta_i + \sum_{j=1}^{J} \theta_j x_{ijk} + \varepsilon_{ik} \quad (3)$$

where β_i is a constant parameter; θ_j is the coefficient of the jth dynamic factor x_j; J is the total number of the factors; ε_{ik} is the error term which is set to reflect the drivers' random attitudes to U_{ik}. U_{ik} is specified as $U_{inside\text{-}k}$, $U_{median\text{-}k}$, or $U_{outside\text{-}k}$ when the inside, median, or outside LTL is available for the kth driver. Assuming that a driver select the LTL with the maximum utility among the alternatives, the probability of the kth driver choosing the ith LTL rather than the oth LTL is expressed as

$$\begin{aligned} P_k(i) &= P_k(U_{ik} > U_{ok}) \\ &= P_k\left(\sum_{j=1}^{J} \theta_j x_{ijk} - \sum_{j=1}^{J} \theta_j x_{ojk} - (\beta_i - \beta_o) > \varepsilon_{ik} - \varepsilon_{ok}\right) \end{aligned} \quad (4)$$

where U_{ik} and U_{ok} are, respectively, the utility of the ith and oth LTLs for the kth driver; ε_{ik} and ε_{ok} assume to be independent identically distributed. In this study, Logit model is applied to analyse the driver's lane choosing pattern, so ε_{ik} is subject to the Gumbel distribution. The probability of the ith LTL being chosen can be calculated as

$$P_k(i) = \frac{\exp\left(\sum_{j=1}^{J} \theta_j x_{ijk}\right)}{\sum_{n=1}^{N} \exp\left(\sum_{j=1}^{J} \theta_j x_{ijk}\right)} \tag{5}$$

where N is the number of available LTLs at a scenario listed in Table 1. The model parameters can be estimated from the likelihood function:

$$L = \sum_{m=1}^{M} \sum_{i=1}^{I} \left(\sum_{j=1}^{J} \theta_j x_{ijk} - \ln \sum_{j=1}^{J} \exp\left(\sum_{j=1}^{J} \theta_j x_{ijk} \right) \right) \tag{6}$$

where M is size of the samples used in the model estimation. Binary Logit model is introduced when two LTLs are available for the drivers (scenarios 1.R, 1.G, 2, 3.1.R, 3.1.G, 3.2.R, 3.2.G, 4.1, and 4.2), while multinomial Logit model is applied when three LTLs are available (scenarios 3.3.R, 3.3.G, and 4.3). Given the assumption of independence of irrelevant alternatives (IIA), multinomial Logit model applies the mixed samples in the analysis at scenarios 3.4.R, 3.4.G, and 4.4.

4. Model Variables

Several static and dynamic factors (marked as "SF" in Table 2 and "DF" in Table 3) that probably impact the drivers' LTL preferences are selected from the driver's view. The measurements of some static factors are illustrated in Figure 1(b). Static factors are classified into three categories: the category of "turning curve", the one of "intersection approach", and the one of "vehicle type". Some of them are set to verify the effects of their dynamic counterparts. All of the factors are introduced in terms of the categories as follows.

4.1. Factor Category: "Turning Curve". Length of left-turn curve inside the intersection could influence drivers' lane preferences at the MLTLs. The inside LTL has the shortest curve, while the outside LTL has the longest one. The curve length depends on two factors: its radius and intersection skewedness. The drivers assume to rank the radius lengths of all LTLs in grade (SF1), as their values are hard to accurately measure in driving state. Since the grade of the curve of an LTL is invariant for a driver choosing the lane, the influence of SF1 on the driver's decisions cannot be identified in the disaggregate analysis. This is why SF1 is omitted in Table 3. When the legs of an intersection are not perpendicular with each other, the skewed configuration (SF2/DF1) aggregates length difference of the turning curves of any two LTLs.

4.2. Factor Category: "Intersection Approach". This category contains the factors that reflect available spatial or temporal resource for left-turn vehicles. Length of signal cycle (SF3) determines the number of the vehicles arriving to the intersection and leaving from there in cycle period. Lengths of red phase (SF4) and green phase (SF5) regulate accumulating and discharging periods of the vehicles. The two factors are related to queue length of each LTL, so their impacts on the left-turn drivers in each LTL are considered in the disaggregate analysis. The impact of queue length difference of any two LTLs (DF5-DF7) on the drivers' decisions is taken into account as well.

Shadowed LTL stores less queued vehicles than the unshadowed one (SF6) in the period of red phase. The storing capacity depends on the length of turn bay (SF7). The probability of shadowed LTL being chosen by a driver determines how the increased capacity provided by the lane is utilized. Its influence on left-turn drivers' decisions is captured by the factors of DF8-DF10 in the disaggregate analysis. The shadowed LTL is only available when the drivers arrive at the lane taper (DF11, see Figure 1(b)). Only drivers in the outside lane of the DLTLs or the ones in the median lane of the TLTLs are able to choose the shadowed LTL if it is not fully occupied by queued vehicles.

Similar to shadowed LTL, other factors that are related to the left-turn drivers' lane changing opportunities are also selected to test their influences on the drivers' decisions. The paralleled white solid lines marked on intersection approach pavement (see Figure 1(b)) are forbidden to cross in China, so the influence of the line length (SF8) on drivers' lane choices should be investigated. In addition, previous studies [7, 10] found that balanced distributed left-turn traffic is easier to see at the intersection approach with a long upstream segment (SF9), as a driver has more space to change to his or her target LTL, or at least to move closer to it. So SF9 could affect the LTL usages. The left-turn sign set at upstream section of the MLTLs could impact drivers' lane choice in a similar way as SF9. The earlier the driver notices the sign, the earlier he or she can make lane choice decision. Hence, the factor of the first left-turn sign located at upstream of the MLTLs (SF10) is selected as a potential influential factor.

4.3. Factor Category: "Vehicle Type". A heavy vehicle occupies more space of a lane than a passenger car. The heavy vehicle has been counted equivalently as the passenger cars in the LTL volume, but its impact on drivers' LTL choices cannot be reflected by the equivalent count. The heavy vehicle accelerates slower than the passenger car does. Its big size could block the following drivers' vision, so it could be repelled by the driver. The impact of leading heavy vehicles on LTL usages is captured by the factor of SF11 that refers to the proportion of heavy vehicles in phase or cycle LTL volume. This impact is reflected by the factors of DF12-DF14 in the disaggregate analysis of individual lane choices. In addition, the more the heavy vehicles in the LTL queue, the slower the discharging speed of the left-turn traffic. Hence, the number of the heavy vehicles on each LTL (DF15-DF17) or the numerical difference of the heavy vehicles on any two LTLs (DF18-DF20) could affect the drivers' decisions. Finally, the heavy vehicle differs from the passenger car in vehicle size and kinematic, so their drivers' decision logics could be different. The heavy vehicle driver could prefer a large turning radius. This concern is captured by DF21 in the disaggregate analysis.

Table 2: Static influential factors of the LTL usage.

No.	Category	Name	Unit/Measurement
SF1	Turning curve	Turning radius	At the DLTLs: 0=inside LTL, 1=outside LTL. At the TLTLs: 0=inside LTL, 1=median LTL, 2=outside LTL.
SF2		Skewedness	0=no, 1=yes.
SF3	Intersection approach	Length of signal cycle	Second.
SF4		Length of red phase	Second.
SF5		Length of green phase	Second.
SF6		Lane type	0=unshadowed, 1=shadowed.
SF7		Length of turn bay	Meter; measured from the stop line to the end of shadowed LTL, or 0 if no LTL is shadowed.
SF8		Length of white solid line	Meter; measured from the stop line to the beginning of white solid line.
SF9		Length of upstream segment	Meter; measured from the beginning of white solid line to the upstream intersection.
SF10		Location of the first left-turn sign	Meter; measured from the stop line to the first left-turn sign at upstream.
SF11	Vehicle type	Proportion of heavy vehicle	Proportion of heavy vehicle number in the each LTL volume.

Table 3: Dynamic influential factors of individual LTL choices.

No.	Category	Name	Unit/Measurement
DF1	Turning curve	Skewedness	0=no, 1=yes.
DF2	Intersection approach	Queue length in inside LTL	Vehicle number; measured at the DLTLs/TLTLs.
DF3		Queue length in median LTL	Vehicle number; measured at the TLTLs.
DF4		Queue length in outside LTL	Vehicle number; measured at the DLTLs/TLTLs.
DF5		Queue length difference in inside and median LTLs	Vehicle number; queue length in median lane minus that in inside lane at the TLTLs.
DF6		Queue length difference in median and outside LTLs	Vehicle number; queue length in median lane minus that in outside lane at the TLTLs.
DF7		Queue length difference in inside and outside LTLs	Vehicle number; queue length in outside lane minus that in inside lane at the DLTLs.
DF8		Lane type of inside LTL	0=unshadowed, 1=shadowed.
DF9		Lane type of median LTL	0=unshadowed, 1=shadowed.
DF10		Lane type of outside LTL	0=unshadowed, 1=shadowed.
DF11		Available of shadowed LTL	0=no, 1=yes.
DF12	Vehicle type	Vehicle type at queue back in inside LTL	0=passenger car, 1=heavy vehicle; measured at the DLTLs/TLTLs;
DF13		Vehicle type at queue back in median LTL	0=passenger car, 1=heavy vehicle; measured at the TLTLs;
DF14		Vehicle type at queue back in outside LTL	0=passenger car, 1=heavy vehicle; measured at the DLTLs/TLTLs;
DF15		Number of heavy vehicles in inside LTL	Vehicle number; measured at the DLTLs/TLTLs.
DF16		Number of heavy vehicles in median LTL	Vehicle number; measured at the TLTLs.
DF17		Number of heavy vehicles in outside LTL	Vehicle number; measured at the DLTLs/TLTLs.
DF18		Number difference of heavy vehicles in inside and outside LTLs	Vehicle number; number of heavy vehicle in outside lane minus that in inside lane at the DLTLs.
DF19		Number difference of heavy vehicles in median and inside LTLs	Vehicle number; number of heavy vehicle in median lane minus that in inside lane at the TLTLs.
DF20		Number difference of heavy vehicles in median and outside LTLs	Vehicle number; number of heavy vehicle in median lane minus that in outside lane at the TLTLs.
DF21		Subject vehicle type	0=Passenger car; 1=Heavy vehicle.

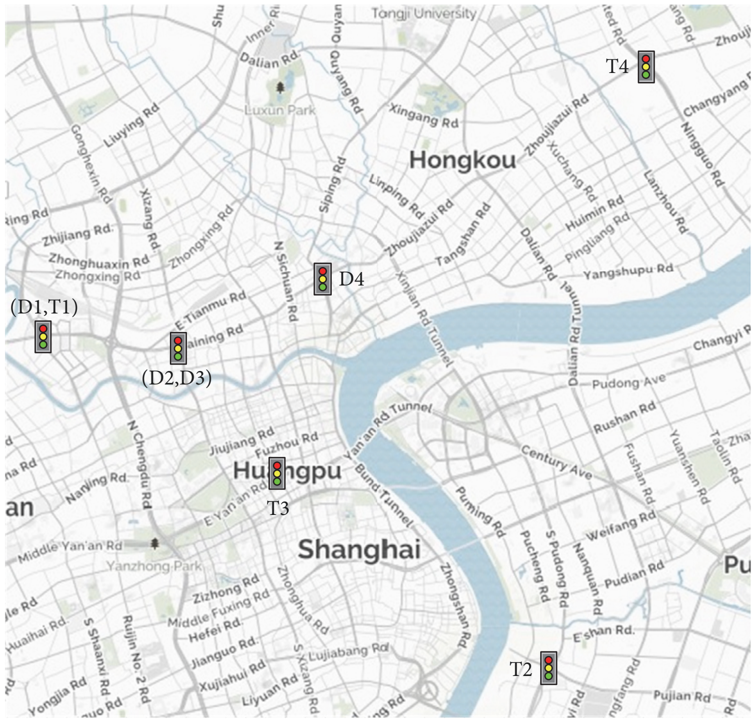


FIGURE 2: Locations of study sites.

5. Data Collection

Eight MLTLs, including four DLTLs and four TLTLs, located at six signalized intersections in Shanghai, China, are selected as the study sites. Their locations are illustrated in Figure 2. Their conditions are reported in Table 4. Left-turn traffic is controlled by exclusive signal phases in fixed timing lengths at each site. The traffic is recorded with digital video cameras, and the LTL volumes and individual drivers' LTL choices are extracted from the videos. The volume in each phase is counted, and then the collected data are aggregated into cycle-scale volumes. The data of individual lane choices at different study scenarios are processed in a similar way. To ensure the indicator of lane usage being able to reflect the drivers' average LTL preferences, only the period during which more than eight vehicles arrive at an LTL is taken as a qualified period to count the vehicle number. A vehicle is counted in the volume when it arrives at the back of a queue, as drivers' lane choice decision is assumed to be made at the instant of arrival. If no queue exists, the vehicle is counted in when it passes the stop line. According to the design code of urban road in China, a heavy vehicle is equivalent to two passenger car units in the volume data.

Table 4 reports the average LTL volumes measured at each site, and unbalanced traffic distribution on the MLTLs can be clearly identified. Table 5 lists the measurements of static factors at each site. SF2, SF6, and SF11 are the binary variables, while the other ones are the ordinal categorical variables. The grades of each factor are set according to the rules that (1) the interval between two levels of SF3-SF5 is more than 10 seconds or (2) the gap of two levels of SF7-SF10 is over 10 meters. Their grades are marked as "(1)", "(2)", "(3)", and "(4)" in the table.

6. Results and Discussion

The statistical software *Stata* is used to identify the factors that could influence the LTL usage or individual LTL choices at 95% confidence level. Null hypothesis is that no factor has significant influence. Testing results of the hypothesis are reported in Table 6. It is found that the hypothesis is only accepted in the analysis of the drivers' lane choices at scenarios 3.2.G and 3.3.G. At the scenarios when the hypothesis is rejected, the estimated unstandardized coefficients of the significant factors are reported in Tables 7 and 8 by the factor category defined in Tables 2 and 3. The coefficients of significant static and dynamic factors belonging to the same factor category are listed in the column of "LUD" and "LC", respectively. The remainder of this section introduces the interpretation of results and then discusses the analysis results of the variance of the LTL usage deviation and individual lane choices at the MLTLs.

6.1. The Way of Result Interpretation. Each static influential factor is modelled as a categorical independent variable of the regression model in (2). The first level of the factor is taken as the regression base when estimating the higher level influences of the factor on the dependent variable $f_{dev\text{-}i}$. The dummy variable regarding the first level of the factor is omitted from (2), and the coefficients of other dummy variables referring to the higher level influences are

Table 4: Study site locations and the data of collected LTL volumes.

Type	Site	Average volume of each LTL (vph)			Average volume of all LTLs
		Inside LTL	Median LTL	Outside LTL	
DLTLs	D1: EB Tianmu Western Rd. at Hengfeng Rd.	211	–	242	227
	D2: WB Haining Rd. at Xizang Northern Rd.	208	–	230	219
	D3: NB Xizang Northern Rd. at Haining Rd.	207	–	212	209
	D4: WB Haining Rd. at Wusong Rd.	342	–	330	336
TLTLs	T1: SB Hengfeng Rd. at Tianmu Western Rd.	240	279	263	261
	T2: EB Pujian Rd. at Pudong Sourthern Rd.	387	344	268	333
	T3: EB Yan'an Rd. at Shimen First Rd.	327	332	305	321
	T4: WB Zhoujia Zui Rd. at Inner Ring Line	173	235	224	211

Note: EB: eastbound; NB: northbound; SB: southbound; WB: westbound; vph: vehicles per hour per lane.

Table 5: Values of static influential factors at the study sites.

Site	Configurations	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10
D1	4SL+2LTL	Yes	220s (3)	190s (2)	30s (2)	No	59m (3)	0m (1)	158m (2)	95m (2)
D2	3SL+2LTL+1RL	No	210s (2)	193s (2)	17s (1)	Yes	48m (2)	91m (3)	107m (1)	77m (1)
D3	2SL+2LTL	No	200s (1)	164s (1)	36s (2)	No	34m (1)	0m (1)	123m (1)	108m (3)
D4	3SL+2LTL	No	260s (4)	205s (3)	55s (3)	Yes	38m (1)	70m (2)	289m (3)	200m (4)
T1	2SL+3LTL+1RTL	Yes	219s (2)	183s (2)	36s (1)	Yes	30m (1)	66m (2)	142m (1)	94m (1)
T2	1SL+3LTL+1RTL	No	104s (1)	76s (1)	28s (1)	No	27m (1)	0m (1)	172m (2)	157m (2)
T3	1SL+3LTL+1RTL	No	242s (4)	194s (3)	48s (2)	No	25m (1)	0m (1)	195m (3)	180m (3)
T4	3SL+3LTL+1RTL	Yes	230s (3)	184s (2)	46s (2)	Yes	30m (1)	148m (3)	300m (4)	200m (3)

Note: SL: straight lane; RTL: right-turn lane; m: meters; s: seconds; "- -": null.

Table 6: Testing results.

Scenarios	Result of the aggregate analysis				Results of analysis to the disaggregate analysis				
	Obs.	F	Sig.	Reject null?	Obs.	L.L.	Prob..>chi^2	Pseudo R^2	Reject null?
1.R	424	12.87	<0.001	Yes	994	-633.57	<0.001	0.38	Yes
1.G	310	2.80	<0.05	Yes	256	-115.7	<0.001	0.31	Yes
2	424	12.59	<0.001	Yes	1250	-796.31	<0.001	0.38	Yes
3.1.R					209	-101.25	<0.001	0.44	Yes
3.1.G					105	-47.58	0.04	0.21	Yes
3.2.R					457	-287.46	<0.001	0.37	Yes
3.2.G					138	-77.28	0.56	0.13	No
3.3.R					408	-337.97	<0.001	0.35	Yes
3.3.G					220	-81.12	0.13	0.07	No
3.4.R	504	13.35	<0.001	Yes	1074	-651.85	<0.001	0.30	Yes
3.4.G	348	10.32	<0.001	Yes	463	-229.31	<0.001	0.37	Yes
4.1					314	-153.59	<0.001	0.33	Yes
4.2					595	-375.51	<0.001	0.47	Yes
4.3					628	-435.58	<0.001	0.32	Yes
4.4	506	19.89	<0.001	Yes	1537	-866.11	<0.001	0.31	Yes

Note: Obs.: number of observations; Sig.: significance of F; L.L.: log likelihood.

Table 7: Factor coefficients at the DLTLs scenarios.

Dependent variable	LUD	LC	LUD	LC		LUD	LC
category	Turning curve		Intersection approach			Vehicle type	
Coefficient at scenario 1.R	**<u>SF1(2)</u>**		SF6(2)	**<u>DF2</u>**	DF8	SF11	DF12
	<u>0.11</u>		0.09	**<u>-0.51</u>**	0.14	0.19	-0.84
			SF7(2)	DF4			DF15
			0.11	0.38			-2.45
Coefficient at scenario 1.G			SF6(2)	DF2	DF8	SF11	DF12
			-0.15	-1.12	1.75	0.16	-3.59
			SF7(3)	DF4			
			-0.17	1.19			
Coefficient at scenario 2			SF3(4)				DF12
			0.05				-0.64

Note: LUD: lane usage deviation; LC: lane choice.

estimated by comparing with the first level influence. Only the coefficients of significant dummy variables are reported in Tables 7 and 8. The positive coefficient in the "LUD" column of the tables means that the upgraded level of a static factor could aggravate the lane usage deviation and vice versa.

Here the coefficient of turning radius (SF1) obtained at scenario 1.R (red phase at the DLTLs) is taken as an example (bolded and underlined in Table 7). The second level of SF1, indicated as SF1(2) in the table, refers to the turning radius of the outside LTL of the DLTLs. The positive coefficient of SF1, 0.11, indicates that the lane usage of the outside LTL is higher than that of the inside LTL; in other words, the outside LTL could attract more left-turn drivers owing to its larger turning radius.

Similar to the analysis of the influence of a static factor on the LTL usages, the analysis of the dynamic factor influences on individual LTL choices needs a regression base as well when calculating the probability of a driver choosing another LTL rather than base one. The base refers to a specific LTL among the DLTLs or the TLTLs.

The outside LTL is selected as the base choice at the DLTLs scenarios, so the interpretation of the estimated coefficient of a significant dynamic factor listed in "LC" column of Table 7 should follow this setting. The positive coefficient indicates that increasing the value of a dynamic influential factor could reduce the chosen probability of the outside LTL of the DLTLs and vice versa. For example, the coefficient of DF7 (queue length of inside LTL) obtained at the scenario 1.R is -0.51 (bolded and underlined in Table 7). Since the value of DF7 is measured in vehicle number, the "-0.51" means that one additional vehicle appearing in inside LTL ahead of a driver in red phase could decrease the probability of being chosen by a driver at [1-exp(-0.51)], or 40% probability.

At the TLTLs scenarios, the median LTL is selected as the base choice. The chosen probabilities of the outside and inside LTLs are calculated by comparing their utilities with the median lane. When a dynamic influential factor performs significant influence on the probabilities of the inside LTL or the outside LTL being chosen by a driver, it is marked by the suffix "i" or "o" associated with the factor code in Table 8. Take the coefficient of DF1 (intersection skewedness) obtained at scenario 3.1.R for example (bolded and underlined in Table 8). "DF1i=-1.98" indicates that the skewed intersection could decrease the probability of the inside LTL being chosen with respect to the median LTL. Similarly, "DF1o=-0.64" at scenario 3.2.R means that the intersection skewedness could decrease the chosen probability of the outside LTL. The outflows of the inside and outside LTLs switch to the median LTL.

6.2. The Results Obtained at the DLTLs Scenarios. This section will interpret the influences of static and dynamic factors on the lane usage deviation and left-turn drivers' lane choices at the DLTLs scenarios in factor categories according to the results reported in Table 7.

6.2.1. Factor Category: "Turning Curve". LTL Usage Deviation (LUD). The large turning radius of outside LTL with respect to that of inside LTL could increase the lane usage deviation of the DLTLs in red phase ("SF1(2): 0.11" at scenario 1.R). Left-turn drivers would prefer the longer turning curve of outside LTL when they have to wait in queue, as the lane favours their vehicle acceleration after traffic signal light turns from red to green. But this pattern is not found in green phase or cycle period.

6.2.2. Factor Category: "Intersection Approach". LTL Usage Deviation (LUD). The length of red or green phase does not affect lane usage deviation of the DLTLs. Only the length of signal cycle demonstrates significant influence at the highest level ("SF3(4): 0.05" at scenario 2). This result means that traffic signal rarely affects the lane usages unless the total DLTLs demand achieves a relative high amount. Moreover, the design of shadowed LTL could be effective at both red and green phases in an opposite direction yet ("SF6(2): 0.09" at scenario 1.R, "SF6(2): -0.15" at scenario 1.G). Extending turn bay length could increase the lane usage deviation in red phase ("SF7(2): 0.11" at scenario 1.R) while reversely reducing it in green phase ("SF7(3): -0.17" at scenario 1.G). The influence of turn bay length is observed at its high level in green phase (the third level of SF7 at scenario 1.G) and the low level in red phase (the second level of SF7 at scenario

Table 8: Factor coefficients at the TLTLs scenarios.

Dependent variable	LUD	LC				LUD	LC						LUD	LC			
Category		Turning curve					Intersection approach							Vehicle type			
Scenarios	3.4.R	3.1.R	3.2.R	3.3.R	3.4.R	3.4.R	3.1.R	3.2.R	3.3.R	3.4.R	3.4.R	3.4.R	3.4.R	3.1.R	3.2.R	3.3.R	3.4.R
Coefficient	SF1(2) -0.10 SF1(3) -0.21 SF2(2) 0.08	**DF1i** **-1.98**	**DF1o** **-0.64**	DF1i 0.96		SF6(2) -0.27	DF2i -0.36	DF3o 0.25 DF4o -0.20	DF2i -0.34 DF3o 0.45 DF4o -0.52	DF2i -1.05 DF2o -0.30 DF3i 1.05	DF4i -0.22 DF6i -0.33 DF8o -1.31	DF11o -1.10			DF14o -0.75 DF21o 1.28	DF16o 0.79 DF17o -1.00 DF21o 1.40	DF14o -0.61 DF21i -0.85 DF21o 1.16
Scenarios	3.4.G	3.1.G	3.2.G	3.3.G	3.4.G	3.4.G	3.1.G	3.2.G	3.3.G	3.4.G	3.4.G		3.4.G	3.1.G	3.2.G	3.3.G	3.4.G
Coefficient						SF6(2) -0.31 SF9(3) 0.11				DF5i 1.36 DF5o -0.32	DF6o 0.61 DF6i -0.56		SF11 0.34	DF16i 2.16			
Scenarios	4.4	4.1	4.2	4.3	4.4	4.4	4.1	4.2	4.3	4.4	4.4	4.4	4.4	4.1	4.2	4.3	4.4
Coefficient	SF1(2) -0.08 SF1(3) -0.21 SF2(2) 0.09	DF1i -1.76	DF1o -0.57	DF1i 0.90		SF6(2) -0.29	DF2i -0.29	DF3o 0.23 DF4o -0.20	DF2i -0.30 DF3i 0.19 DF3o 0.46 DF4o -0.41	DF2i -0.70 DF2o -0.19 DF3i 0.65	DF4i -0.17 DF5i 0.96 DF6i -0.36	DF8o -1.61 DF11o -1.32		DF13i 0.71	DF14o -0.78 DF21o 1.29	DF21o 1.42	DF13o -0.99 DF14o -0.66 DF21i -0.84 DF21o 1.31

Note: LUD: LTL usage deviation; LC: LTL choice.

1.R). This indicates that the drivers' LTL preferences could be more easily affected by shadowed lane in red phase than green phase.

LTL Choice (LC). The influence of shadowed LTL on the drivers' LTL preferences is found in both red and green phases ("DF8: 0.14" at scenario 1.R; "DF8=1.75" at scenario 1.G). Besides, queue length also affects their lane choices. If the queue length in inside LTL increases, it is not surprising to find the drivers switch to outside LTL and vice versa ("DF2: -0.51", "DF4: 0.38" at scenario 1.R; "DF2: -1.12", "DF4: 1.19" at scenario 1.G).

6.2.3. Factor Category: "Vehicle Type". LTL Usage Deviation (LUD). Increase of proportion of heavy vehicle in a LTL volume could enlarge the lane usage deviation in red and green phases ("SF11: 0.19" at scenario 1.R; "SF11: 0.16" at scenario 1.G), but such influence does not exist in signal cycle period (scenario 2).

LTL Choice (LC). The influence of heavy vehicle on individual lane choice is also observed. Heavy vehicle at queue back in inside LTL ("DF12: -0.84" at scenario 1.R; "DF12: -3.59" at scenario 1.G; "DF12: -0.64" at scenario 2) could reduce the drivers' intention to choose. The reduction is the most obvious in green phase, as the limited accelerating ability of heavy vehicle slows down the discharging flow speed in this period. The more the heavy vehicles appear in a lane, the lower discharging flow speed is. This can explain why more heavy vehicles in inside LTL in red phase could induce the drivers' reluctance of choosing ("DF15: -2.45" at scenario 1.R).

6.3. The Results Obtained at the TLTLs Scenarios. This section will interpret analysis results of the variances of lane usage deviation and left-turn drivers' lane choices at the DLTLs scenarios are listed in Table 8.

6.3.1. Factor Category: "Turning Curve". LTL Usage Deviation (LUD). The increase of turning radius could decrease lane usage deviation of the TLTLs in both red phase and cycle period ("SF1(2): -0.10", "SF1(3): -0.21" at scenario 3.4.R; "SF1(2): -0.08", "SF1(3): -0.21" at scenario 4.4). Intersection skewedness also presents its negative influence on the balance of LTL usages in the two periods ("SF2(2): 0.08" at scenario 3.4.R; "SF2(2): 0.09" at scenario 4.4).

LTL Choice (LC). The skewedness could increase the probability of median LTL being chosen by individual drivers in red phase and circle period when only two LTLs are available ("DF1i: -1.98" at scenario 3.1.R; "DF1o: -0.64" at scenario 3.2.R; "DF1i: -1.76" at scenario 4.1; "DF1o: -0.57" at scenario 4.2). But the probability would decrease when all LTLs are available ("DF1i: 0.96" at scenario 3.3.R; "DF1i: 0.90" at scenario 4.3). This indicates that the drivers' lane preferences could vary with the number of alternative lanes they can choose under exogenous influences.

6.3.2. Factor Category: "Intersection Approach". LTL Usage Deviation (LUD). The design of shadowed lane always decreases LTL usage deviation in all periods ("SF6(2): -0.27" at scenario 3.4.R; "SF6(2): -0.31" at scenario 3.4.G; "SF6(2): -0.29" at scenario 4.4). Since the length of turn bay has no obvious difference at all study sites (only one level of SF7 at the lower part of Table 4), its influence on the usage deviation is not considered in the analysis. In addition, if upstream segment of the TLTLs is too long, LTL usage deviation would increase in green phase ("SF9(3): 0.11" at scenario 3.4.G). The particular significance of this factor in green phase implies that its influence only appears at the TLTLs when drivers have enough freedom, i.e., right of way or all three alternatives, to choose target lanes.

LTL Choice (LC). The function of shadowed lane in balancing lane usage at the TLTLs is supported by the results of disaggregate analysis. Shadowed inside LTL could decrease the chosen probability of outside LTL indirectly ("DF8o: -1.31", "DF11o: -1.10" at scenario 3.4.R; "DF8o: -1.61", "DF11o: -1.32" at scenario 4.4). The probability of median LTL being chosen could increase correspondingly. In addition, more queued vehicles in inside or outside LTL could increase the probability of median LTL being chosen in red phase and circle period ("DF2i: -0.36" at scenario 3.1.R; "DF2i: -0.34" at scenario 3.3.R; "DF2i: -1.05", "DF2o: -0.30" at scenario 3.4.R; "DF2i: -0.29" at scenario 4.1; "DF2i: -0.30" at scenario 4.2; "DF2i: -0.70", "DF2o: -0.19" at scenario 4.4). The driver's repulsion of increased queue length is also found in red phase and cycle period ("DF3o: 0.25", "DF4o: -0.20" at scenario 3.2.R; "DF3o: 0.45", "DF4o: -0.52" at scenario 3.3.R; "DF3i: 1.05", "DF4i: -0.22" at scenario 3.4.R; "DF3o: 0.23", "DF4o: -0.20" at scenario 4.2; "DF3i: 0.19", "DF3o: 0.46", "DF4o: -0.41" at scenario 4.3; "DF3i: 0.65", "DF4i: -0.17" at scenario 4.4). Although the influence of queue length is not observed in green phase, length difference of the queues in two LTLs could still affect the drivers' lane choices in this period ("DF6i: -0.56", "DF6o: 0.61" at scenario 3.4.G). Similar influence also exists in red phase and cycle period ("DF6i: -0.33" at scenario 3.4.R; "DF5i: 0.96", "DF6i: -0.36" at scenario 4.4).

6.3.3. Factor Category: "Vehicle Type". LTL Usage Deviation (LUD). Result shows that a large ratio of heavy vehicles with LTL volume in green phase could increase lane usage deviation of the TLTLs ("SF11: 0.34" at scenario 3.4.G). But such influence is not observed in red phase or cycle period (scenarios 3.4.R and 4.4).

LTL Choice (LC). Left-turn driver's lane preference could vary with vehicle type. The heavy vehicle driver prefers outside or median LTL ("DF21o: 1.28" at scenario 3.2.R; "DF21o: 1.40" at scenario 3.3.R; "DF21o: 1.16" at scenario 3.4.R; "DF21o: 1.29" at scenario 4.2; "DF21o: 1.42" at scenario 4.3; "DF21i: -0.84", "DF21o: 1.31" at scenario 4.4). Besides, the heavy vehicle at queue back in a LTL impels the follower to switch to other lanes ("DF14o: -0.75" at scenario 3.2.R; "DF14o: -0.61" at scenario 3.4.R; "DF13i: 0.71" at scenario 4.1; "DF14o: -0.78" at scenario 4.1; "DF13o: -0.99", "DF14o: -0.66" at scenario 4.4). An interesting finding is that the number of heavy vehicles ahead performs opposite influences on LTL usage deviation and the drivers' LTL choices. DF16 has significant influence on LTL choices in red phase and cycle period ("DF16o: 0.79", "DF17o: -1.00" at scenario 3.3.R; "DF16i: 2.16" at scenario 3.1.G), yet when its related factor (SF11) is not significant for LTL usage deviation. But the effect of DF16 on LTL choices turns out be insignificant at the scenario when its related factor is significant ("SF11: 0.34" at scenario 3.1.G). The opposite influences could be attributed to the equivalent treatment of heavy vehicle to passage cars in volume counting. This treatment cannot reflect the drivers' attitudes toward heavy vehicle, so it results in the opposite results.

6.4. Comparison of the Results Obtained at the DLTLs and the TLTLs Scenarios. The analysis results of lane choosing scenarios at the DLTLs and the TLTLs are compared as follows to explore the influence of a factor on the left-turn drivers' lane preferences at the two infrastructures.

6.4.1. Factor Category: "Turning Curve". The influences of turning radius on lane usage deviation are different at the DLTLs and the TLTLs. The deviation decreases from inside LTL to outside LTL at the TLTLs ("SF1(2): -0.10", "SF1(3): -0.21" at scenario 3.4.R; "SF1(2): -0.08", "SF1(3): -0.21" at scenario 4.4 in Table 8). This is opposite to its increasing trend at the DLTLs ("SF1(2): 0.11" at scenario 1.R in Table 7). Maybe one more lane of the TLTLs than the DLTLs makes it easier to deal with diverse left-turn demands, instead of letting the drivers make either-or choice between the two alternatives at the DLTLs. Intersection skewedness only affects LTL usage deviation and individual LTL choices at the TLTLs. This design decreases the possibility of inside or outside LTL being chosen when two lanes of the TLTLs are available (scenarios 3.1.R, 3.2.R, 4.1, and 4.2 in Table 8), but it increases the chosen possibility of inside LTL when all lanes are available (scenarios 3.3.R and 4.3). At the other two scenarios, 3.4.R and 4.4, the insignificance of this factor could be caused by the mixed data samples collected at the two scenarios. Another finding is that the length of turning curve (SF1 and SF2) never performs significant influence in green phase at the DLTLs and the TLTLs. Probably the slight advantage obtained from the variance of the length is unattractive for the drivers when they can pass the intersection in a short time. This makes the influences of other factors more possibly affect the drivers' decisions.

6.4.2. Factor Category: "Intersection Approach". The influence of shadowed LTL on lane usage deviation in red phase is different at the DLTLs and the TLTLs. This design could increase the usage deviation of shadowed inside lane at the DLTLs ("SF6(2): 0.09" at scenario 1.R in Table 7) and decrease the one at the TLTLs ("SF6(2): -0.27" at scenario 3.4.R in Table 8) in red phase. This pattern is verified by the disaggregate analysis results ("DF8: 0.14" at scenario 1.R in Table 7; "DF8: -1.31" at scenario 1.G in Table 8). But SF6 has similar influence on lane usage deviation at the DLTLs and the TLTLs in green phase ("SF6(2): -0.15" at scenario 1.G in Table 7; "SF6(2): -0.31" at scenario 3.4.G in Table 8). The opposite influences imply that when the drivers have more lane choosing freedom in green phase at the DLTLs or in red or green phase at the TLTLs, their preferences of specific lane could be weakened with the appearance of shadowed LTL, while the preferences could be enhanced when the freedom is limited in red phase at the DLTLs. As for the dynamic incentive, the drivers' responses of the variance of queue length (DF2-DF4) are similar at the DLTLs and the TLTLs scenarios, but the variance of queue length difference (DF5-DF7) is only effective at the TLTLs. The queue-related incentives are easier to be observed and would have more direct influences on the drivers' decisions, which can infer from the larger absolute values of their coefficients than those of other factors. From a general point of view, the number of the factors in the category of "intersection approach" that significantly affect individual lane choices are more in red phase than that in green phase. This condition is also found in the category of "vehicle type". Hence, it is reasonable to indicate that the drivers' lane preferences could switch with the change of signal light.

6.4.3. Factor Category: "Vehicle Type". Increased proportion of heavy vehicles in LTL volume could increase lane usage deviation at the DLTLs and TLTLs (SF11 at scenarios 1.R, 1.G, and 3.4.G). The insignificance of SF11 in red phase at the TLTLs could attribute to less average heavy vehicle in each lane of the TLTLs than those in the DLTLs. The details of heavy vehicle influence on the drivers' lane choices could be obtained from the disaggregate analysis. The heavy vehicle at queue back of an LTL could weaken the drivers' intention to choose this lane at nearly all scenarios. Besides, heavy vehicle drivers' preferences to the outside or median LTL are only found at the TLTLs (DF21 at scenarios 3.4.R and 4.4 in Table 8). Maybe the DLTLs have fewer alternatives than that of the TLTLs for the drivers to choose, which depresses the drivers' lane preferences.

7. Conclusions

This study conducts an empirical analysis of the unbalanced traffic distribution in the MLTLs. Some static and dynamic factors influencing the MLTLs utilization are selected from left-turn drivers' view and their significances are identified based on the data of LTL volumes and individual lane choices. The drivers' LTL preferences can be inferred from the study results. The influences of some static factors on LTL usage can be verified by the disaggregate analysis results of individual lane choices. Based on the identified factors and their influences on the drivers' decisions, it is able to design some customized countermeasures to improve unbalanced traffic distribution at the MLTLs in practice by adjusting the drivers' lane preferences [19, 20].

This study can be improved from the following aspects in future. First, besides the MLTLs, unbalanced traffic distribution also usually appears at other multilane infrastructure, such as multiple right-turn lanes or auxiliary through lane at intersection, and similar study like this one can also be conducted. The comparison of the analysis results of the underutilization conditions at these multilane infrastructures can improve the understandings of the drivers' lane choice behaviours at various circumstances. Second, LTL usage deviations are taken as dependent variable of aggregate analysis indistinctively. Hence, the significant influential factors of the deviations that are identified in the analysis cannot interpret the strict trade-off relationship among the deviations. However, such relationship indeed exists, as increase of one lane usage definitely decreases the sum of other lane usages. The authors expect an aggregate "Logit-like" model to analyse the strict trade-off of LTL usages.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

No potential conflicts of interest were reported by the authors.

Acknowledgments

This work was supported by the National Key Research and Development Program of China (Grant no. 2018YFB0105104), the National Natural Science Foundation of China (Grants nos. 51505037 and 71701031), the Key Research and Development Program of Shaanxi Province (Gr-ants nos. 2018ZDCXL-GY-05-04 and 2018ZDCXL-GY-05-07-02), and the Fundamental Research Funds for the Central Universities (Grants nos. 300102328401, 300102328205, and 300102328501).

References

[1] J. Bie, H. K. Lo, and S. C. Wong, "Capacity evaluation of multi-lane traffic roundabout," *Journal of Advanced Transportation*, vol. 44, no. 4, pp. 245–255, 2010.

[2] S. Xie and H. Jiang, "Increasing the capacity of signalized intersections by allocating exit lanes to turning movements," *Journal of Advanced Transportation*, vol. 50, no. 8, pp. 2239–2265, 2016.

[3] C. Chai and Y. D. Wong, "Traffic performance of shared lanes at signalized intersections based on cellular automata modeling," *Journal of Advanced Transportation*, vol. 48, no. 8, pp. 1051–1065, 2014.

[4] *Highway Capacity Manual*, Transportation Research Board, the National Academies, Transportation Research Board, Washington, D.C., U.S, 2010.

[5] T. Sando and R. N. Mussa, "Site characteristics affecting operation of triple left-turn lanes," *Transportation Research Record*, vol. 1852, pp. 55–62, 2003.

[6] T. Sando and R. Moses, "Influence of intersection geometrics on the operation of triple left-turn lanes," *Journal of Transportation Engineering*, vol. 135, no. 5, pp. 253–259, 2009.

[7] *Akcelik and Associates Pty Ltd, SIDRA INTERSECTION User Guide for Version 6*, 2014.

[8] AG. PTV, "VISSIM 5," *30-05 User Manual*, 2011.

[9] C. K. Wong and B. G. Heydecker, "Optimal allocation of turns to lanes at an isolated signal-controlled junction," *Transportation Research Part B: Methodological*, vol. 45, no. 4, pp. 667–681, 2011.

[10] J. Zhao, W. Ma, H. M. Zhang, and X. Yang, "Increasing the capacity of signalized intersections with dynamic use of exit lanes for left-turn traffic," *Transportation Research Record*, no. 2355, pp. 49–59, 2013.

[11] Y. Zhou and H. Zhuang, "The optimization of lane assignment and signal timing at the tandem intersection with pre-signal," *Journal of Advanced Transportation*, vol. 48, no. 4, pp. 362–376, 2014.

[12] J. Zhao, Y. Liu, and T. Wang, "Increasing Signalized Intersection Capacity with Unconventional Use of Special Width Approach Lanes," *Computer-Aided Civil and Infrastructure Engineering*, vol. 31, no. 10, pp. 794–810, 2016.

[13] S. Kikuchi and N. Kronprasert, "Determining lengths of left-turn lanes at signalized intersections under different left-turn signal schemes," *Transportation Research Record*, no. 2195, pp. 70–81, 2010.

[14] J. Yang and H. Zhou, "Integrating left-turn lane geometric design with signal timing," *Journal of Transportation Engineering*, vol. 137, no. 11, pp. 767–774, 2011.

[15] L. Yu, Y. Qi, M. Azimi, L. Guo, and C. Guo, *Left-turn lane design and operation*, Department of Transportation Studies, Texas Southern University, Houston, 2007.

[16] P. Liu, C. Xu, W. Wang, and J. Wan, "Identifying factors affecting drivers' selection of unconventional outside left-turn lanes at signallised intersections," *IET Intelligent Transport Systems*, vol. 7, no. 4, pp. 396–403, 2013.

[17] S. Cooner, S. Ranft, Y. Rathod et al., *Development of guidelines for triple left and dual right-turn lanes*, College Station, Texas: Texas Transportation Institute, Texas, 2011.

[18] Federal Highway Administration, *Manual on uniform traffic control devices (MUTCD) for streets and highways*, Washington, D.C., U.S.: Federal Highway Administration, U.S. Department of Transportation, 2009.

[19] R. Yao, "Sensitivity analysis of optimization models for isolated intersections with short left-turn lanes on approaches," *Journal of Advanced Transportation*, vol. 47, no. 1, pp. 28–42, 2013.

[20] Y. Liu and C. K. Wong, "Refining lane-based traffic signal settings to satisfy spatial lane length requirements," *Journal of Advanced Transportation*, vol. 2017, Article ID 8167530, 2017.