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Research Article

Analysis on Lane Capacity for Expressway Toll Station Using Toll Data

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Toll stations are bottlenecks in the traffic flow of expressways, and the evaluation of their capacity is essential for the operation of the expressway. Traditional capacity studies are mostly based on theoretical modelling of traffic engineering or simulation, with a focus on parameter tuning and idealized hypotheses, resulting in poor reliability. In view of the coexistence of electronic toll collection lanes and compound toll collection lanes at toll stations of expressways in China, the present study analyses the capacity of entrance and exit lanes of toll stations under mixed traffic conditions using a real toll data-driven approach. Firstly, the service time of a single vehicle during the saturation period was taken as the starting point for the capacity estimates. Secondly, the variation in service time for multiple categories of vehicles is modelled using lognormal distribution. Finally, the capacity of the two types of toll lanes at the designated toll station is determined. The important outcome of this study is the calculation of authentic capacity at the toll stations and the discussion of individual special toll lanes. Accordingly, it contributes to the development of appropriate policies to manage the operation of the toll plaza effectively.

1. Introduction

As the junction point between the expressway and ordinary roadway, the operation of the toll station has a significant effect on the traffic network [1–3]. Toll stations can act as traffic network bottlenecks due to various reasons, such as the complex layout of toll station plazas, increased traffic during peak hours, vehicle slowdown through the tollbooths, and so on [4]. This leads to lower utilization of road resources as well as more energy consumption and greenhouse gas emissions [5]. Consequently, improving the traffic efficiency and service level of toll stations is instrumental in the operation of expressways.

The establishment of the electronic toll collection (ETC) system, as it effectively eases traffic congestion and improves toll station capacity, has been a dominant trend in China [6–8]. While vigorously promoting the application of ETC, a small number of compound toll lanes, i.e., compound lanes of ETC system and manual toll collection (MTC) system, are retained in toll stations [9, 10]. With the coexistence of two kinds of toll lanes becoming the main construction form of expressway toll stations in China, its capacity analysis has been a hot topic for research.

Before the ETC system was installed on the expressway, toll data were lacking, and theoretical modelling of traffic engineering and simulation were the main research means for this issue [11–13]. However, these methods suffer from some drawbacks, such as over-idealized assumptions and focus on microscopic parameter tuning. The reliability of the analysis results is less than data-driven methods. Motivated by this, a method for estimating the toll station lane capacity by modelling the service time distribution is proposed, which is based on real toll data to avoid over-idealistic hypotheses. In general, the main contributions of this paper are listed as follows. (1) We consider the study of single-vehicle service time during the saturation period as the breakthrough point for the capacity estimation problem and use a lognormal function to fit the statistical distribution of service time to obtain estimates of capacity. (2) In order to calculate the capacity of toll station lane-wise more precisely, the proposal considers the conditions of mixed traffic and the coexistence of two toll lanes at the toll station.

This article is structured as follows. Section 2 describes the traditional studies on toll station capacity in detail, whose drawbacks are pointed out. Section 3 presents the methodology for estimating lane-wise capacity at toll stations. Section 4 shows the service time distribution under mixed traffic flow according to the proposed method and calculates the capacity of the target toll station. Section 5 gives the conclusion and future work.

2. Literature Review

In this section, studies related to toll station capacity are discussed, mainly including theoretical modelling of traffic engineering and simulation [14].

Toll stations are a typical queuing service system [15], and many scholars use the queuing theory and car-following theory to model the process of vehicles passing through toll booths. Daniel and Krishnamoorthy [16] first considered the single-server queuing model to estimate toll station capacity, assuming that interarrival times satisfy general distribution and service times satisfy exponential distribution. Obviously, this is not how vehicles queue at a toll plaza because toll plazas are not single-queue systems. Komada and Nagatani [17] studied the relationship between traffic density and queue length at multi-lane toll booths. Chinese scholars tend to adopt the M/G/1 queuing model and M/G/K model, which are more suitable for the actual situation in China, to analyse the capacity of toll stations [14]. Deng and Wu [18] were the first to investigate toll station capacity using the M/G/1 model. Unlike the M/M/1 model, this work treats the service time as a normal distribution. In the case of congested toll plazas, vehicles are generally unable to change lanes after entering the queuing system. Therefore, the toll plaza is simplified into a multiple M/G/1 model for analysis. Wang et al. [19] established the lane work-schedule prediction model based on M/G/K queuing theory, combined with the particle swarm optimization (PSO) algorithm and the long short-term memory model (LSTM). Luo and Ma [20] studied the capacity of ETC and MTC lanes in composite toll stations. Specifically, this work determines the ETC lane capacity considering the car-following theory and braking process and calculates the MTC lane capacity using the M/G/K queue theory model. These queuing models require pre-assumptions about performance measure equations and the necessary components used in queuing theory such as statistical distribution of vehicle arrival and service times at the toll stations, choice process of vehicle entry into a queue like "join the shortest queue," and number of toll station lanes etc. [15]. A change in one parameter in any of the proposed models may result in a significant change in performance measurement results. Considering those limitations, the mathematical models may not always be reliable [21, 22].

Microscopic traffic simulation has come to the fore with the increasing capability of nowadays computers modelling the complex dynamics of traffic flow [23]. Van Dijk et al. [24] first proposed to combine queuing and simulation for the design of a toll plaza. By engaging in simulations early in the design phase of an infrastructure project, capacity characteristics can be determined and pitfalls can be avoided. With the development and application of the ETC system, a large number of mixed toll stations with MTC lanes ETC lanes have emerged. Liu et al. [25] analysed the traffic flow characteristics of MTC lanes and ETC lanes and established a simulation model with the field survey data and parameter calibration. This work provides a reference for the capacity of mixed toll stations with the different percentages of ETC vehicles. In order to obtain a more fine-grained toll station capacity, Wang et al. [26] conducted a simulation study on the lane-level capacity based on Vissim and analysed the impact of different toll collection methods on the capacity. Regrettably, the work did not investigate the ETC lane capacity. Zhang et al. [27] Focused on the efficiency of different ETC lane allocations in a toll station. This work investigated different ETC lane allocation schemes using microsimulation methods, with Hangzhou arterial toll collection station selected as an example. The simulation results show that a particular number of ETC lanes can determine the maximum capacity of the whole station and that assigning ETC lanes to the middle of the station gives better results. The flexibility of simulation tools allows the investigation of many aspects relevant to transportation systems analysis. This comes at the cost of complexity [28]. In this review, two major issues associated with the simulators are highlighted. The first is the difficulty of embedding complex simulation tools in the optimization framework. The simulation must be considered as a detailed analysis of the distribution of complex random variables. The second is that simulation tools are commonly used for infrastructure design and station configuration. The degree of confidence is questionable regarding the calibration of capacity standards.

The above research studies are based on model-driven methods, and the accuracy of the results is not as precise as data-driven methods. With the large-scale establishment of ETC systems on expressways and the improvement of MTC capability, the generated toll records provide rich data for the capacity study [29]. Inspired by the literature [30], this work estimates the capacity of toll lanes by analysing the statistical distribution of vehicle service time during saturation period. The proposed method is based on real toll data, avoiding idealized assumptions and complex multi-objective modelling. Moreover, different toll stations can be modelled uniformly without calibration of parameters for specific scenarios, which extends the application scope of the proposal. This is the biggest difference from the existing research.

3. Methodology

3.1. Preliminary. For the present study, the real toll data were derived from Fujian Provincial Expressway Information Technology Co. Ltd. Each toll station is located and

Table 1: The details of the selected toll station.

No. of toll station	Name of toll station	City	Number of lane	Date
6706	Xiangqian Station	Fuzhou	13	6/1/2021 to 6/5/2021 (Tuesday to Saturday)
3501	Xiang'an Station	Xiamen	10	
3304	Chidian Station	Quanzhou	11	
6705	Fuzhou South Station	Fuzhou	10	

planned differently, and its traffic composition and vehicle driving preferences vary widely. Therefore, the capacity should be analysed separately for the designated toll stations. Four representative toll stations were selected for the study. These toll stations have high traffic flow and are often congested during peak hours. The details of the selected toll station are provided in Table 1.

Process the toll data of each vehicle as a multi-tuple $D = (s, l, \Lambda, t, c, \Gamma)$, where s is the number of the toll station, l and $\Lambda = \{e, m\}$ are the number and type of lane, respectively, t is the time when the vehicle is tolled, c is the category of the vehicle, and $\Gamma = \{E, M\}$ is the toll type for passing vehicles. Furthermore, e denotes ETC lane, m denotes ETC/MTC compound lane, E indicates ETC toll, and M indicates MTC toll.

Group the toll data according to s, l, and t, and each group is a collection of toll records of the subject lane at a particular toll station within a time period. Sort the collection by t, and calculate the interval time t_s of each toll data of the subject lane by

$$t_{si} = t_i - t_{i-1}, \quad (1)$$

where t_i and t_{i-1} are tolling moments of the ith and $i-1$th data of the lane, respectively, and t_{si} is the interval time of them.

t_s is calculated by subtracting the toll time of the leading vehicle from the toll time of the vehicle behind and has the following characteristics [31]. (1) When the toll station lane is not saturated, t_s can be divided into two parts. The first part is the time required to pay the toll by the vehicle and is defined as the service time (MTC requires payment manually). The second part is the vehicle-free time for the previous vehicle to leave the toll station and wait for the next vehicle to arrive. (2) When the toll station lane is saturated, it is considered to serve two vehicles continuously. t_s does not consist of vehicle-free time and is single-vehicle service time.

3.2. Combination and Conversion of Vehicle Categories. Toll station lane capacity is defined as the maximum passenger car equivalent (PCE) served per unit time in the subject lane [32]. Traffic at toll stations is lane-based but mixed in nature, and hence the priority is to determine the proportional share of vehicle category in the subject lane. According to Vehicle Classification of the Toll for Highway [33], the traffic composition of different types of vehicles at the toll stations for 5 days is shown in Figure 1.

Over-classification can reduce the sample size of each type of vehicle and affect the results. As can be observed from the figure, passenger vehicle I and goods vehicle I account for a large share of the total, which can be analysed separately. The proportion of II or above vehicles is less than 12% and exerts little effect on capacity, which can be combined for analysis. Besides, to assess the different types of vehicles on a common basis, a mixed vehicle traffic stream is converted to an equivalent traffic stream composed exclusively of passenger cars or basic vehicles by referring to the provisions in the Technical Standard of Highway Engineering [34]. The conversion factors of vehicles are shown in Table 2.

3.3. Saturation Period Determination and Capacity Calculation. In this study, representative high-traffic toll stations are selected as research objects, and historical records show that congestion occurs in both ETC lanes ETC/MTC compound lanes. Therefore, there are saturation periods in the sample data, and it can be inferred that the high-volume lanes are in saturation during peak hours. However, scholars have found that the layout of lanes has a significant impact on their capacity. The capacity of the lane is reduced with the location away from the centre of the toll plaza, and thus the capacity of the saturation period should be calculated separately for each lane.

The present study aggregates all real toll data of toll station lanes to calculate the lane saturation period, and the specific steps are as follows. For the designated lane: (1) the traffic flow of the lane is counted for every 5-minute count period and the volume set $\{V\}$ is generated; (2) the historical data show that the peak flow of the designated toll station accounts for 15% of the whole day, determining the saturation periods as 15% in $\{V\}$; (3) extract the set $\{V_s\}$ that exceed the 85th-percentile in $\{V\}$ and consider that 5-minute periods in $\{V_s\}$ are the saturation periods of the lane. The capacity during these periods is a representative value of the lane capacity.

Extract t_s of each toll data in $\{V_s\}$ as a sample of the single-vehicle service time during the saturation period and add it to the set $\{T_s\}$ that is further used to investigate the distribution of service time. The literature [30] indicates that lognormal distribution fits the best relative to the other distributions in terms of the service time distribution for each vehicle class. Therefore, the service time of different vehicle types is modelled using lognormal distribution in this work. The probability density function (PDF) of the lognormal distribution is shown in

$$f_{T_s}(t_s; \mu, \sigma) = \frac{1}{t_s \sigma \sqrt{2\pi}} \exp\left(-\frac{(\ln t_s - \mu)^2}{2\sigma^2}\right), \quad t_s, \mu, \sigma \geq 0, \quad (2)$$

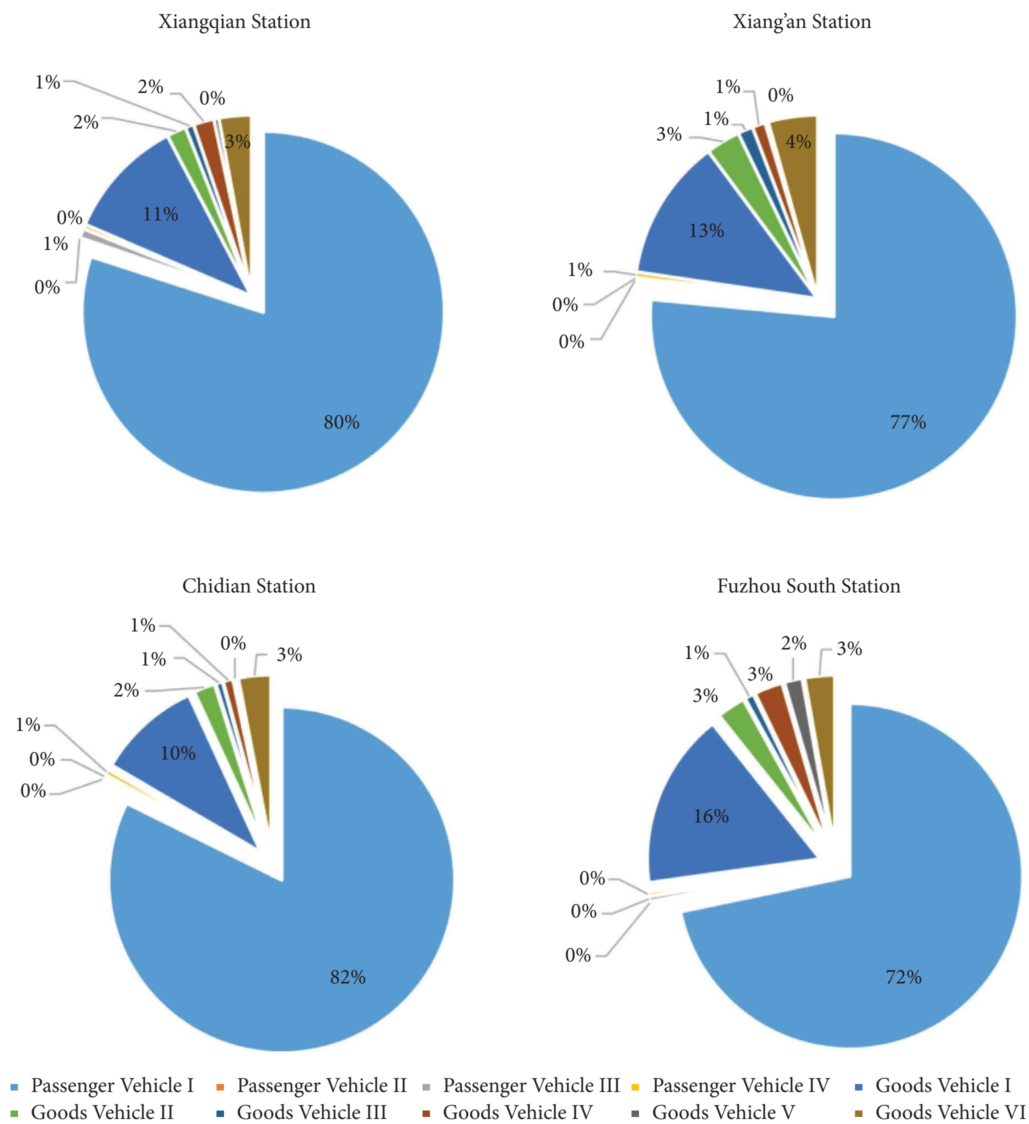

FIGURE 1: The proportion of vehicle types at toll stations.

TABLE 2: PCE for different types of vehicles.

	Vehicle types	PCE
Passenger vehicle	I	1
	II	1.5
	III	2
	IV	2
Goods vehicle	I	1
	II	1
	III	2.5
	IV	3
	V	3
	VI	3

where f_{T_s} is a continuous probability distribution of t_s, t_s is the sample of service time in $\{T_s\}$, μ is the location parameter (and is also the mean of the natural logarithm of t_s), and σ is the shape parameter. According to the fitted parameter μ for service time, the saturation capacity of the designated lane can be calculated by

$$T = \frac{3600}{\exp(\mu)} \times \sum_{c=1}^{C} P_c \times \alpha_c, \quad (3)$$

where T is the saturation capacity of the designated lane, P_c is the ratio of the category c vehicle volume to the total volume in the lane, and α_c is the conversion factor of the vehicle.

4. Experiments and Analysis

4.1. Service Time Analysis in ETC Entrance Lanes. A scatter plot of the time intervals of all passing vehicles in ETC lane $1^{\#}$ at No. 6706 toll station is observed in Figure 2. According to the proposed method, the set $\{T_s\}_e$ of service time during the saturation period of this lane is generated and its probability distribution is analysed. Figure 3 depicts the

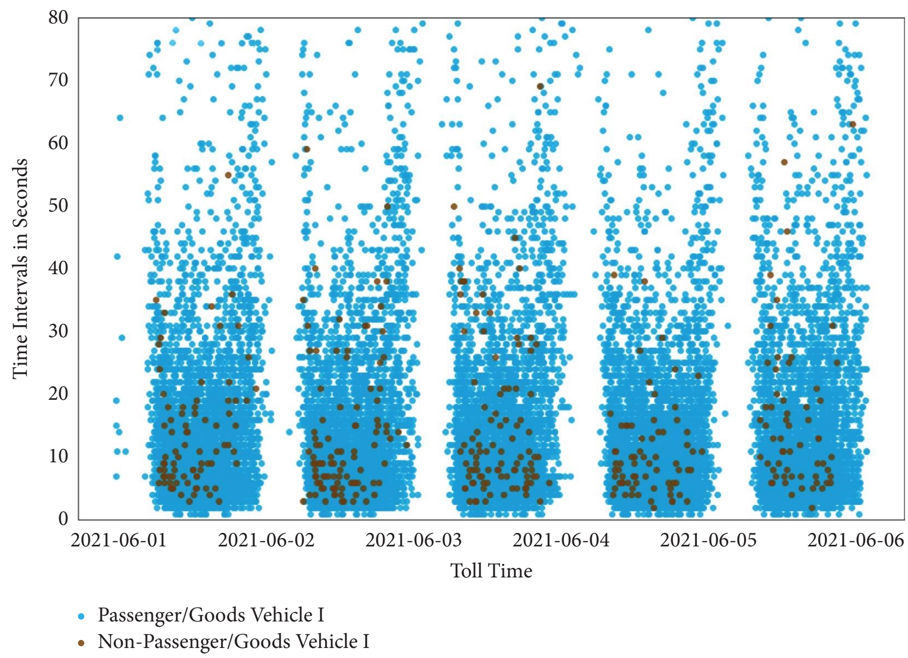

Figure 2: Scattergrams of time intervals of ETC entrance lane 1# at No. 6706 toll station.

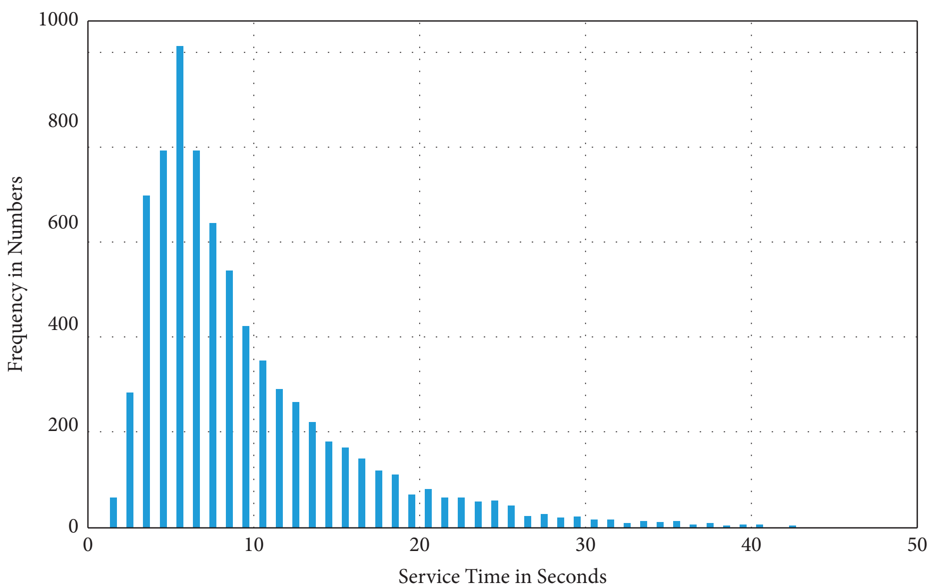

Figure 3: Frequent distribution of service time of lane 1# during the saturation period.

frequent distribution of set $\{T_s\}_e$, which shows an overall right-skewed distribution and is concentrated in the interval [3 s, 7 s].

Given the mixed traffic conditions and lane locations at toll stations, the distribution of service time for different vehicle categories in different lanes is further analysed. The fitting distribution of service time for different lanes and different vehicle types is provided in Figures 4 and 5. The necessity of analysing the distribution of service time for different lanes and different vehicle categories separately was supported by these. Table 3 shows the estimated parameters μ for service time distribution at different lanes and for varied traffic compositions.

As shown in Table 3, the high proportion of passenger/goods vehicle I has a great impact on the level of service of the ETC entrance lanes because these vehicles' fitting

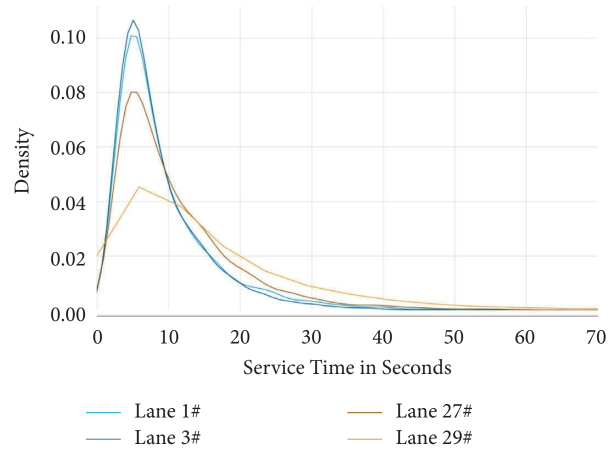

FIGURE 4: Density plot of service time variation for different ETC entrance lanes at No. 6706 toll station.

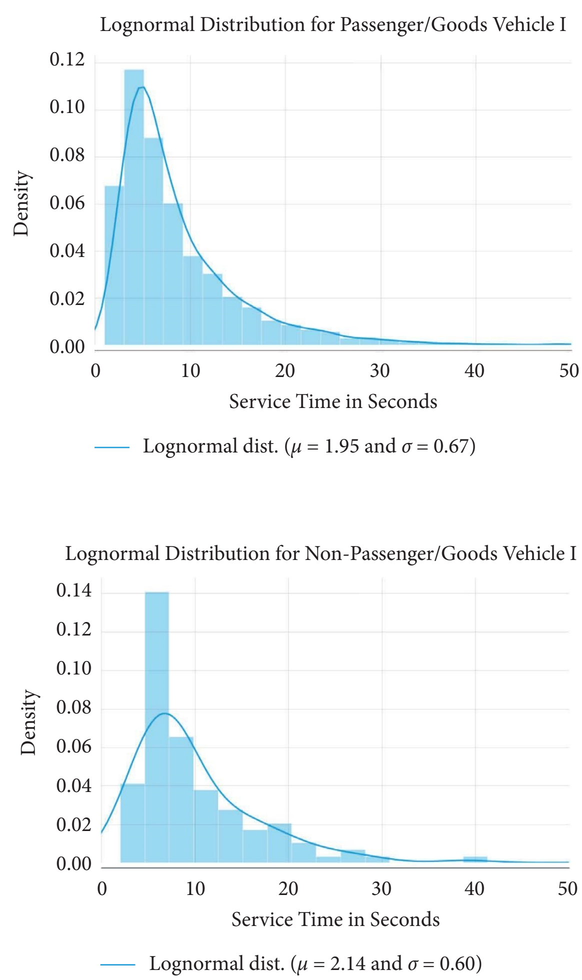

FIGURE 5: Lognormal distribution for different vehicle classes of lane $1^{\#}$.

parameters of the service time distribution are closer to the mixed traffic. Moreover, μ_{I} is smaller than $\mu_{\mathrm{Non-I}}$, which indicates that the larger size of the vehicle results in longer service time.

4.2. Service Time Analysis in ETC Exit Lanes. The same approach is utilized to analyse the service time of ETC exit lanes, and the fitting parameters are given in Table 4.

Table 3: Fitting parameters for the lognormal distribution of service time when ETC entrances of toll stations are saturated.

No. of toll station	No. of lane	Sample size (veh)	ETC type I		ETC type non-I		μ
			Proportion (%)	μ_{I}	Proportion (%)	μ_{Non-I}	
6706	1#	6534	98.30	1.95	1.70	2.14	1.95
	3#	7197	97.60	1.89	2.40	2.05	1.90
	27#	5562	97.18	2.07	2.82	2.26	2.08
	29#	4468	96.42	2.23	3.58	2.38	2.23
3304	1#	5967	98.59	1.86	1.41	2.11	1.86
	3#	6816	98.62	1.82	1.38	2.14	1.83
	5#	4497	97.80	1.97	2.20	2.07	1.97
3501	3#	4567	99.26	2.06	0.74	2.22	2.06
	5#	6531	99.13	1.92	0.87	2.01	1.93
	7#	6858	98.88	1.85	1.12	2.15	1.85
6705	1#	7160	98.55	1.89	1.45	2.03	1.89
	3#	5619	97.47	1.96	2.53	2.09	1.97

μ denotes fitting parameters in traffic mix for the lane; μ_I denotes fitting parameters in passenger/goods vehicle I; μ_{Non-I} denotes fitting parameters in passenger/goods vehicle non-I.

Table 4: Fitting parameters for the lognormal distribution of service time when ETC exits of toll stations are saturated.

No. of toll station	No. of lane	Sample size (veh)	ETC type I		ETC type non-I		μ
			Proportion (%)	μ_{I}	Proportion (%)	μ_{Non-I}	
6706	2#	7258	97.96	1.77	2.09	2.03	1.78
	4#	7683	96.13	1.79	3.87	2.07	1.80
	28#	4971	91.41	2.08	8.59	2.37	2.10
	30#	3594	87.73	2.38	12.27	2.55	2.40
3304	2#	4580	96.59	2.06	3.41	2.35	2.07
	4#	5776	95.88	2.11	4.12	2.52	2.12
	6#	5842	94.25	2.09	5.75	2.44	2.11
	8#	4439	95.02	2.24	4.98	2.62	2.26
3501	2#	5322	97.11	2.00	2.89	2.44	2.02
	4#	5067	93.96	2.23	6.04	2.56	2.25
	6#	3753	91.29	2.33	8.71	2.63	2.36
6705	2#	6283	92.84	1.94	7.16	2.05	1.95
	4#	6741	88.90	1.96	11.10	2.18	1.99

4.3. Service Time Analysis in ETC/MTC Compound Entrance Lanes. A scatter plot of the time intervals of all passing vehicles in ETC/MTC compound lane 15# at No. 6706 toll station is observed in Figure 6. Figure 7 shows the frequency distribution of the set $\{T_s\}_m$, which is concentrated in the interval [9 s,13 s]. Similarly, Figure 8 provides the fitting distribution of the service time for different types of vehicles. The estimated parameters μ for the lognormal distribution of the service time of the ETC/MTC entrance lanes are given in Table 5.

As can be seen in Figure 8, the peak of the ETC passenger/goods vehicle I' s distribution on the horizontal axis is left compared to that of the MTC passenger/goods vehicle I, which indicates the shorter service time of the ETC passenger/goods vehicle I. Furthermore, the distribution of service time for the ETC passenger/goods vehicle I in Figure 8 is more discrete and the peak is to the right relative to that in Figure 6, which demonstrates that the MTC vehicles in the ETC/MTC compound lane affect the passing speed of ETC vehicles in the same lane.

As shown in Table 5, MTC type I in the ETC/MTC entrances has a more significant impact on the capacity of the lanes. In the case of ETC entrances, the proportion of vehicle categories is stable, and the percentage of ETC type I is over 96%, whereas at the ETC/MTC entrances, the composition of MTC type I varies from 45% to 97%, with greater heterogeneity in traffic composition of these lanes.

4.4. Service Time Analysis in ETC/MTC Compound Exit Lanes. The service time of ETC/MTC exit lanes is still fitted with lognormal distribution, and the fitting parameters μ are shown in Table 6.

4.5. Capacity Calculation. Calculate the capacity of different lanes at toll stations according to (2), and the results are shown in Table 7. As mentioned earlier, there are differences in the composition of the passing vehicles and the layout of each lane, resulting in an impact on the capacity of the same type of toll lanes at the same toll stations.

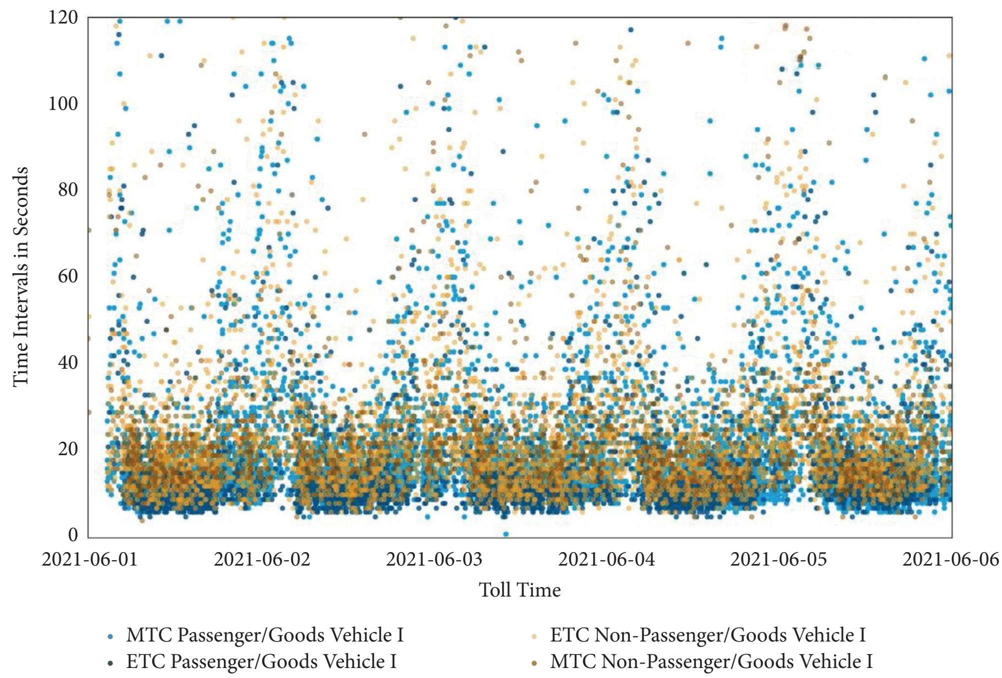

FIGURE 6: Scattergrams of time intervals of ETC/MTC compound entrance lane $15^{\#}$ at No. 6706 toll station.

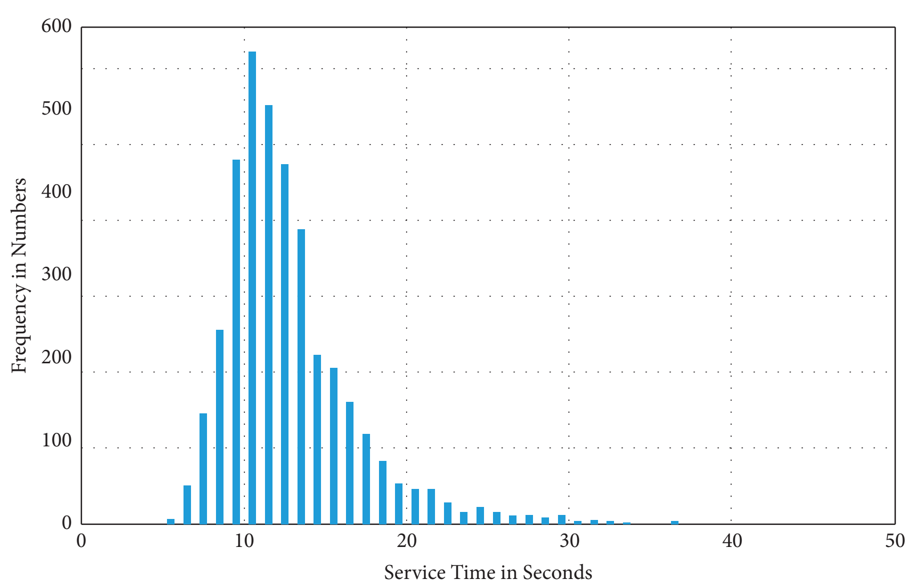

FIGURE 7: Frequent distribution of service time of lane $15^{\#}$ during the saturation period.

Some of the lanes with large differences in capacity are discussed. In the case of No. 6706 station, the capacity is influenced by the toll plaza layout. The toll lanes away from the centre of the plaza, where vehicles need to change lanes to enter, have a discounted capacity. These lanes may not be saturated during peak traffic hours at the toll booths, which is also corroborated by the difference in sample size in service time from Tables 3 and 4. In the case of exit of ETC/MTC compound lanes, the capacity is much lower than other types of lanes. The main reason for this is that MTC vehicles need to stop and pay tolls when passing through the lanes, and the variations in service time are related to the efficiency of the driver and the toll booth operator. According to the results, the service time of MTC single vehicle is about [20 s, 24 s], and the passing efficiency is low. In addition, lane $7^{\#}$ at No. 3304 station and lane $14^{\#}$ at No. 3501 station are height-restricted lanes, where II or above vehicles are not present in traffic mix. The proportion of MTC type I vehicles is relatively increased and the lane capacity is reduced compared to other lanes of the same type.

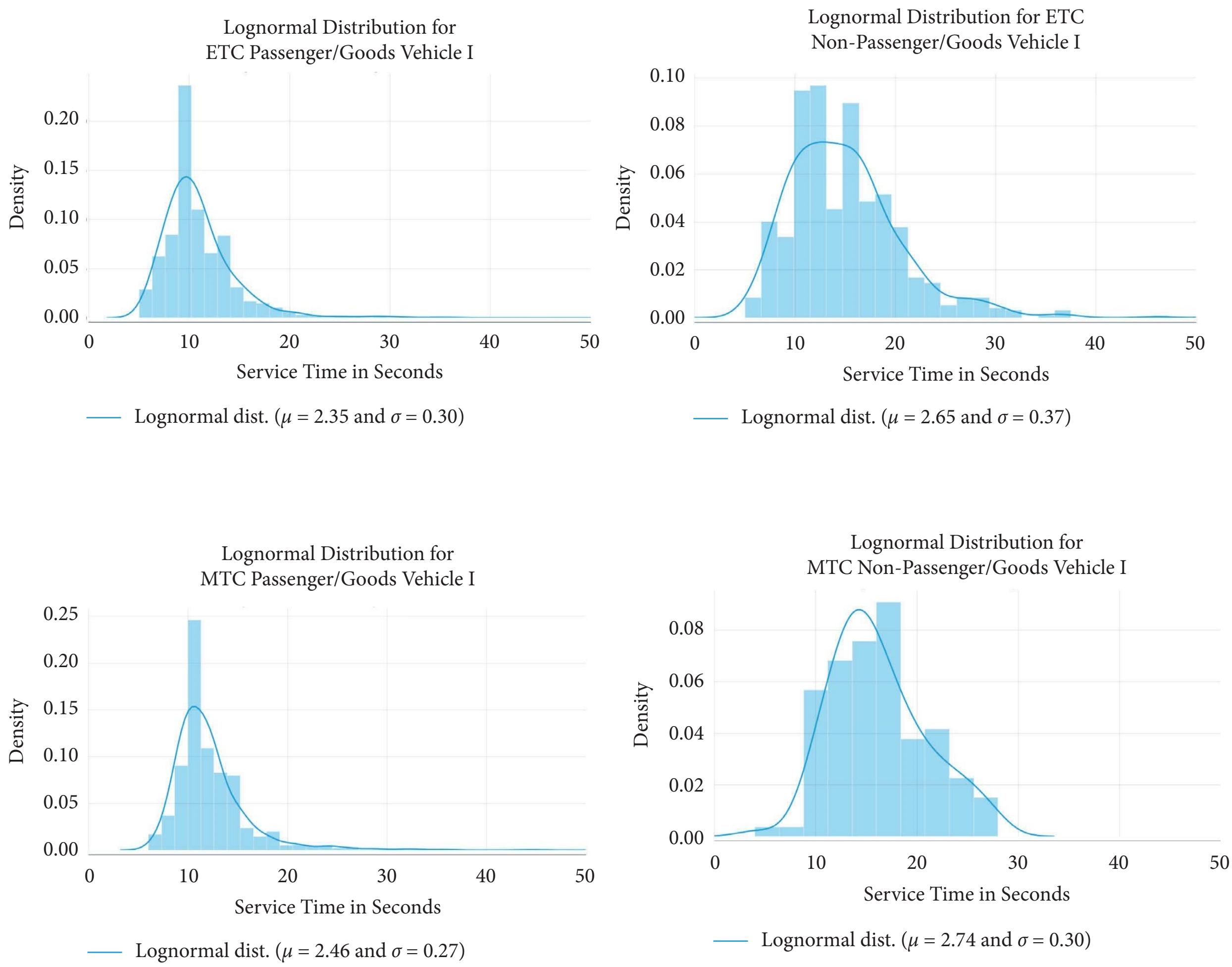

Figure 8: Lognormal distribution for different vehicle classes of lane 15#.

Table 5: Fitting parameters for the lognormal distribution of service time when ETC/MTC entrances of toll stations are saturated.

No. of toll station	No. of lane	Sample size (veh)	ETC type I		ETC type non-I		MTC type I		MTC type non-I		
			Proportion (%)	μ	Proportion (%)	μ	Proportion (%)	μ	Proportion (%)	μ	μ
6706	13#	4168	19.27	2.41	5.69	2.61	73.73	2.45	1.32	2.72	2.46
	15#	4104	26.41	2.35	14.23	2.65	56.68	2.46	2.68	2.74	2.47
3304	7#	3519	2.29	2.70	N.P.	N.P.	97.71	2.86	N.P.	N.P.	2.86
	11#	4076	16.90	2.43	13.54	2.77	64.01	2.53	5.54	2.75	2.56
3501	11#	4053	30.10	2.34	14.16	2.62	50.95	2.45	4.79	2.78	2.46
	13#	3907	28.03	2.37	19.86	2.72	45.20	2.50	6.91	2.83	2.53
6705	15#	4174	23.77	2.39	8.77	2.59	64.09	2.44	3.38	2.67	2.45
	17#	3214	23.21	2.45	19.38	2.82	49.81	2.46	7.59	2.76	2.55

N.P. = not present in traffic mix.

Table 6: Fitting parameters for the lognormal distribution of service time when ETC/MTC exits of toll stations are saturated.

No. of toll station	No. of lane	Sample size (veh)	ETC type I		ETC type non-I		MTC type I		MTC type non-I		μ
			Proportion (%)	μ	Proportion (%)	μ	Proportion (%)	μ	Proportion (%)	μ	
6706	18#	759	6.46	3.08	1.05	3.14	91.17	3.06	1.32	3.24	3.06
	20#	1638	7.14	3.15	0.49	3.27	89.13	3.07	3.24	3.16	3.08
	22#	1015	6.40	3.02	2.66	3.31	85.81	3.08	5.12	3.26	3.10
3304	12#	1175	11.06	3.06	0.26	3.44	86.04	3.03	2.64	3.13	3.04
	14#	1421	9.99	3.10	1.13	3.50	84.45	3.06	4.43	3.14	3.07
3501	14#	1403	5.49	3.61	N.P.	N.P.	94.51	3.38	N.P.	N.P.	3.40
	18#	1736	10.25	3.13	1.09	3.55	84.39	3.14	4.26	3.32	3.15
6705	12#	588	9.18	3.10	0.51	3.13	88.10	3.07	2.21	3.24	3.08
	14#	1102	10.71	3.16	0.82	3.21	85.75	3.17	2.72	3.36	3.17
	16#	569	7.91	3.03	0.53	3.22	89.98	3.09	1.58	3.23	3.09
	18#	1645	8.08	3.23	1.76	3.52	83.89	3.18	6.26	3.49	3.21

Table 7: Capacity of different lanes at toll stations.

No.	ETC lane capacity (PCE/h)				ETC/MTC lane capacity (PCE/h)			
	Entrance		Exit		Entrance		Exit	
6706	1#	518	2#	622	13#	333	18#	174
	3#	552	4#	620	15#	372	20#	173
	27#	462	28#	483			22#	181
	29#	397	30#	373				
Average		482		525		353		176
3304	1#	565	2#	469	7#	205	12#	175
	3#	586	4#	450	11#	349	14#	164
	5#	511	6#	465				
			8#	397				
Average		554		445		277		170
3501	3#	463	2#	493	11#	368	14#	120
	5#	529	4#	406	13#	376	18#	163
	7#	570	6#	379				
Average		521		426		372		142
6705	1#	549	2#	561	15#	329	12#	168
	3#	515	4#	572	17#	392	14#	157
							16#	165
							18#	159
Average		532		567		361		162

5. Conclusions and Future Work

This work investigates the capacity of two types of lanes under mixed traffic conditions by modelling the service time distribution based on real toll data. First, lane capacity estimation is considered as a single-vehicle service time distribution problem. Second, over-classification is avoided by vehicle category combination and car equivalent conversion. Finally, the samples during service saturation are counted for statistical analysis and the capacity of each lane is calculated. With four representative toll stations as examples, the experimental results present the authentic capacity and explain the difference in capacity between lanes of the same category. The following conclusions are drawn. (1) The capacity of designated toll stations is determined using lognormal distribution fitted to the service time, providing specific values and research ideas that can be referenced. (2) The parameter estimation calculated applies to the designated toll stations in this work only and cannot be directly pertained to other toll stations due to different driver behaviour, operational efficiency of toll booth staff, the layout of toll plazas, and other variables. (3) Furthermore, a reference point is provided for the level of service at toll stations, which is evaluated the operational efficiency of toll lanes of any type.

In the present study, the vehicle service time is considered as the interval time between the front and rear vehicles under mixed traffic conditions. However, a combination of various leader-follower pairs is not studied, which is often heterogeneous. Also, the service time is a function of traffic composition and volume, and it varies spatially and temporally, which is somewhat simplistic to fit with a single statistical distribution. Therefore, the models of capacity calculation that fuse multiple statistical distributions can be constructed. These can be further investigated in future work.

Data Availability

The expressway toll data used to support the findings of this study may be released upon application to the Fujian Provincial Expressway Information Technology Co. Ltd, who can be contacted at public@mgskj.com.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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