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THE CELLULAR TRAFFIC CAPACITY MODEL OF TOLL STATION SQUARE

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Abstract:

Traffic capacity is an important index to measure the operation efficiency of expressway toll stations. In order to provide relevant theoretical support for accurately evaluating the congestion degree and service level of toll stations, this paper establishes a traffic capacity calculation model for the square in front of expressway toll stations based on the traditional cellular transmission method. Firstly, by dividing the square in front of the station into regular cells, the process of calculating the traffic capacity is simplified; Secondly, the capacity model of the square in front of the station is established based on cellular transmission, and a large amount of data is collected through the monitoring videos of several toll stations. The theoretical capacity of the square in front of the station is calculated by using the important parameters of the model calibrated by the measured data under different lengths of the square in front of the station and the configuration of toll lanes. Then, the simulation platform of VISSIM software is used, and many experiments are carried out with relevant measured data to verify the accuracy of the model in multiple scenarios. Finally, the simulation value of the capacity of the square in front of the station is obtained, and the error is calculated by using the simulation value and the calculation value. The results show that the error of the verification result is 5.19%, and the error is within the allowable range, which shows that the model is accurate and feasible. The theoretical capacity calculated by the capacity model of the square in front of the toll station established in this paper is compared with the actual capacity, which can be used as a standard to judge the congestion degree of the square in front of the toll station and further provide a theoretical reference for evacuation of congestion.

Keywords: *Highway toll station, traffic capacity, toll station square, cell transmission, microscopic simulation*

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1. Introduction

By 2021, China's highway mileage had reached 161,200 kilometers, and 10,788 toll stations had been built across the country. The existing highway system has been relatively perfect, but from the overall highway system congestion frequency, toll stations are one of the most frequently congested areas. Due to the problems of excessive heavy vehicle rates, unreasonable lane settings and sudden increases in traffic volume, toll stations produce traffic congestion, which limits the operational efficiency of expressway traffic systems [Wang et al., 2020]. By studying toll station traffic capacity, the congestion degree can be evaluated, and improved toll clearance methods, such as controlling static velocity [Lu et al., 2010], setting up reversible lanes at toll stations [Kumar et al., 2020], and optimizing lane allocation [Liu et al., 2022], can be adopted according to the congestion degree of different lanes to achieve the purpose of easing traffic congestion.

Most scholars study the capacity of toll stations by analyzing driving behavior, service level, vehicle type ratio and other influencing factors. To address the influencing factors of driving behavior, Saad et al. [2019] established a series of linear mixed models based on random effects to reveal the factors influencing driving behavior at toll stations. Wang [2017] established a nonlinear integer programming model based on minimizing the toll station operating cost and the driver waiting cost. Bari et al. [2021] analyzed the influence of many factors on the service time using the statistical distribution of the data of toll stations in India. Li et al. [2021] transformed the problem of capacity estimation into two aspects, service duration distribution and influencing factors, and determined a description method for the proportion of vehicle types in toll lanes. Toll station traffic is mixed traffic flow. Navandar et al. [2019] proposed an equivalent coefficient, which equates the mixed traffic flow to a balanced traffic flow composed of cars. On this basis, they studied the service level and traffic efficiency of toll stations [Navandar et al., 2020]. Liu et al. [2011] used mathematical analysis to determine the distribution characteristics and the maximum likelihood estimation of single lane service time, thus determining the capacity of a single lane of a toll station. Zhao et al. [2022] analyzed the traffic flow characteristics of mixed toll stations, quantitatively divided the service level of toll stations, and determined the service level standard of different types of toll stations and the corresponding maximum traffic volume. Mohammed et al. [2019] studied the impact of the percentage of heavy vehicles on the queue length performance of toll plazas, and the results showed that the percentage of heavy vehicles in the traffic flow significantly affected the queue length of toll plazas. Most of these research methods analyze the capacity of toll stations from the perspective of different influencing factors. Lane changes, acceleration and deceleration will increase the risk of traffic accidents. A long service time and electronic toll collection (ETC) equipment identification error may lead to traffic congestion. The proportion of manual toll collection (MTC) system vehicles and heavy vehicles will also affect traffic efficiency. These influencing factors can indeed reflect the level of traffic efficiency to a certain extent, but the explicit value of traffic capacity needs further study.

At present, there are two main types of models for calculating toll station capacity: analytical models and simulation models. Most analytical models are based on traffic flow theory, which is more logical and applicable, but the calculations are often complicated [Bari et al., 2020]. Based on vehicle types, toll lane configuration and other factors, Zarillo et al. [2009] built a toll station square capacity calculation model. Zhao [2012] compares MTC lanes with ETC lanes and proposes a new model to calculate and analyze the capacity of toll lanes. Gui et al. [2021] studied the design capacity of toll plazas by establishing a balance model and two mathematical programming models. Yu et al. [2021] developed an integer programming model based on simulation to provide a more efficient operation scheme for toll plazas. Qian et al. [2013] established an improved cellular automata model based on a traditional NS model, which was used to analyze the traffic flow of a mixed toll station. Cheolsun Kim et al. [2016] established a model to analyze the traffic capacity of toll plazas by observing the real-time traffic flow and travel time of vehicles. It is more convenient and intuitive to use simulation software to build models, but there is some randomness, resulting in insufficient precision [Yu et al., 2020]. The commonly used microsimulation software is VISSIM, developed by PTV Company in Germany. Dong et al. [2019] designed five kinds of conventional toll station traffic scenes in VISSIM, which were used to compare and analyze the traffic capacity between different guidance strategies. The results show that guidance measures in front of toll lanes is better than guidance measures behind toll plazas. Bains et al. [2017] developed a well-calibrated and verified toll plaza simulation model in VISSIM and simulated several scenarios to test the efficacy in improving traffic capacity. Bartin [2019] combined reinforcement learning with a genetic algorithm to study the capacity of toll plazas and used a simulation toll plaza developed using Paramics simulation software for experimental analysis. Most existing studies are based on models to calculate the capacity value of toll stations [Jian et al., 2021]. A simulation model can address a variety of traffic scenes simply and intuitively, but it is not accurate enough. Although a theoretical analysis model has complex calculations, it has high accuracy. Considering the advantages and disadvantages of both models, this study adopts a method combining theoretical analysis with simulation to calculate the capacity value to achieve better results.

Daganzo et al. [1993] proposed a cell-transmission model (CTM) based on a classical macroscopic traffic flow model. Combined with the theory of fluid mechanics, the model divides a road into connected cells and describes the traffic flow state of the section according to the traffic flow transmission relationship between the cells. Tampere et al. [2007] combined a CTM with a linear Kalman filter and proposed an extended Kalman filtering-cell-transmission model (EKF-CTM), enabling the CTM to switch between linear and nonlinear traffic conditions for prediction. Laval et al. [2005] added lane change behavior on the basis of a CTM and established a lane-changing (LC) model, which well reproduced the phenomenon of unstable slow growth in queuing and had a good short-term dynamic prediction effect of traffic flow. Based on the present situation, the existing research has not developed a method to determine the display value and has not combined simulation, theoretical modeling and actual inspection. In this study, through the cellular transmission idea, a toll station square is equivalent to a regular geometric area, and the calculation process is simplified. A traffic capacity model of the toll station square is established. Studying the capacity of toll station squares with different lengths, different lane numbers and different lane configurations not only provides a theoretical basis for evaluating the degree of congestion but also has a certain reference for improving operational efficiency.

2. Modelling

As the number of lanes in a toll station square changes from fewer to more, the transition area is irregular, resulting in differences in the capacity of each section. A cellular transmission model can divide a toll station square into regular areas and describe the changes in traffic flow in the whole area through the changes in the number of vehicles in each cell, thus simplifying the traffic capacity calculation process. To improve the toll station square capacity calculation precision and provide theoretical support for subsequent congestion alleviation at the toll station, the advantages and disadvantages of a common traffic capacity calculation method and the actual station square situation are considered and a cell-based capacity model is proposed to analyze the toll station traffic capacity.

2.1. Toll station square regularization

A CTM is mainly used in research on highways and dedicated lanes but has not been applied to toll stations. In this study, based on the principle of a CTM, the toll station square is divided into n cells of the same length so that the distortion area can be equivalent to a regular geometric area, and the traffic capacity can be calculated more directly, as shown in Figure 1.

The toll station square is divided into regularly shaped cells:

$$q_{i-1,out} = q_{i,in} \tag{1}$$

$$q_{i,out} = q_{i+1,in} \tag{2}$$

where $q_{i,in}$ represents the number of vehicles flowing into cell i per unit time, $q_{i,out}$ represents the number of vehicles flowing out of cell i per unit time.

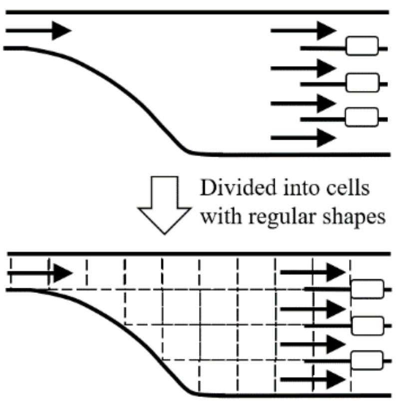

Fig. 1. The toll station

A vehicle will continuously drive from one cell to the next until it leaves the final cell. Since the traffic flow is a continuous process, the number of vehicles leaving the previous cell is equal to the number of vehicles entering the next cell, and the maximum number of vehicles entering a single cell is related to the maximum number of vehicles entering the initial cell in unit time. The capacity of a single lane is determined by the capacity of all cells in the lane. Lane change behavior will occur among multiple lanes, so the capacity of a single lane cannot be simply added directly. Therefore, the capacity of multiple lanes can be calculated by applying a lane reduction coefficient.

2.2. Traffic capacity of a single lane

The traffic capacity of an entire lane is the maximum number of vehicles that can pass through this section in a certain period of time. According to the cellular transmission characteristics, the traffic capacity of a single lane is the maximum number of vehicles that can pass through all the cells in the process of entering the initial cell and exiting the end cell in a certain period of time. Therefore, the vehicle running state of a single cell is analyzed first, and the maximum number of vehicles passing through a single cell is obtained. Then, all the cells in the lane are used to calculate the traffic capacity of a single lane. The maximum number of vehicles leaving a cell in Δt time is only related to the distance traveled per unit time and the spacing between vehicles. To postulate that at t_0 the first car just pulled into cell i, and after a unit time delta Δt, at t the first car moves out of cell i a certain distance. For the validity of the model, it is assumed that the number of vehicles passing in unit time is at least one, that is, the distance of vehicles passing in unit time is at least one cell length, as shown in Figure 2. The capacity of a single cell is the maximum number of vehicles that can pass through the cell in a unit time, and its capacity is related to the cell length, vehicle speed and unit time length. To simplify the analysis, all vehicles are treated as one point, the length is ignored, and only the headway distance is considered.

$$\bar{x} = \bar{V} \times \Delta t \tag{3}$$

$$\bar{x} \geq l \tag{4}$$

$$Q_{i,k} = \left\lceil \frac{\bar{x} - l}{\bar{s}} \right\rceil \tag{5}$$

where $\overline{V}$ represents the average velocity, Δt represents the unit time, $\bar{x}$ represents the distance traveled by a vehicle per unit time, $\bar{s}$ represents the mean headway distance, l represents the cellular length, and $Q_{i,k}$ represents the number of vehicles that can pass through a cell per unit time.

The maximum number of vehicles leaving a single cell in time t is calculated, and the capacity of a single lane can be obtained using the number of cells in a single lane for calculation.

$$C_0 = \int_0^{3600} Q_{i,k}\, dt \tag{6}$$

$$\beta = \frac{L}{l} \tag{7}$$

$$C_d = \int_0^{\beta} C_0\, dx \tag{8}$$

where C_0 represents the maximum number of vehicles leaving a single cell at time t, β represents the number of cells on the road, L represents the length of the lane, l represents the cellular length, and C_a represents the capacity of a single lane.

2.3. Toll station square traffic capacity

The capacity of multiple lanes is not the sum of the capacity of all individual lanes. This is because different lane location layouts will produce reductions to a certain extent. There are many lanes in a toll station square, and the location of each lane is different. However, the number of ramp lanes is small, and most vehicles need to change lanes to reach the target toll station. As the lane change process will affect the traffic flow status to a certain extent, there will be a certain reduction in traffic capacity, so a capacity reduction factor is introduced. If n ETC or MTC lane is directly opposite to the entrance lane of the toll station, vehicles do not need to change lanes, and the capacity reduction factor is set to *1*, i.e., the capacity is not reduced. For lanes in other locations, the capacity reduction coefficient can be calculated as the ratio between the traffic volume of a single lane and the traffic volume of the opposite lane [Luo et al., 2018]. The specific substitution process is as follows.

$$f = (f_1, f_2, f_3, \cdots, f_n) = \left(1, \frac{Q_2}{Q_1}, \frac{Q_3}{Q_1}, \cdots, \frac{Q_n}{Q_1}\right) \tag{9}$$

where f_n represents the reduction coefficient of lane *n*, the number of lane offsets from the main line to the outside is in turn 1, 2, 3……n, and Q_n represents the number of vehicles passing lane *n*.

At present, ETC/MTC mixed lanes and ETC special lanes are mainly used in toll stations in China. The design of ETC/MTC mixed lanes must conform to higher design specifications to meet the needs of ETC and large cars. If a mixed lane is used only by ETC vehicles, the capacity of that mixed lane is equal to the capacity of a single ETC lane. When the lane is only used by MTC vehicles, the capacity of the mixed lane is the same as that of a single MTC lane. When the lane serves both types of vehicles, the smaller the proportion of MTC vehicles, the greater the capacity. In mixed traffic flow, the larger the proportion of MTC vehicles, the smaller the impact of ETC vehicles on traffic capacity, and the slower its decay rate.

The capacity of an ETC/MTC mixed lane decreases with the increase in the proportion of MTC vehicles in the mixed traffic flow, and the decreasing rate gradually increases from 0 to a certain degree and then gradually decreases. The change process can be approximately expressed by a cosine function [Junlong Cheng et al., 2015], and the mixed lane capacity formula can be obtained.

$$C = \sum_{j=1}^{m} f_j C_M + \sum_{j=1}^{k} f_j C_E + \sum_{j=1}^{p} f_j C_h \tag{10}$$

where C_e represents the ETC traffic capacity, C_m represents the MTC traffic capacity, C_{mix} represents the mixed toll lane traffic capacity, and ∂ represents the proportion of MTC vehicles in mixed toll lanes.

Therefore, the multilane capacity of a toll station square can be expressed as follows.

$$C = \sum_{j=1}^{m} f_j C_M + \sum_{j=1}^{k} f_j C_E + \sum_{j=1}^{p} f_j C_h \, (\tag{11}$$

where *m* represents the number of MTC lanes, *k* represents the number of ETC lanes, p represents the number of mixed lanes, f_j represents the reduction factor of lane j, and C represents the capacity of the toll station square.

The model divides the entire irregular area of a toll station square into multiple regular cells, uses the cells to calculate the capacity of a single lane, considers the lane change behavior between different lanes, then introduces a lane capacity reduction coefficient, reduces the capacity of each lane, and finally obtains the capacity of the toll station square. Compared with other models, this model is based on the geometric shape of the toll station area, which can better reflect the traffic characteristics of the toll station. The use of cellular transmission simplifies the modeling process and makes the calculation simpler on the premise of ensuring accuracy.

3. Model validation

Since some model parameters cannot be directly obtained, the traffic volume of different lanes and the average speed and time of vehicles can be counted by investigating surveillance videos of multiple toll stations. A large amount of measured data can be used to calibrate key model parameters. After parameter calibration, the toll station square capacity model needs to be verified.

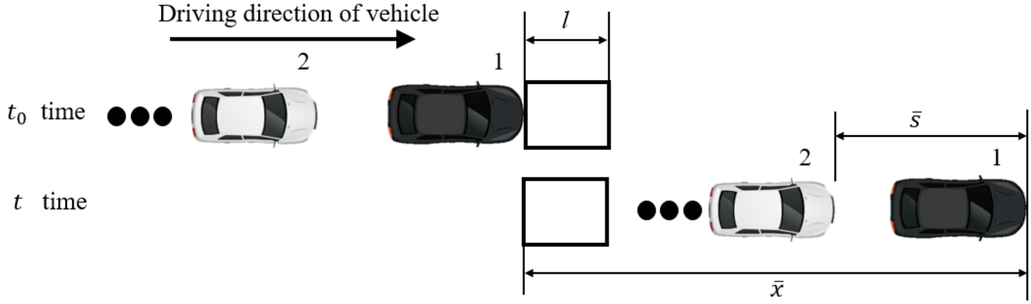

Fig. 2. A vehicle passes through a single cellular procesThe maximum number of vehicles leaving a single cell in time t is calculated, and the capacity of a single lane can be obtained using the number of cells in a single lane for calculation.

The number of ETC lanes does not need to be taken as an experimental variable. Therefore, the data set with the maximum traffic capacity, that is, the largest number of ETC lanes, is selected for verification.
To verify the accuracy of the model in multiple scenarios, a VISSIM simulation model was used to establish toll station scenes with different lengths and different numbers of lanes, set corresponding parameters for simulation to obtain simulation results, verify the model and conduct error analysis.

3.1. Parameter calibration

The main parameters to be statistically measured in the established model are as follows: the average vehicle speed, the average vehicle passage time, and the lane capacity reduction factor. After the calibration of these three parameters, the toll station square capacity value can be calculated to facilitate model verification.
Through the investigation of multiple toll stations in Yinchuan South, Yinchuan East, Helan, Wuzhong, and Liupanshan, the length of most toll station squares is between 80 and 180 meters, and the total number of one-way toll gates is between 4 and 8. For the entrance of a single lane ramp toll station, the number of toll gates is between 4 and 6. Therefore, the maximum length of the gradient section of a toll station square is 180 meters, the minimum is 80 meters, and the number of toll gates is 4 to 6.
DSS Cloud remote monitoring software was used to collect video data of multiple toll stations in the Ningxia Hui Autonomous Region, and the average speed and average time parameters of vehicles passing through the toll stations under different square lengths in front of the stations and different types of lanes were counted, as shown in Table 3.
It can be concluded from the above table that with the increase in the length of the toll station square, the average speed increases gradually. The main reason is that drivers will not slow down immediately after entering the toll station square. Instead, they will maintain the original speed for a period of time or speed up for a period of time according to the length of the toll station square and then slow down when they are close to the toll gate. Because a driver is evaluating the acceleration and deceleration according to the visual distance from the toll gate in front, when the distance is closer to the toll gate, that is, the shorter the length of the toll station square, the driver will slow down in advance. When the distance from the toll gate is farther, that is, the length of the toll station square is longer, the driver will maintain a uniform speed or even accelerate to a proper distance and then slow down.
The traffic volume obtained from the investigation is calculated according to formula (9), and the reduction coefficient value is obtained by taking the lane directly opposite the entrance lane of the toll station as the standard, as shown in Table 4 and Table 5.
From the results in the above two tables, it can be seen that the traffic volume of the lane directly opposite the toll gate entrance is the largest, and the greater the lane deviates from the opposite lane, the smaller the number of vehicles passing. The MTC

reduction ratio will be slightly greater than the ETC reduction ratio because when MTC vehicles change lanes away from the main line, the speed will be smaller than when ETC vehicles change lanes, and the resulting capacity reduction will be greater. Statistically, drivers tend to prefer the toll lane on the left, regardless of traffic conditions.

Table 1. Parameters list

Parameter	Symbol
Average vehicle speed	$\bar{V}$
Average vehicle passage time	t
Lance capacity reduction factor	f
Cell length	l
Lane length	L
Mean headway distance	$\bar{s}$
Number of ETC lanes	k
Number of MTC lanes	m
Number of mixed lanes	p
Proportion of MTC vehicles in mixed toll lanes	∂

Fig. 3. Part of the toll station surveillance video

Table 2. Parameters of some toll station squares

	Liupanshan toll station	Helan toll station	Yinchuan South toll station	Yinchuan East toll station
Length of toll station square(meters)	80	100	120	160
Number of ETC lanes	3	2	3	3
Number of MTC lanes or mixed lanes	2	5	5	5

Table 3. Average speed and average time parameter table

Lane category	Relevant parameter	Length of toll station square					
		80 m	100 m	120 m	140 m	160 m	180 m
ETC	Average velocity (m/s)	10.47	10.87	10.92	11.75	12.07	12.38
	Average time (s)	7.64	9.20	10.99	11.91	13.26	14.54
MTC	Average velocity (m/s)	8.77	9.76	9.91	10.29	10.65	11.06
	Average time (s)	9.12	10.25	12.11	13.60	15.02	16.28

Table 4. ETC lane reduction factor

Lane position	Main line	First lane off the main line	Second lane off the main line	Third lane off the main line	Fourth lane off the main line
Volume of traffic	768	726	648	606	522
Reduction factor	1	0.95	0.84	0.79	0.68

Table 5. MTC lane reduction factor

Lane position	Main line	First lane off the main line	Second lane off the main line	Third lane off the main line	Fourth lane off the main line
Volume of traffic	360	336	300	276	216
Reduction factor	1	0.93	0.83	0.77	0.60

3.2. Capacity of different toll station square lengths

With the rapid development of ETC in China, the number of ETC users reached 265.79 million in 2021, and the ETC penetration rate was approximately 86.21%. Therefore, it is assumed that the number of ETC lanes is at least one. Because ETC is not exclusively utilized, the number of MTC lanes is at least one. Therefore, the capacity of different ETC quantities is discussed when the total number of lanes is 4 to 6 and the number of ETC and MTC lanes is at least one. According to formula (11), taking the entrance toll station of a single lane as an example, the maximum capacity values of different lanes under different square lengths in front of the station are calculated as shown in Table 6 below.

The table shows that the capacity increases with the length of the toll station square when the total number of lanes remains the same. When the length of the toll station square and the total number of lanes remain the same, the capacity increases with the increase in the number of ETC lanes.

4. Error analysis

According to the toll station square capacity model, which is different from the traditional toll station capacity, the toll station square capacity is calculated based on the length of the toll station square, the location of the lane, and the key traffic flow parameters, and the influence of the service rate on it is not considered. Therefore, to verify the effectiveness of the model, a VISSIM simulation is used for verification, as shown in Figure 4.

The case with the largest number of ETC lanes is selected for verification. When the number of ETC is the largest, the capacity is the largest. To maximize the simulated capacity, a simulation scheme is designed from the following two aspects: different lane configurations and the length of the toll station square. For the toll station square capacity under different station front square lengths and lane configurations, the entrance single lane toll station is taken as an example to conduct the simulation, as shown in Table 7 below.

According to the above table, the trend is consistent with the conclusion obtained from the model calculation value. To verify the effectiveness of the model, the following formula is used to analyze the error.

$$\varepsilon_j = \frac{1}{m}\sum_{i=1}^{m}\frac{X_i - Y_i}{X_i} \tag{12}$$

where ε_j represents the total number of lanes and is the error between the calculation capacity value and the simulation value of j lanes, X_i represents the calculated values of the capacity of group i data, Y_i represents the simulated values of the capacity of group i data, and m represents the total amount of data.

The error calculated when comparing the theoretical calculation data and simulation result data in the above table are shown in Table 8 below.

The results show that the error between the simulation results and the calculation results is 5.19%. This error indicates that the results of the simulation model and the calculation model are different for several reasons.

(1) There are some differences between the theoretical following model and the Wiedemann99 simulation model, and to simplify the calculation, the length of the car body is ignored in the theoretical model, which will lead to some errors.

(2) The key parameter in the theoretical model is the average speed, but in fact, changes in the speed are all different in the process of cellular transmission, and the average speed cannot fully reflect the changes in the overall speed.

(3) In the simulation model, vehicles choose different lanes, and some drivers even make more than two lane changes. The impact of such lane changes on traffic capacity cannot be fully reflected in the theoretical model.

Table 6. The capacity of the plaza in front of the single lane toll station entrance with different lengths and different numbers of lanes

Length **Number of lanes**	**80 m**	**100 m**	**120 m**	**140 m**	**160 m**	**180 m**
4 lanes, 3 ETC	1344	1566	2150	2299	2529	2783
4 lanes, 2 ETC	1138	1353	1896	2007	2369	2595
4 lanes, 1 ETC	1036	1147	1545	1817	2213	2310
5 lanes, 4 ETC	1653	1931	2662	2858	3131	3454
5 lanes, 3 ETC	1552	1724	2408	2667	2974	3265
5 lanes, 2 ETC	1446	1611	2258	2479	2721	3080
5 lanes, 1 ETC	1245	1505	2004	2288	2564	2891
6 lanes, 5 ETC	1937	2264	3134	3375	3686	4074
6 lanes, 4 ETC	1836	2057	2986	3196	3437	3895
6 lanes, 3 ETC	1730	1845	2734	2907	3282	3607
6 lanes, 2 ETC	1629	1738	2584	2720	3032	3422
6 lanes, 1 ETC	1527	1632	2332	2531	2877	3234

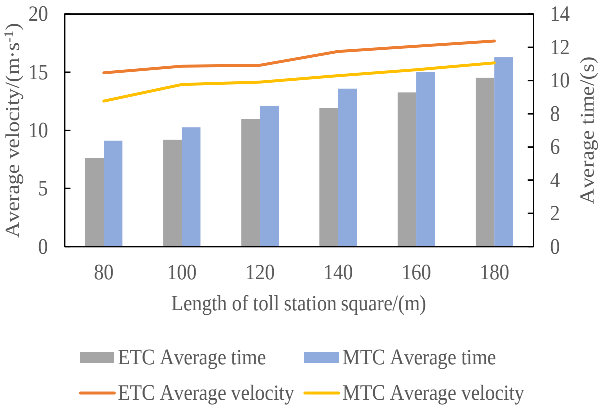

Fig. 4. Average speed and average time of different lanes under different lengths of toll station square

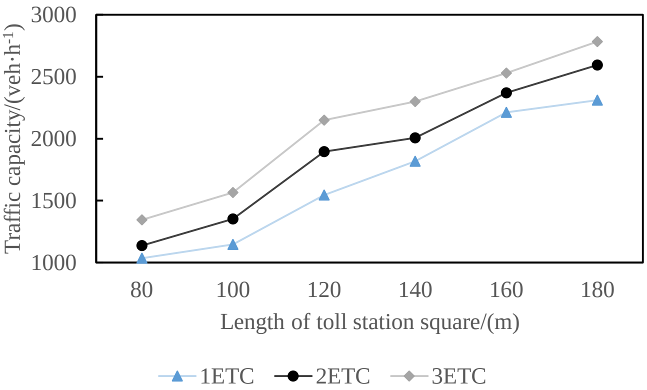

Fig. 5. Capacity of 4 lanes under different station square lengths

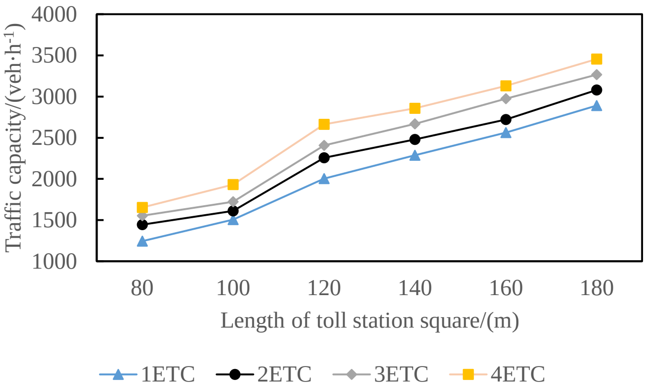

Fig. 6. Capacity of 6 lanes under different station square lengths

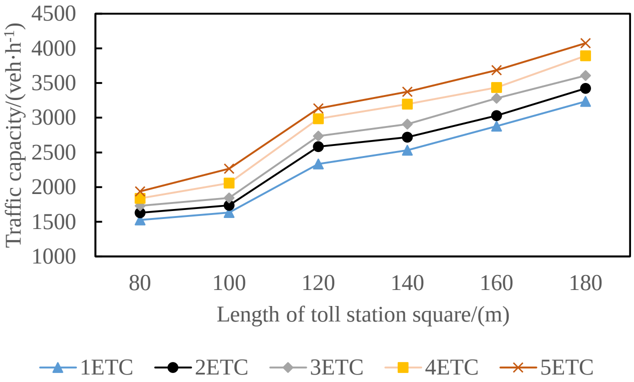

Fig. 7. Capacity of 6 lanes under different station square lengths

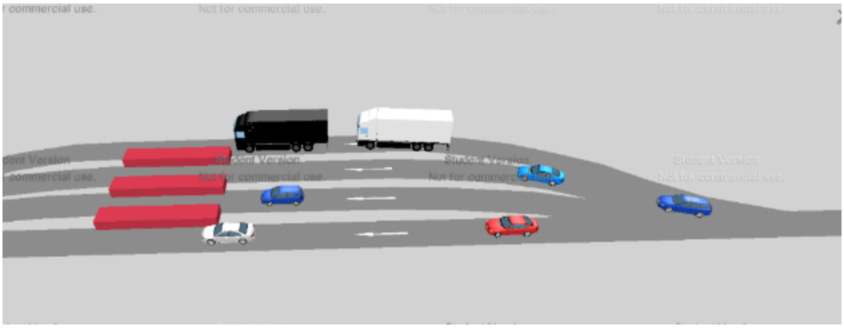

Fig. 8. Toll station simulation

Table 7. Maximum simulation capacity

Length / **Number of lanes**	**80 m**	**100 m**	**120 m**	**140 m**	**160 m**	**180 m**
4 lanes, 3 ETC	1468	1722	2238	2376	2655	2823
5 lanes, 4 ETC	1809	2152	2757	2948	3257	3512
6 lanes, 5 ETC	2138	2567	3230	3466	3818	4134

Table 8. Error between calculation value and simulation value

Length / **Number of lanes**	**80 m**	**100 m**	**120 m**	**140 m**	**160 m**	**180 m**
4 lanes, 3 ETC	8.45%	9.06%	3.93%	3.24%	4.75%	1.42%
5 lanes, 4 ETC	8.62%	10.27%	3.45%	3.05%	3.87%	1.65%
6 lanes, 5 ETC	9.40%	11.80%	2.97%	2.63%	3.46%	1.45%

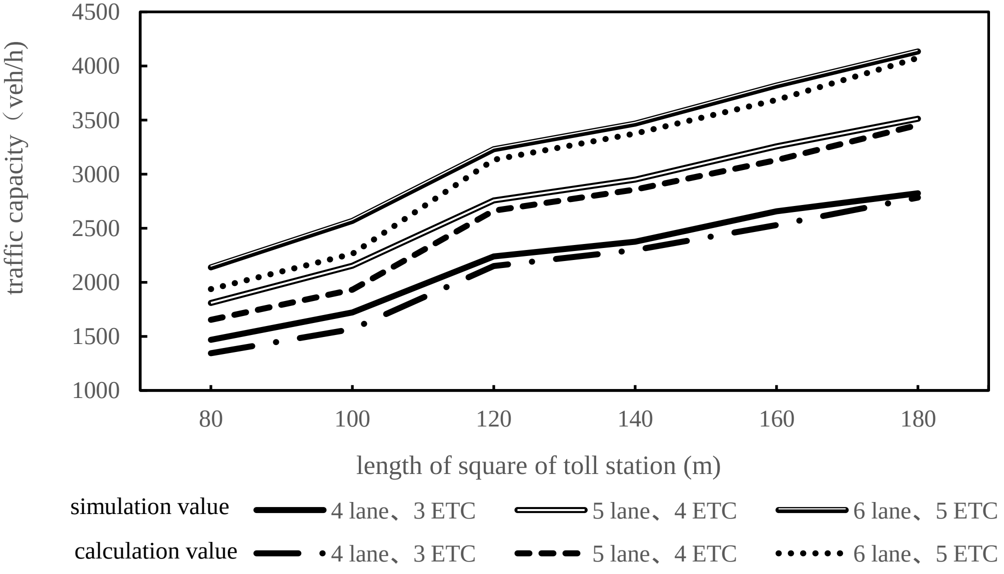

Fig. 9. Simulated and calculated capacity values

5. Conclusion

By dividing the irregular area of a toll station square into regular cells, a toll station square traffic capacity model is established. According to the calculation results of the model, the traffic capacity increases with the length of the toll station square when the number of lanes is fixed. When the length of the toll station square and the total number of lanes remain the same, the capacity increases with the increase in the number of ETC lanes.

The VISSIM simulation is used to verify the capacity. The error of the verification results is 5.19%, which is within the acceptable range and has certain theoretical guidance significance. This model can be used to calculate the display value of the capacity of a toll station square, and the calculated display value can be used as the criterion to evaluate the congestion degree. When the actual traffic volume is more than the capacity display value, it indicates that the toll station is congested. The relevant measures need to be taken to guide vehicles to avoid traffic paralysis, improve traffic efficiency and ensure smooth vehicle travel.

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