An Optimum Strategy of Expressway Toll Collection System

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Abstract
Based on the traffic flow and queuing theory, this paper analyzes the existing toll collection station from the point of view of the capacity of toll station, and uses the VISSIM method to verify the stability of its function. From the perspective of safety, Professor Babcov's safety coefficient method for assessing hazardous road has been improved. At the request of the length and width of the conditions, Considering the different situation of randomness and the number of lanes at the same time the number of vehicles into the driveway, The analysis shows that the capacity is the strongest when the number of ETC channels is 5 and MTC is 3. Under the condition of satisfying the design of the toll station, VISSIM is used to analyze the performance of the solution under the traffic volume. The experimental error is about 100pcu/h, which indicates that the charging system is stable.

Key words: Traffic Flow, Queuing Theory, Optimum Strategy, Expressway, Toll Collection System

1. INTRODUCTION
The establishment of the highway toll system involves the economic base, the financial system and the management structure of the truth. At the same time, it is necessary to consider the existing road pricing system (Gao, 2013).

In the current international situation, there is a certain gap between the development of countries and regions, so the traffic, the construction speed is not consistent, and the existing fee management system is not uniform. In terms of the design of the toll square, it is difficult to fully adopt the ETC way, in a certain transition period it will be parking fees and non-stop charges in two ways coexist (Kato, Sakashita and Tsuchiya, 2015). At this time, ETC vehicles are not stop charging, rather than waiting for vehicles to implement parking fees.

This hybrid charging method for the toll lane and the design of the toll square will cover the following questions: the use of subway lane charges or the same lane mixed charges (Nagaraja, Sharath, Yang and Adamovich, 2013), what happens to the ETC toll lane geometry (Ding, Lu, Song and Bao, 2014) and how to determine the separation of the toll square and the driving characteristics of the vehicle (Habtemichael, Filmon, and Cetin, 2016), the above points will be the main points of the toll booth system design.

2. STUDY ON THE DELAY PROCESS OF TOLL SQUARAE
In this paper, 95 of New Jersey Intercontinental high-speed, for example, the vehicle through the toll plaza process is divided into three parts, the following diagram.
2.1. The Pre-delay Phase

Using the basic principle of fluid mechanics, the continuity equation of traffic flow is established. If the traffic flow is free flow, the traffic flow enters the toll plaza with the initial traffic flow $q_0$ and the initial traffic flow rate. (Gorcun and Faruk, 2017) According to the traffic flow theory,

$$ q_0 = v_0 k_0 $$  \hspace{1cm} (1)

At some point in the transition section, the relationship between traffic flow, traffic velocity and traffic density is

$$ q_0 = v(x) \cdot k(x) $$  \hspace{1cm} (2)

The relationship between the traffic density at $x$ and the width of the transition area is

$$ k_0 w_n = k(x) \cdot w(x) $$  \hspace{1cm} (3)

Then the equation is established

$$ \frac{y}{x} = \frac{w_f - w_n}{l_n} $$  \hspace{1cm} (4)

$$ w(x) = w_n + y $$  \hspace{1cm} (5)

The resulting final expression is

$$ T_n = \frac{nw_n a}{v_0 (nd - w_n)} \ln \left( \frac{nd}{w_n} \right) $$  \hspace{1cm} (6)
2.2 The Charging Service Phase

At this stage, the average traffic flow $q_1$ is equally assigned to each toll intersection, that is, each toll intersection traffic flow $q_1/n$, the queue for payment, and then enter the exit phase. (Otsuki, Takaaki, Kasai and Terabe, 2016) Known $\lambda = \frac{q_1}{n}$, then the number of toll booths $n$ constraints

$$n \geq \frac{q_1}{\mu}$$  \hspace{1cm} (7)

According to the queuing theory, each toll intersection obey the system, then the charging service stage is multiple systems, can calculate the vehicle in the second stage of the average time consumption

$$T_w = \frac{n}{n\mu - q_1}$$  \hspace{1cm} (8)

2.3. The Leaving Phase

As $q_2$ to leave the bus traffic flow phase of service, and then as $q_3$ to traffic into the main line. Since the process of phase 3 can be analogous to process 1, the time to get out of the stage

$$T_w = -\frac{n^2 da_i}{v_2(n d - w_n)} \ln \left( \frac{w_n}{n d} \right)$$  \hspace{1cm} (9)
3. OPTIMIZED DESIGN OF CAPACITY OF TOLL

A single MTC or ETC design cannot fully reflect the properties of the expressway and will cause traffic congestion. Therefore, a hybrid toll station is the future trend of highway system development. This article mainly analyzes the capacity of the highway and establishes the model of toll stations (Agrawal, Animesh, Jeet and Jaiswal, 2014), designing the hybrid toll station’s specific program.

![Figure 5. Schematic diagram of the shape of the toll plaza](image)

According to Figure 7, the moving process of vehicle passing through toll plaza is analyzed. The number of vehicles entering the toll plaza at the same time is random, and the number of lanes is $B = 1, 2, 3, \ldots, 8$, the number of vehicles entering the toll plaza at the same time is random, and the number of lanes is $B = 8$, so this paper considers the number of vehicles entering the toll plaza at regular intervals from 1 to 8, and the probability of each case corresponding to the Poisson distribution is

$$P_k = \frac{e^{-\lambda} \lambda^k}{k!}$$

(10)

When $n = 1$, occupies 1 lane; $n = 2$, occupies 1, 2 lanes; when $n = 3$, occupies 1, 2, 3 lanes; $n = 4$, ... and so on, when $n = 8$, occupies the full lane; Lane. In this paper, the number of vehicles per unit area as a judge whether the traffic congestion or traffic accidents occurred in the index, that is, the number of vehicles than the area on the area. Combined with the relevant standards, it is known that when $k = 8$, the upper limit of safety is reached.

The change in the number of vehicles in the merged area ($170 \leq x \leq 190$ ) in each case with time is determined from the above model. Then, the Poisson distribution probability of each change is integrated, and its function relation is as follows, While $n$ represents the change in the number of vehicles in the merged region with time with different values of $n$. The integrated curve is fitted by the Nasch model (He, Li, Gao and Zhang, 2015).

![Figure 6. The number of vehicles in the merged area varies with time](image)

From the figure, it can be seen that, when the time from 50 to 70, beyond its safety limit, the model needs to continue to improve.
Change the distance between the toll stations $X \left( \frac{1}{4} L_x \leq X \leq \frac{3}{4} L_x \right)$, and then get the number of vehicles in the merger area of the peak.

![Graph](image.png)

**Figure 7.** The relationship between the number of vehicles and Traffic flow

It is found that when $x = 75$, the minimum peak appears, in which case the corresponding $k$ is less than the safety upper limit.

Then adjust the vehicle flow $q_0 \ (3200 \leq q_0 \leq 6000)$, to determine the vehicle area of the peak.

![Graph](image.png)

**Figure 8.** The relationship between distance and the number of car

According to the table data fitting curve, the traffic volume and the number of vehicles in the merging area are positively correlated.

It can be concluded that when the peak value exceeds 6000, the corresponding $k$ is greater than the standard range, and traffic jams or traffic accidents may occur. Therefore, we need to adjust the number of MTC and ETC to optimize the design. As shown in the table 1.

<table>
<thead>
<tr>
<th>Number of ETC channels</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_0$</td>
<td>5350</td>
<td>5650</td>
<td>5730</td>
<td>6610</td>
<td>6730</td>
<td>6300</td>
<td>5920</td>
<td>6100</td>
</tr>
</tbody>
</table>

Therefore, we can determine the optimal charging scheme for the ETC channel is 5. When MTC is 3, the highest capacity is 6730.

4. SIMULATION ANALYSIS OF TOLL SQUARE PERFORMANCE BASED ON VISSIM

The carts of road occupation is greater than the car, so the traffic is mainly affected by the proportion of cart. In this paper, by analyzing the proportion of carts in traffic, the influence of light or heavy traffic on road capacity is obtained. In order to explore the performance in light and heavy traffic, use the VISSIM to analyze...
the results of the simulation which compares the road traffic capacity of the simulation with theoretical calculation (Zhao, Cai and Cheng, 2014).

4.1. Simulation of the Basic Traffic Capacity of the Car with Mixed Charging Mode

There are five MTC toll lanes and three ETC toll lanes in the eight toll lanes. In the process of simulation, the proportion of private cars to the total traffic flow starts from 10%, and increases by 10%, then the theoretical and simulated values of the traffic flow can be obtained.

![Figure 9](image9.png)

**Figure 9.** The theoretical value of small flow and simulation simulation value

Analysis shows that in the process of the increase of the proportion of private cars, there is error between the simulation value and the theoretical value, but generally the error is not more than 100 pcu/h. The result is within the allowable error range. The stability of the improvement program of the toll plaza is good.

4.2. Simulation of the Basic Capacity of Heavy Traffic Flow with Mixed Charging Mode.

The design of the simulation scheme is the same as the light traffic, in which 5 of the toll lanes are MTC and the other 3 are ETC. In the process of simulation, the proportion of private cars in the total traffic flow rises from 10 percent, and each time it increases 10 percent.

![Figure 10](image10.png)

**Figure 10.** The theoretical value of large flow and simulation simulation value

Finally we can obtain the figure of theoretical and simulated values of the vehicle flow. Analysis shows, it can be seen that when the proportion of cars changes, the error is obviously higher than the error of the change of the car flow rate, and the capacity of the toll station is reduced. However, the error analysis of traffic shows that the error fluctuation is in the range of 105–110 pcu/h at present, still within the acceptable range.

5. CONCLUSIONS

In this paper, a one-way example is used to establish the delay-time model of expressway toll plaza. Because the vehicle can be divided into three stages through the toll plaza and the behavior of each stage is different, then the time is divided into three submodel. According to the data of the New Jersey toll station, the curve of the total time and the toll station B is fitted to find the optimal number of lanes corresponding to the shortest delay time, and the width of the toll plaza is calculated according to the known L; from the safety
analysis, the length of the toll plaza is determined by the safety degree of the index and the safety degree of the index, and the length and the width of the toll plaza are determined. Considering the randomness of the vehicles entering the lane at the same time and the different lanes and then the probability of the Poisson distribution is obtained by the probability of the Poisson distribution, and the change of the total number of vehicles is obtained. According to the image’s combination, it is judged whether the indicators of the traffic jam and the accident occurred to find more than the upper limit of the safety point, so we should adjust the station spacing and traffic flow. At the same time, according to the permutation and combination of special location to determine the specific distribution.

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