Merge after toll more quickly

Min Qin [a], Yuguang Jia [b] and Xuezhen Gong [c]

Shandong University of Science and Technology, Qingdao 266590, China

[a]qinminttkl@163.com, [b]2492524008@qq.com, [c]gxuezhen@126.com

Abstract

With the rapid development of the transportation industry, the problems of expressway are becoming more and more serious. Research shows that more than 85% of freeway problems are concentrated at tollbooths, especially on the main road. This paper focuses on solving the related problems of expressway toll station. Taking the main road (one-way) as an example, this paper analyzes the problem and gives the solution, and puts forward some suggestions on the improvement of the existing charging mode. The simulation results show that the higher the traffic flow is, the more obvious the advantages are. At last, based on our model, some recommendations are offered.

Keywords

Freeway problems, charging mode.

1. Introduction

With the rapid development of the transportation industry, the development of the highway is faster and faster, more and more problems are also produced. the toll plazas always interrupt traffic on multi-lane highways. This paper focuses on how to solve the problem of how to integrate the toll station into the lane quickly and effectively.

Take New Jersey Garden Island as an example to analyze the concrete problems. Fluid mechanics simulation theory combined with queuing theory to establish the time delay model, the Toll Station Lane configuration scheme, the use of MATLAB simulation results, analysis shows that this is the optimal program. The schematic diagram is shown below

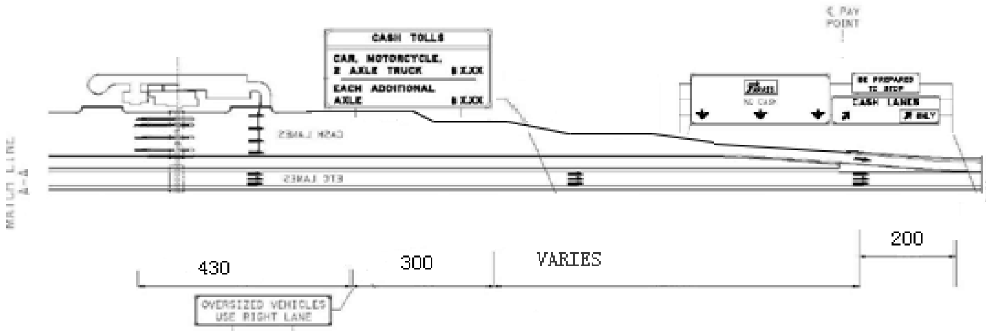

Figure 1 schematic diagram

2. Model design

According to international experience, in a toll station the ratio of operating costs and income is 5%~10% with the reasonable number and simple facilities[1]. If the number of toll facilities is greater than the required quantity, this ratio would reach to 10%~15% and if the poor management occurs, this ration can be 30% or more. The size of the toll plaza and the number of lanes required depend on traffic volume, the capacity of each toll lane and service level.

2.1 Queuing theory

Queuing system consists of three components: input process, queuing rules and service organization.

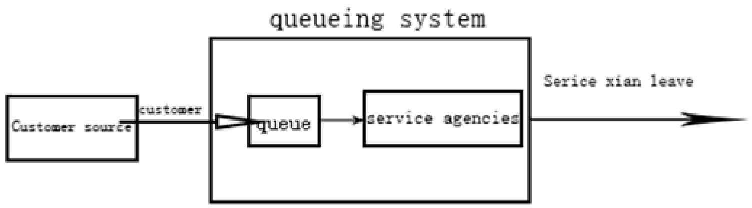

Fig2 A model for the queuing theory

The law of customer arrival service system is described by a certain number of customers within a certain time before or after the arrival of two customers in the interval time, and generally it can be divided into two types of deterministic and stochastic. In this paper, stochastic model is adopted. The input of stochastic model is the number of arrivals reaches a certain random distribution in time *t*. For example, if the number of arrivals reaches Poisson distribution, The probability of reaching *q* customers in time *t* is :

$$P_q(t) = \frac{e-\lambda t(\lambda t)^n}{\text{q!}}(q=0,1,2,\ldots,\text{Q}) \tag{2-1}$$

In queuing theory, the time interval between two adjacent customers obeys negative exponential distribution, which is:

$$P(T_0 \le t) = 1 - e^{-\lambda t} \tag{2-2}$$

The service time t_f obeys a random negative exponential distribution, which is:

$$P(t_f \le t) = 1 - e^{-ut}(t \ge 0) \tag{2-3}$$

2.2 Single channel service model(M/M/1)

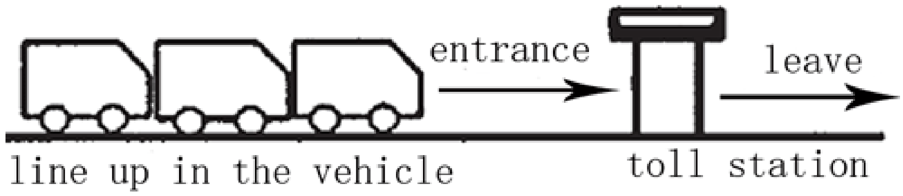

Fig3 Single channel service model

The probability of q cars in the system is

$$P_q = \left(\frac{\lambda}{\mu}\right)^q P_0 = \rho^q P_0 \tag{2-4}$$

$$\rho = \lambda / \mu < 1 \tag{2-5}$$

According to the probability properties $\sum_{q=0}^{\infty} P_q = 1$,

$$P_0 \sum_{q=0}^{\infty} \rho_q = P_0 \frac{1}{1-\rho} = 1 \tag{2-6}$$

$$\begin{cases} P_0 = 1-\rho \\ P_q = (1-\rho)\cdot\rho^q \end{cases} \tag{2-7}$$

Supposing there are cars in the system with a probability of , queue length L is:

$$L=\sum_{q=0}^{\infty} qP_q=\sum_{q=1}^{\infty} q(1-\rho)\rho^q=\rho+\rho^2+\rho^3+\cdots+\rho^q+\cdots=\frac{\rho}{1-\rho}=\frac{\lambda}{\mu-\lambda} \tag{2-8}$$

$$\begin{aligned} L_q &= \sum_{q=1}^{\infty}(q-1)P_q=\sum_{q=1}^{\infty}(q-1)(1-\rho)\rho^q=\sum_{q=1}^{\infty}q(1-\rho)\rho^q-\sum_{q=1}^{\infty}(1-\rho)\rho^q \\ &= L-\rho=\frac{\rho^2}{1-\rho}=\lambda^2/\mu(\mu-\lambda) \end{aligned} \tag{2-9}$$

The expected dwell time W of the vehicle in the system obeys a negative exponential distribution with parameter $\mu-\lambda$,and the distribution function and density function are:

$$\begin{cases} F(\omega)=1-e^{-(\mu-\lambda)\omega} \\ f(\omega)=(\mu-\lambda)e^{-(\mu-\lambda)\omega} \end{cases} \tag{2-10}$$

The expected waiting time of the vehicle within the system W_q is:

$$W_q=W-\frac{1}{\mu}=\frac{1}{\mu-\lambda}-\frac{1}{\mu}=\frac{\mu}{\mu(\mu-\lambda)}=\frac{L_q}{\lambda} \tag{2-11}$$

Multi-channel service model is composed of multiple single-channel service model.

2.3 Lane configuration model

For a toll plaza, The process of passing through the toll plaza is not only the process of toll collection, but also the transition before entering the toll booth and the transition from the toll station. Vehicles through the toll plaza process can be divided into three stages: driving into the transition section, waiting for the service section, leaving the transition section.

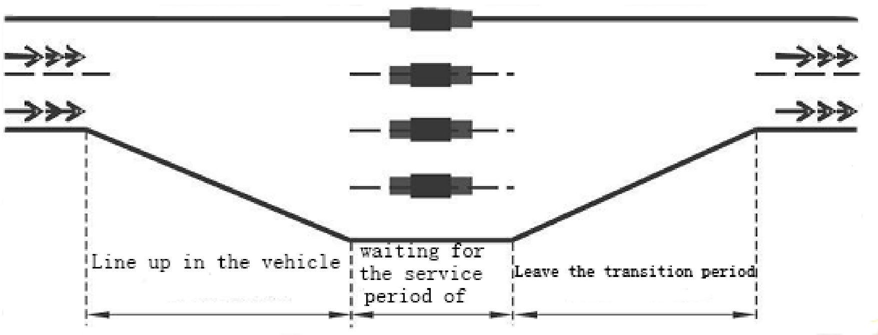

Fig4 Toll plaza (one-way)

The unidirectional toll plaza layout and stage division are shown in Figure 1.In these three stages, vehicle behavior is different, so three sub-models were needed to calculate for each section of the time consumed.

The total model can be divided into three sub-models, each sub-model through the traffic flow q and flow velocity v are interrelated. Traffic flow in the first stage and the third stage are constant but in the second stage, due to the existence of toll stations, at some instant, q_2 is likely to be less than q_1.

(1) Entrance sub-model

The structure of the model is shown below:

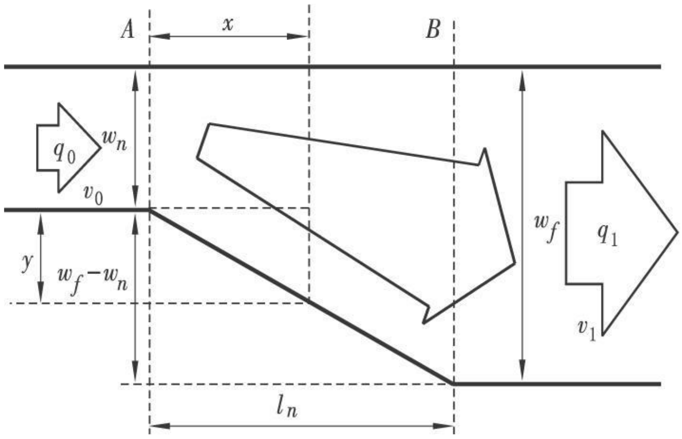

Fig5 Enter the jokes model (one-way)

Freeway has closed, full interchange, strict control of access characteristics. In this paper, fluid mechanics simulation theory is used to study it. The fluid mechanics simulation theory uses the basic principle of fluid mechanics, simulates the continuity equation of the fluid, establishes the continuity equation of the traffic flow. The density change of traffic density is compared with the fluctuation of water wave and abstracted as traffic slope. Suppose that the traffic flow is free-flow, the traffic enters the toll plaza with the initial traffic flow q_0 and the initial traffic velocity v_0 .

According to traffic flow theory:

$$q_0 = v_0 k_0 \tag{2-12}$$

When the traffic flow in a transition point, the traffic flow, traffic velocity, traffic density relationship is:

$$q_0 = v(x) k(x) \tag{2-13}$$

Because the traffic flow is constant, the relationship between the traffic density and the transition area width is:

$$k_0 w_n = k(x) w(x) \tag{2-14}$$

According to geometric knowledge，

$$\frac{y}{x} = \frac{w_f - w_n}{l_n} \tag{2-15}$$

$$w(x) = w(n) = y \tag{2-16}$$

The total width of the transition zone and the length of the transition section and the number of toll stations n relationship are:

$$w_f = nd \tag{2-17}$$

$$l_n = na_1 \tag{2-18}$$

According to the above formula $v(x)$ can be solved.

$$dT = \frac{dx}{v_x} \tag{2-19}$$

$$T_n = \int_0^{l_n} T \tag{2-21}$$

$$T_n = \frac{nw_n a_1}{v_0 (nd - w_n)} \ln\left(\frac{nd}{w_n}\right) \tag{2-22}$$

(2)Waiting for the service model

The flow of traffic through Stage 1 is constant for a certain period of time, which is:

$$q_1 = q_0 \tag{2-23}$$

The model structure is shown below:

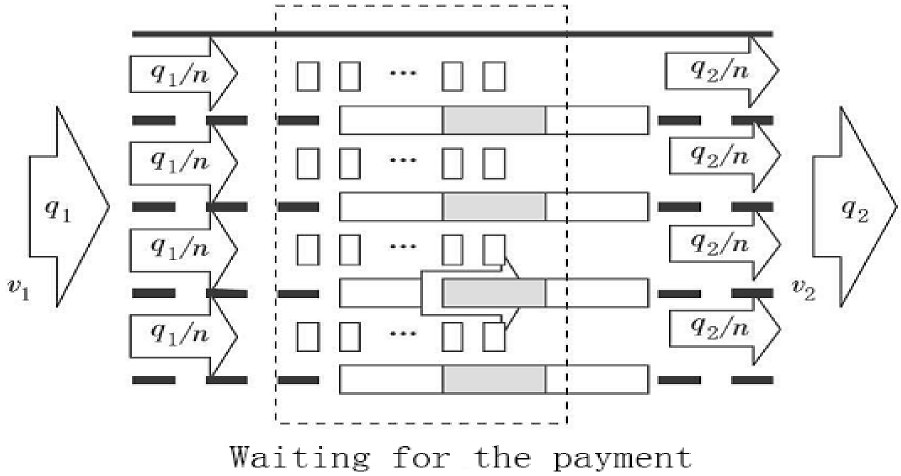

Fig6 Waiting for the service

According to queuing theory, each toll intersection obeys M/M/1 system, and waiting for service stage is several M/M/1 system. In this stage, average time spent on vehicles is described by:

$$T_w = \frac{1}{\mu - \lambda} \tag{2-24}$$

$$\lambda = q_1 / n \tag{2-25}$$

$$T_w = \frac{n}{n\mu - q_1} \tag{2-26}$$

Number of toll booths, $n > q_0 / \mu$.

For the sake of simplicity, it is assumed that there is an initial speed when the vehicle leaves the toll lane and enters the transition section.

(3) Model of leaving the transition section

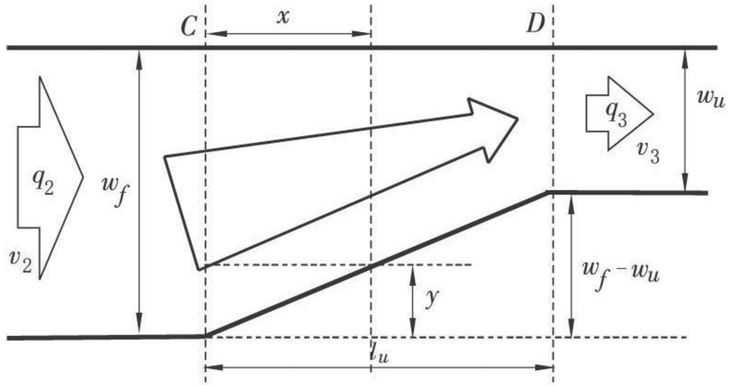

Fig7 Leave the jokes model

The traffic flow leaves the billing service stage, and after leaving the transition zone, the road becomes wider and then enters the main flow at the flow rate line. Time spent is:

$$T_u = \frac{n^2 d a_1}{v_2 (nd - w_u)} \ln\left(\frac{nd}{w_u}\right) \tag{2-27}$$

Toll time total delay model is:

$$T = T_n + T_w + T_u = \frac{n w_n a_1}{v_0 (nd - w_n)} \ln\left(\frac{nd}{w_n}\right) + \frac{n}{n\mu - q_1} + \frac{n^2 d a_1}{v_2 (nd - w_u)} \ln\left(\frac{nd}{w_u}\right) \quad (2\text{-}28)$$

3. Model solving and results

(1)Simulation analysis

This pager takes New Jersey as an example to carry on the detailed solution. Through the Google map query to get the actual toll station as follows:

Fig8 One-way toll station actual figure of New Jersey

New Jersey uses two-way toll station mode, the reverse direction is symmetrical with the reverse distribution, the same principle. Here, for simplicity, only the unidirectional mode is analyzed.

New Jersey vehicle flow data table as follows:

Table61 New Jersey vehicle flow data table

New Jersey's Historical Daily VMT											
By Area Type											
YEAR	STSTEWIND RORAL	SMALL URBAN AREAS	*URBANIZED AREA*								TOTAL
			New Yoek-Newark NY-NJ-CT	*Philadelphia PA-NJ-DE-MD*	*Allentown PA-NJ*	*Trenton NJ*	*Atlantic City,NJ*	*Vineland NJ*	Twin Rivers-Hightstown, NJ	Villas NJ	
1989	30,339,000	2,792,000	94,462,000	22,045,000	732,000	7,084,000	4,299,000	1,667,000	N/A**	N/A**	163,420,000
1990	28,814,000	2,777,000	94,948,000	20,772,000	706,000	6,888,000	4,120,000	1,702,000	N/A**	N/A**	160,727,000
1991	32,183,000	2,751,000	93,236,000	20,053,000	685,000	6,992,000	4,021,000	1,778,000	N/A**	N/A**	161,699,000
1992	32,379,000	2,786,000	92,908,000	20,151,000	685,000	6,768,000	4,108,000	1,805,000	N/A**	N/A**	161,590,000
1993	27,745,000	1,801,000	96,882,000	21,136,000	690,000	8,040,000	4,689,000	1,912,000	N/A**	N/A**	162,895,000
1994	29,977,000	1,896,000	97,232,000	20,898,000	654,000	7,691,000	4,507,000	1,961,000	N/A**	N/A**	164,816,000
1995	31,494,000	1,925,000	97,742,000	20,911,000	624,000	7,206,000	4,625,000	1,873,000	N/A**	N/A**	166,400,000
1996	33,061,000	2,076,000	100,047,000	20,404,000	718,000	7,255,000	4,307,000	1,729,000	N/A**	N/A**	169,597,000
1997	33,845,000	1,960,000	101,882,000	20,610,000	746,000	7,417,000	4,453,000	1,777,000	N/A**	N/A**	172,690,000
1998	34,885,448	2,016,851	104,254,742	20,982,481	710,387	7,380,156	4,265,516	1,857,198	N/A**	N/A**	176,352,779
1999	35,769,000	2,070,000	106,576,000	21,180,000	695,000	7,561,000	4,131,000	1,940,000	N/A**	N/A**	179,922,000
2000	37,404,000	2,121,000	107,903,000	21,202,000	681,000	7,798,000	4,291,000	1,953,000	N/A**	N/A**	183,353,000
2001	38,619,000	2,150,000	109,656,000	21,555,000	643,000	8,066,000	4,310,000	1,980,000	N/A**	N/A**	187,663,000
2002	39,313,000	2,156,000	112,136,000	22,188,000	628,000	8,204,000	4,685,000	1,957,000	N/A**	N/A**	191,267,000
2003	18,912,000	3,504,000	127,613,000	26,278,000	777,000	7,134,000	6,512,000	2,307,000	1,296,000	904,000	195,237,000
2004	19,286,000	3,638,000	130,351,000	26,662,000	853,000	7,302,000	6,273,000	2,394,000	1,349,000	1,011,000	199,119,000
2005	19,696,000	3,702,000	132,446,000	27,264,000	908,000	7,463,000	6,588,000	2,464,000	1,479,000	1,066,000	203,076,000
2006	19,913,000	3,808,000	134,840,000	27,709,500	951,000	7,658,500	6,957,000	2,606,000	1,527,000	1,161,000	207,131,000
2007	18,961,000	3,741,000	137,782,400	27,328,300	906,000	7,645,300	6,767,000	2,608,000	1,552,000	1,128,000	208,419,000
2008	17,292,000	3,348,000	133,866,000	26,715,000	811,000	7,253,000	6,163,000	2,560,000	1,539,000	1,104,000	200,651,000
2009	17,107,000	3,452,000	132,996,000	26,569,000	866,000	7,353,000	6,177,000	2,482,000	1,497,000	1,087,000	199,586,000
2010	17,598,240	3,441,786	133,215,644	26,624,054	841,617	7,067,787	6,162,665	2,462,803	1,501,811	1,159,372	200,075,779
2011	17,255,330	3,424,836	134,090,113	26,581,030	886,983	7,051,255	5,990,104	2,413,872	1,487,167	1,076,217	200,256,907
2012	12,434,980	4,066,554	137,226,621	28,816,252	1,068,787	7,562,633	6,522,309	2,174,394	1,886,971	1,042,073	202,801,573
2013	12,453,071	4,153,052	137,721,443	28,624,742	1,069,271	8,478,630	6,516,392	2,179,209	1,945,693	1,049,709	204,191,211
2014	12,846,425	3,876,314	138,599,077	28,784,688	1,075,862	8,076,101	6,451,368	2,233,533	2,032,054	1,110,564	205,085,987
2015	13,246,834	4,078,013	138,938,960	29,007,591	1,193,472	8,328,189	6,296,146	2,285,778	2,094,852	1,087,479	206,557,313
Daily VMT for the Poughkeepsie--Newburg, NY-NJ Urban area is included in New York--Newark, NY--NJ--CT andUrban area figures											
Urban area names change based on 2010 census (which include the old areas also)											
Source: Bureau of Transportation Data and Safety, Roadway Systems Section											

Assuming the freeway is a standard cross-section, the single lane width is 3.75m and the one-way three-lane expressway wn and wu are both 11.25m. The width of each toll booth (including toll booths and toll lanes) is 5m. Assuming an average service rate of 712 pcu/h, the average rate of arrival at the toll plaza is 4000 pcu/h. The initial speed of the vehicle entering the toll plaza is assumed to be 40 km/h while the initial speed is assumed to be 20 km / h when leaving the tollgate. The specific values of each parameter are shown in the following table:

Table2 The specific values of each parameter table

W_n/km	W_u/km	d/km	μ/(p cu/h)	q_0/(p cu/h)	v_0/(km/h)	v_2/(km/h)
0.01125	0.01125	0.005	712	4000	40	20

The parameters in the table above into the time delay model, the use of MATLAB simulation to get the lane configuration results are as follows (the program see appendix):

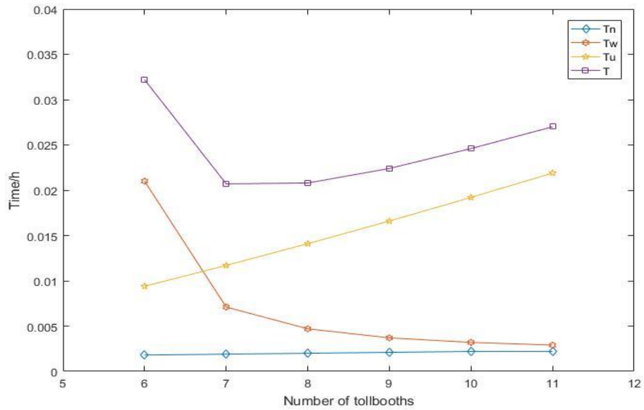

Fig9 Lane configuration results

According to the above analysis, when the number of toll stations is 7, the average time T of vehicles passing through the toll plaza is the smallest. Combined with queuing theory, according to the actual situation in New Jersey, the use of MATLAB simulation results are as follows (see appendix):

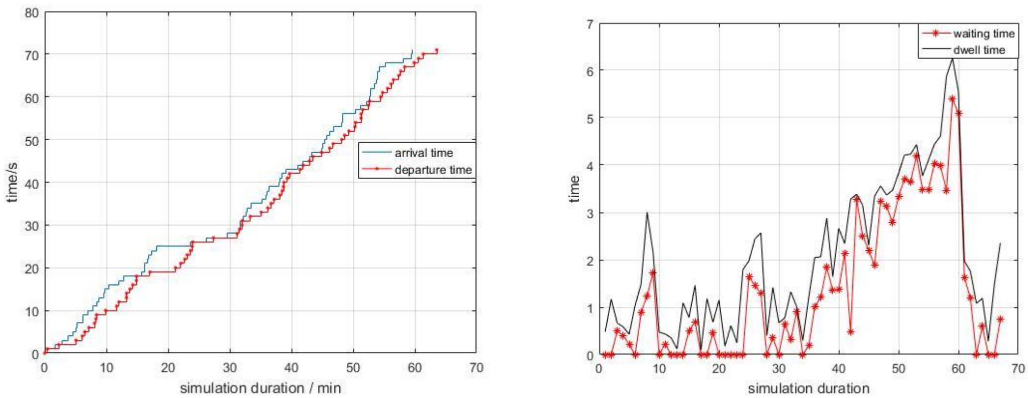

Fig10 a time delay picture of 7 toll booths

(2)Merge After Toll model

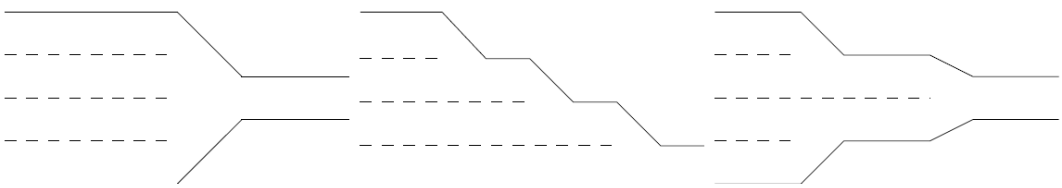

Fig11 Toll Plaza Lane merge mode

According to the results of the survey, multiple deceleration into the lane mode in the toll plaza residence time is shortest, the result is optimal.

(3)Variable Speed Cellular Automata Traffic Flow Model

Under the premise of ensuring the toll station security, the dynamic capacity of the toll station is improved by dynamic non-linear control of the vehicle speed strategy by using cellular automata (CA) modeling and analysis.

The phenomenon of traffic in high-speed road toll station is characterized by disorder and chaos. Reasonable speed limit value in the improvement of traffic conditions, improve road capacity and so play an important role. Based on the original STNS model, the variable speed limit cellular automata model of highway toll station is established, and the traffic flow characteristics of dynamic speed control region are

simulated. According to the simulation results, the influence of different effective speed limit, segment length and traffic condition on traffic flow and road capacity was analyzed.

Taking into account the characteristics of New Jersey toll roads, as a two-way six-lane continuous and high-pressure traffic freeway, each lane is divided into L cells. The cells i contain two states. One is empty, and the other is occupied by the vehicle in speed of v (the v can only be 0,1,2, ... and other integer values, which is the maximum allowable speed of the vehicle). $x(i,t)$ and $v(i,t)$ are used to represent the space and speed of the i-th in t time respectively. $d(i,t)$ is the cell number of the i-th vehicle at the moment t and the preceding vehicle $i+1$. l is the number of cells occupied by each vehicle.

$$d(i,t) = x(i+1,t) - x(i,t) - l \quad (3\text{-}1)$$

In each time step, according to the characteristic of the traffic flow in the highway toll station, all the vehicles in the cell are set to update and evolve the following four rules at the same time:

1) Speed up:

$$v(i,t+1/3) = \min[v(i,t)+1, v_{\max}] \quad (3\text{-}2)$$

Speed up corresponds to the fact that the driver desires to travel at maximum speed in reality. Vehicles enter the highway toll station area after being speed limit,

$$v(i,t+1/3) = \min[v(i,t)+1, V_{\max}] \quad (3\text{-}3)$$

$V_{\max}$ is the maximum speed of toll station area. $V_{\max} \le v_{\max}$

2)Slow down:

$$v(i,t+2/3) = \min[v(i,t+1/3), d(i,t)] \quad (3\text{-}4)$$

The driver slow down in order to avoid collision with the vehicle in front or to avoid the sudden situation.

3) Randomized moderation (in probability p):

$$v(i,t+1) = \max[v(i,t+2/3)-1, 0] \quad (3\text{-}5)$$

The vehicle decelerates due to various uncertainties.

4)Movement:

$$x(i,t+1) = x(i,t) + v(i,t+1) \quad (3\text{-}6)$$

The vehicle travels at the adjusted speed. In order to make the simulation closer to the real highway toll station, according to the lane change rule of the vehicle and the possible situation of the highway toll station, the asymmetric lane changing rule is formulated on the basis of the STNS lane change. In the toll station area, when a road congestion occurs, if the congested lane on the vehicle to meet:

a. $d(i,t) < \min(v(i,t)+1, v_{\max})$

b. $d_{other}(i,t) > d(i,t)$

c. $d_{back}(i,t) > 1 + \min(v_{back}(i,t)+1,\ v_{\max}) - \min(v(i,t)+1, v_{\max})$

d. $rand() < pchange1$

Vehicles in the toll station area change lanes, then $pchange1 >> pchange2$.

The freeway toll station area belongs to the building body with export nature, so the open boundary conditions are used. At the end of each update, the position of the headway near the exit of the roadway x_{lead} and the location of the wagon near the entrance to the tollgate at the highway x_{last} are monitored. At the exit, if $x_{lead} > L$,the vehicle runs out of the toll station and the next car becomes the front. At the entrance, if $x_{last} > l_x$,vehicles at a certain speed into the highway toll station. l_x is the number of cells between the tail car and the proposed car.

In order to combine the actual situation as much as possible, freeway toll station is 4000 meters long bi-directional multi-lane, and the length of each cell is 1.5 meters. Data shows that the New Jersey highway traffic pressure, the passage of more peak hours and the adjacent peak time interval is small, so the highway toll station area consists of 3000 cells. Taking into account the large freight cars and small private cars are not the same length, average treatment is carried out. Each standard car occupies 4 cells, $l_f = 4$. The speed of the vehicle is $40 km/h$. Simulation step length is $4s$. The static speed upper limit (no variable speed limit) is 24. Highway toll station is bi-directional into and out, so the use of open boundary conditions. The optimal value of effective speed limit, the length of different speed section and the efficiency of speed limit are simulated and analyzed under different traffic conditions and general traffic conditions.

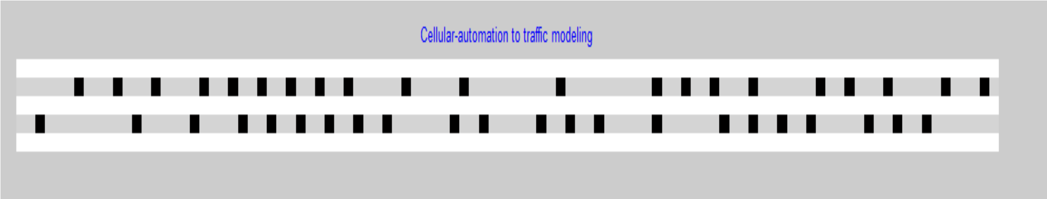

Fig12 Traffic model of freeway toll station based on cellular automata

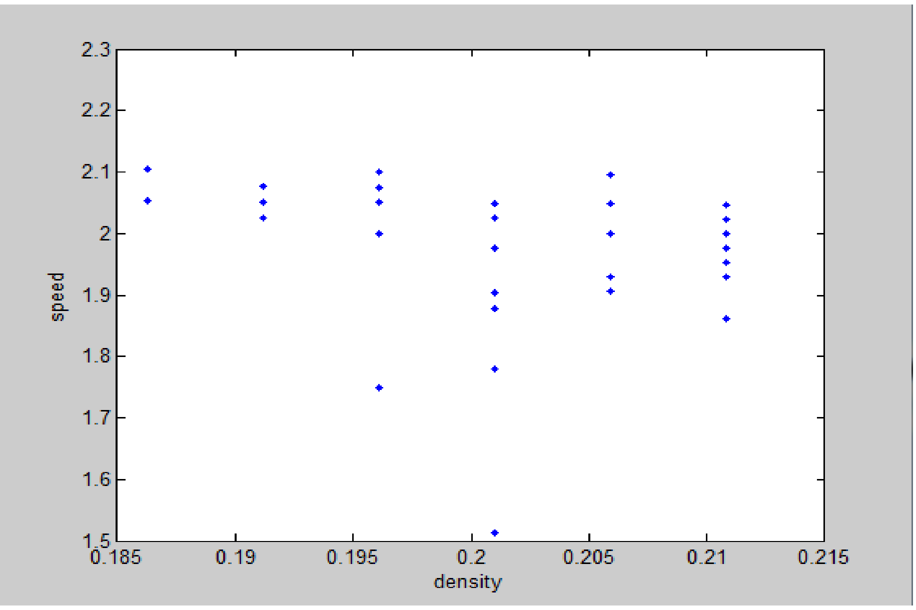

Fig13 The average velocity (av) - density curve of (ap)

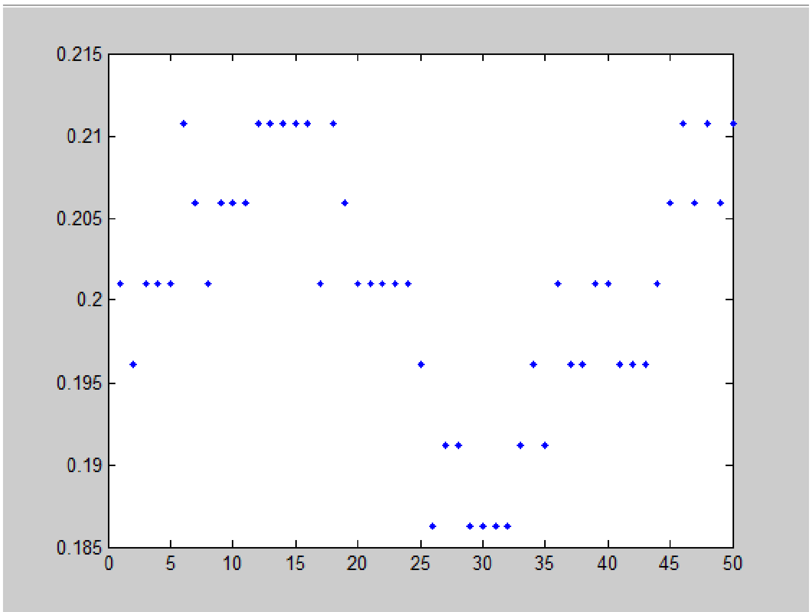

Fig14 The curves of traffic flow density (ap)

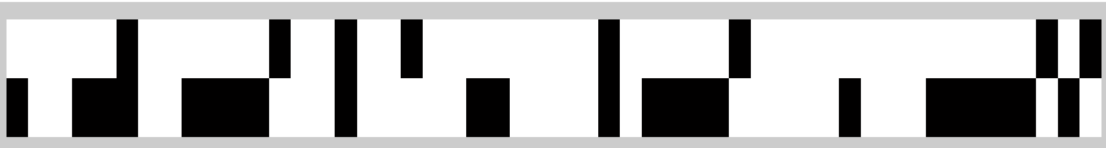

Fig15 A single lane from the simulation

Simulation results show that total traffic flow is 175, traffic flow on the right side is 80, traffic flow on the left side is 95. The right side of the lane brake law appears 1068 times, and the left side of the lane brake law appears 439. The number of left turns is 1056, and the number of right turns is 944 times. The conclusions can be drawn that the program has a good ability to disperse traffic jams

(4)Cost model

Highway traffic in New Jersey is growing during its life cycle. If the existing basis to increase the size of the toll station, it would increase the construction and operation costs, and cause the idle waste of resources. Toll booth construction should be strictly in accordance with toll station design standards, reasonable to determine the scale of construction for the latter part of the expansion or transformation of the left redundant and upgrade space. New Jersey highway toll station is divided into the main line toll station and ramp toll station. In this paper, mainline toll station is studied.

Type of Charging Facility: Mainline toll station

Construction area: 800~1700 m^2

Number of toll channels: 4~12

Design traffic flow

$$DHV = AADT * K\% * D \tag{3-7}$$

$D = 0.6$ is optimal

Toll channel model

Cost Analysis: When the vehicle enters the toll plaza area, two kinds of economic consumption generate. On the one hand, from the perspective of the operating costs of tolls, the operating costs of toll booths are generated, which mainly include labor costs, facilities operating costs and basic purchase costs; On the other hand, the main vehicle point of view, resulting in a delay in fuel consumption costs, loss of travel time value.

Perspective of consumers

(1). Cost of labor

The cost of labor is to maintain the normal operation of the toll station of human consumption costs. New Jersey toll road toll station staff can be divided into toll collectors and other logistics support staff in two parts. The labor cost of the toll station shall be the average daily wage of all employees who meet the normal operation of the toll station.

$$c_r = \frac{c}{30} * r * n \tag{3-8}$$

(2). Operating costs of toll stations

Facilities operating costs are mainly reflected in the maintenance of facilities and power consumption[2]. Facilities are the basis of toll station operation, power supply is to ensure the normal operation of the premise of a variety of facilities, and to ensure the normal operation of the facilities must be regular maintenance and repair work, so here the cost of using the cost of these two parts and as a toll station Of the facility's operating costs.

$$c_s = \frac{M + W}{30} \tag{3-9}$$

c_s is average monthly operating cost, M is average monthly electricity charges (water, electricity and gas),and W is monthly average maintenance costs for various facilities.

(3). Basic purchase cost

To meet the normal operation of the toll station, the procurement of fuel and related work must be necessary. The average daily acquisition cost is determined based on the average monthly acquisition cost of toll stations.

$$c_g = G / 30 \tag{3-10}$$

c_g is daily average basic acquisition fee and G is monthly average purchase cost.

Driver 's perspective

(1) Delay fuel consumption costs

The vehicle repeats the idle-start acceleration-braking behavior in the toll area, so vehicle fuel consumption in the delay time is mainly consumed in the idle and start the acceleration of two stages[3].

a. Idle fuel consumption costs

Idle fuel consumption costs depend on the idle time and the average idling fuel consumption rate. Passenger car and truck idling fuel consumption rate are $0.23ml/s$ and $0.69ml/s$ respectively so the idle fuel consumption costs for passenger cars and trucks are

$$c_k^1 = 0.23 \times w_s \times c_1 \tag{3-11}$$

$$c_h^1 = 0.69 \times w_s \times c_2 \tag{3-12}$$

respectively. c_1, c_2 are market prices of gasoline and diesel. w_s is average in-system residence time.

b. Accelerate fuel consumption costs

According to relationship between the various fuel consumption, fuel consumption of the vehicle activating once is probably equal to two minutes of idle consumption of fuel consumption. From the average fuel consumption rate of van can get the average fuel consumption of passenger cars were started once. The average starting fuel consumption of passenger cars and trucks are $27.6ml$,$82.8ml$. Average number of customers waiting in the system is $\overline{L}$ .According to Principle of Average Team Length Distribution, the average number of waiting vehicles in a single channel is $\overline{L}/n$ .The times of the vehicle accelerates during passage is $\overline{L}/n$, so the passenger cars and trucks to start fuel consumption are $c_k^2 = 27.6 \times c_1 \times \overline{L}$ and $c_h^2 = 82.8 \times c_2 \times \overline{L}$ respectively.

(2) Value of vehicle travel

The value of vehicle travel time is the monetary performance of the amount of loss due to the passage of time. In the process of travel, the vehicle always want to save time and increase economic value, stay in the toll gate passage longer, resulting in the greater the value of vehicle travel time. According to the vehicle type, the vehicle travel value includes the passenger travel time value and the truck traveling time value.

a. Bus travel time value

The value of passenger travel time is defined by the economic value lost by the individual in the delay time. The travel time value of a single passenger car can be determined by the average passenger capacity, the average travel time value T_s and the length of stay of the vehicle in the system. According to the investigation and analysis of the passenger capacity of the highway vehicles, the average carrying capacity of the individual passenger cars is determined by the average number of passengers and the proportion of the total number of passenger cars

Table3 the number of passenger car

Vehicle model	Small passenger car	Medium-sized passenger car	Large passenger car
Carrying capacity	2	15	35
Survey proportion	60	10	30
Average carrying capacity	13.2		

Per capita travel time value is the amount of economic value loss that a person can achieve per unit of time and it can be estimated according to the average social wage.

Through the above analysis, a single passenger car in the trip time value for the trip is

$$CK = 13.2 \times 2.78 \frac{w_s}{3600} = 0.01 w_s \quad (3\text{-}13)$$

Model optimization

From the cost analysis, the relationship between customer cost and toll cost is not relatively independent. Additional toll booths will help reduce customer costs, while increasing the toll booth operating costs. It is unreasonable to blindly increase toll booths. The number of toll booths is modeled in this paper. The model[2] is shown below:

$$\begin{aligned} &\min Z(C) = X_1 C + X_2 W_s(C) \\ &C > 0 \\ &X_1 = a(0.23W_s c_1 + 27.6 c_1 \overline{L} + 0.01W_s) + (1-a)(0.69W_s c_2 + 82.8 c_2 \overline{L} + 0.0058W_s) \\ &X_2 = \frac{C \times r \times n + M + W + G}{30} \end{aligned} \quad (3\text{-}14)$$

C is number of toll booths, X_1 is the use cost of per unit time, X_2 is the queuing cost, $W_s(C)$ is average length of stay in the toll collection channel and a is proportion of traffic flow.

Objective function is

$$W_s(C^*) - W_s(C^*+1) >= X_1 / X_2 >= W_s(C^*-1) - W_s(C^*) \quad (3\text{-}15)$$

The New Jersey data is substituted into the above equation.

$$W_s(C^*) - W_s(C^*+1) >= \frac{0.6\cdot(0.00176W_s + 0.21114\cdot\bar{L} + 0.01W_s) + 0.4\cdot(0.00523W_s + 0.627624\cdot\bar{L} + 0.058\cdot W_s)}{\frac{C\cdot r\cdot n + M + W + G}{30}} \quad (3\text{-}16)$$

$$>= W_s(C^*-1) - W_s(C^*)$$

According to the cost model described above, the particle swarm algorithm is used to process the data. six-dimensional ten-cell is used to simulate the existing three-lane seven toll stations. The results show with the increase in the number of cars passing through toll booths, on the X-axis, the cost difference between the toll station and the driver is gradually reduced. When the number of cars through the toll station reached 220, the cost difference between the two 0.This construction of the toll station is effective to lower the cost of the two. At the same time, fuel consumption costs reduce, and the corresponding reduction in vehicle exhaust emissions follows.:

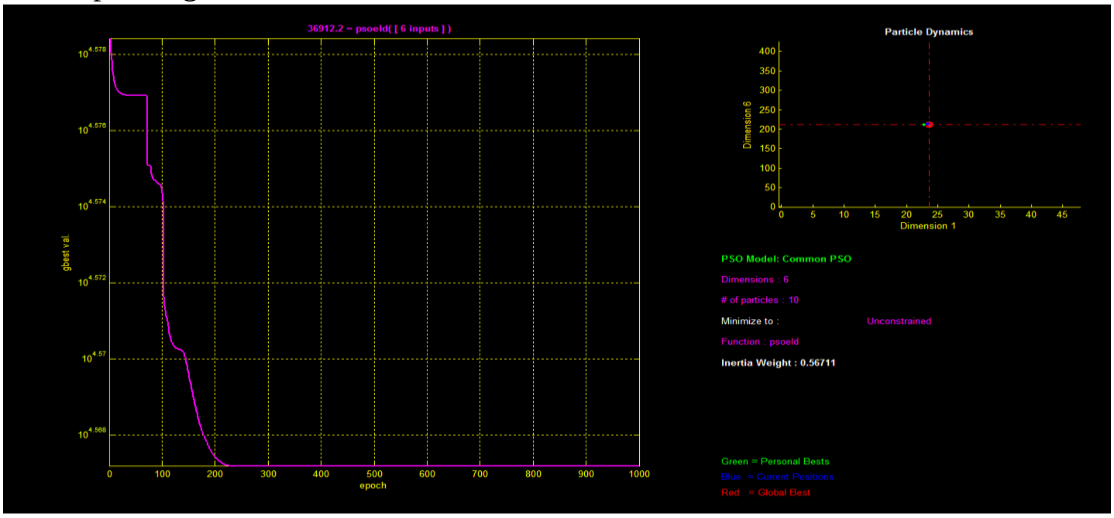

Fig16 Simulation results

Simulation and comparison of three lane changing ways show the first lane change obviously deviates from the center of the dotted dashed line (the green deviates from the red dot). Although the second lane changes in the cross-dotted line coordinates, but amplified and found that it is also off-center (blue, although in the red center, but slightly offset). The third way of changing lanes (light green, the smaller the area that the kind of lane cost of the lowest cost) with the red dotted line slightly the same as the center offset, but its area is significantly smaller than the other two lane way. On the cross dotted line center of local amplification, the phenomenon is more obvious. The first two lane changes cause the discrete point to deviate from the center of the dotted line and the third lane change can be maintained at the center of the dashed cross. The result proves that the third lane changing method is superior to the other two lane changing ways.

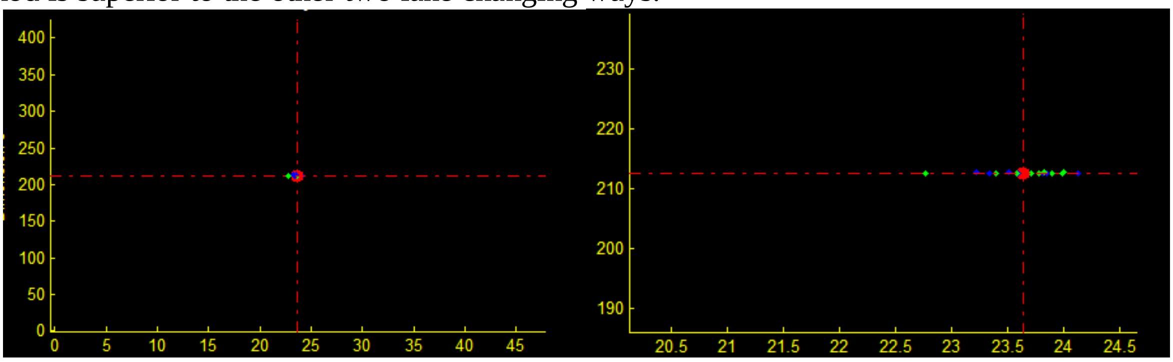

Fig17 Lane comparison chart

4. Conclusion

In summary, combined with the simulation results of the model, three-lane seven tollbooths, using multiple lane into the lane mode is the optimal solution.

The toll collection mode of the tollbooths adopts the electronic toll collection in the middle 3, and the outside 4 is the artificial charge. The simulation results show that the higher the traffic flow is, the more obvious the advantages are.

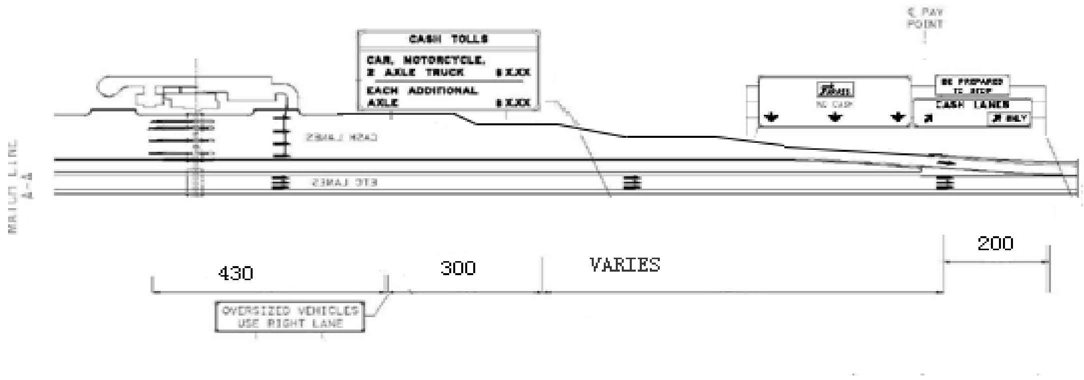

Fig18 Optimal structure diagram

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