Curve Design of Expressway Toll Square

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Abstract

The shape, size and merging pattern of toll plaza on highway affect the throughput. Our goal is to build models to design the toll plaza and to develop merging pattern in toll plaza in order to increase throughput and land utilization.

Keywords

Toll plaza, highway, throughput

1. Introduction

1.1 Problem Background

New Jersey is the fourth-smallest state but the 11th-most populous and the most densely populated of the 50 United States. In New Jersey, there are two highways-New Jersey Turnpike and Garden State Park. The New Jersey Turnpike is one of the most prominent and heavily traveled roadways in the United States. This toll road carries interstate traffic between Delaware and New York, and the East Coast in general. With the increase of population, traffic flow is heavier than previous, so the toll plaza as bottleneck in highway should be redesigned to meet the requirement. At present, ETC and self-driving technologies are rapidly developed, it is urgent to design the new toll plaza and to develop merging strategy.

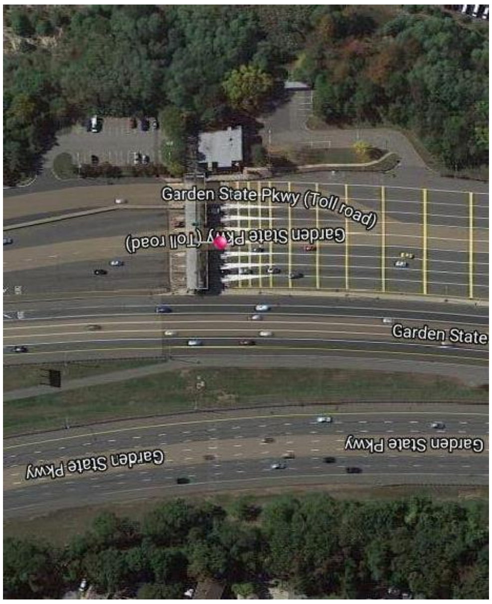

Fig 1. Garden State Park way.

1.2 Previous Research

The design of highway toll plaza should mainly consider capacity, cost and accident prevention. Previous research only focused on capacity. The United States studied the corresponding capacity of each type of charge, and the actual capacity will be affected by the different traffic flow characteristics and service conditions. The research on the toll plaza capacity of other developed countries is limited to experience. There are two classic research methods: queuing theory and simulation

Based on the two sets of formulas derived from the United States TRB special report Traffic Flow Theory and Japan highway design standard, the M/M/K queuing model is chosen by the United States and Japan. In the queuing study of toll booths. Two sets of formulas for the system without the probability of vehicles and the system with many vehicles and the average waiting time are calculated by the same ways. As for the cost and accident prevention, they are less mentioned in the previous literature.

Table 1.Accessibility of a toll channel in various US toll systems

Charging System Type	Capacity of each toll channel (pcu/h)
Labor charge (change)	350
Labor charges (only for sale)	500
Coin charging machine（Collect some coins）	500
Coin charging machine（Collect all coins）	650
Low Speed Automated vehicles Identification Charging System	1200
High Speed Automatic vehicles Identification Charging System	1800

1.3 Our work

For all previous research on toll plaza, the study object is the same (classic toll plaza). But with the increase of payment ways and self-driving vehicles, the toll plaza configuration should be adjusted. By considering the cost of occupancy, throughput, accident prevention and other factors, we find that there are some deficiencies in the existing scheme as follows:

Toll plaza covers a large area leading to high costs.

The ratios of ETC, MTC and manual charges do not reach optimal ratio.

There is no reasonable speed buffering area, which result in the frequent accidents.

The current merging pattern in heavy traffic flow will lead to car congestion. Aiming at solving these, we have made the following solutions.

Establish a new merging pattern to reduce the possibility of traffic jams.

Improve the size and shape of the toll plaza aided by the queuing model for less floor space.

Consider the effect of light and heavy traffic and autonomous (self-driving)vehicles on the model and suggest improvements

2. Notations

See Table 2.

3. Assumptions

Toll booth is operating normally, the service is the same for every vehicle, regardless of traffic congestion caused by the accident.

The vehicles arrive at the toll booth according to Poisson distribution and “first come first serve”.

The vehicles receive independent service and the service time obeys the same negative exponential distribution.

The physical factors of the staff and the motorists are in normal condition.

Electronic toll, manual toll channel are independently of each other, only one car enters the toll booth at a time. We do not consider repeated charges.

Traffic flows of Manual charges and MTC and ETC can not affect each other.

Table 2.Symbols.

Symbol	Definition
Symbols for area	
d	The total length of toll booths
β	Tilt of the toll booth
b	Half short axis
a	Half long axis
S	The area of the toll plaza
	Symbols for cost
M	Average monthly tariff at the toll station
W	Various maintenance costs
L	Various maintenance costs
r	Other workforce
n	Number of lane turns on
	Symbols for fitting
x	Toll plaza Gradient ratio
y	Accident prediction value
	Symbols for queuing length
ρ	Service intensity
L_q	Average queue length
W_q	Average waiting time
P_0	Probability that service personnel are all free
	Symbols for throughput
λ	Vehicle arrival rate
t	Each count interval duration
K	Number of toll lanes
$E[S]$	Expected value of service time
$E[G]$	Expected value of departure time

4. The parameters of existing toll plaza

The land use planning of toll plaza

The lifetime of the classic toll plaza is the same as the lifetime of the main line of the highway based on traditional land use planning. On average, it is 5 years. The general shape is similar. The general design is that there is an involute entrance which can import the traffic flow. It is perpendicular to the highway direction. Then the size of merging area after toll booth is gradually reduced. Considering the traffic expansion of the land requirements, the general solution will set aside a certain area, so that the cost will increase.

Number of Toll booths

Under normal circumstances, the number of toll lanes should meet the demands of vehicles up and down the highway in the opening 15 years.What is usually used is "two in two out of the toll station" design.

Toll station failure, will inevitably lead to congestion. ETC charges Lane transformation can result in the shortage of toll lanes.The number of toll lanes will bring security issues, and have a certain impact on the toll station handling capacity.

Geometric index of toll plaza

There is a lot of problems in the existing toll plaza, the too large gradient of the entrance is easy to make the vehicle unstable. There is usually an indicator to limit the rate of the toll plaza gradient and the length of the charging square section .The general main toll station length can not be shorter than 35 meters. In our improved design, we recommend using more ETC channel in the middle. When the traffic volume is small, the inner lane arc length is shorter than the outer lane, which improve the traffic efficiency. When the traffic volume is large, the ETC lane is in the innermost entrance, which can also prevent "illegal vehicles" traveling into the ETC channel way lanes are mostly located in the outer lane. In order to satisfy the entrance and exit of large vehicles, ultra-wide lane in the central location is relatively wide. The proportion of ETC lanes is random according to the number of ETC vehicles, which is conducive to expanding the toll station throughput capacity.

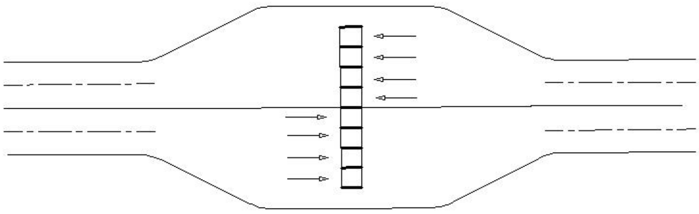

Fig 2. Toll plaza design that already be implemented

5. Model Ⅰ: Toll Station Area Optimization Model

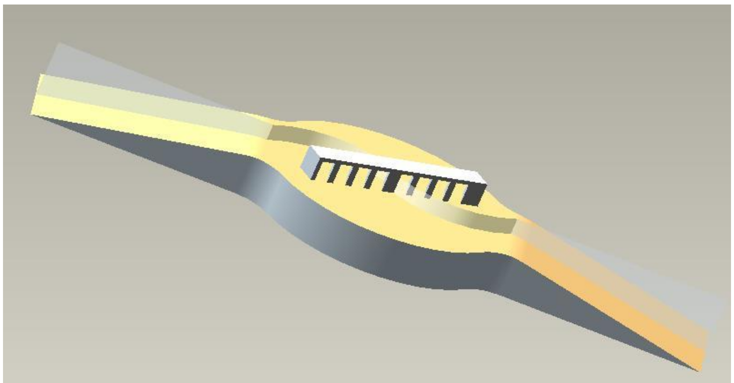

Fig 3. Design of toll plaza structure

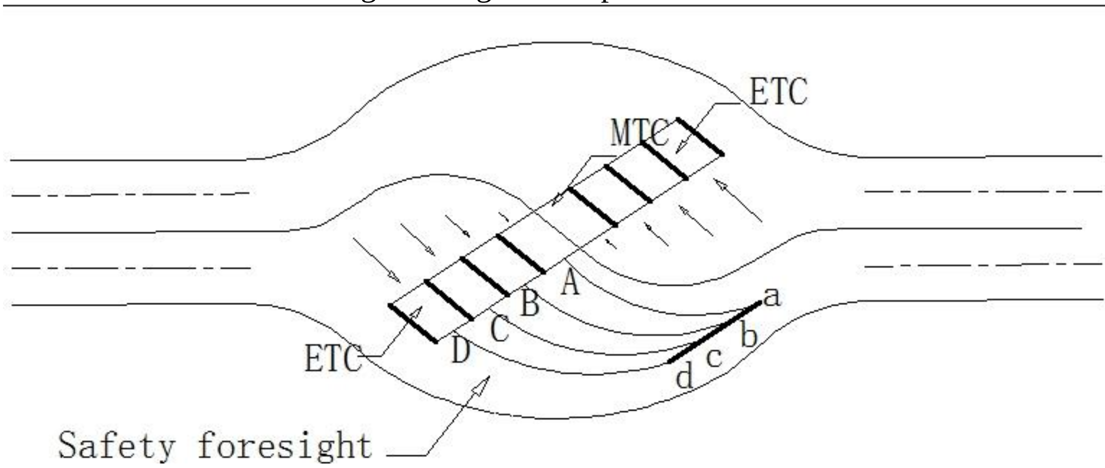

Fig 4. Merging schematic

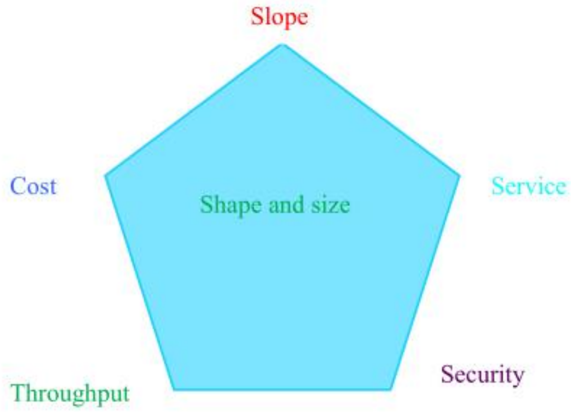

Fig 5. First-level factors

Since the throughput is a relatively constant value at New Jersey Turnpike and Garden State Parkway, our discussions are implemented by assuming the throughput is fixed in the discussions about shape and size of toll plaza.

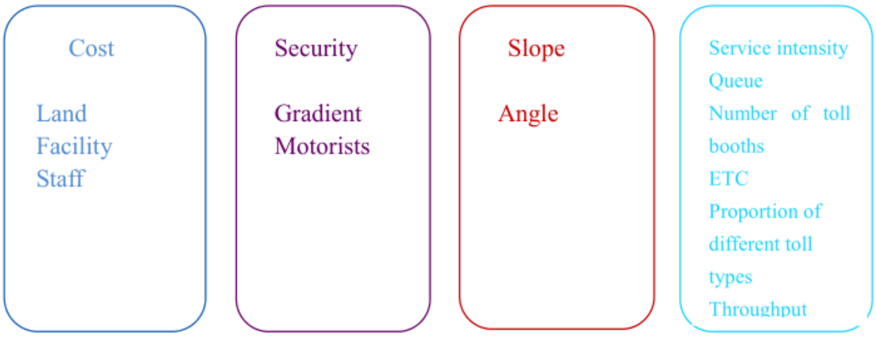

Fig 6. Second-level factors

5.1 5.1 Cost

5.1.1. Land

The area of the toll plaza is approximated as an ellipse, as shown in figure 7.

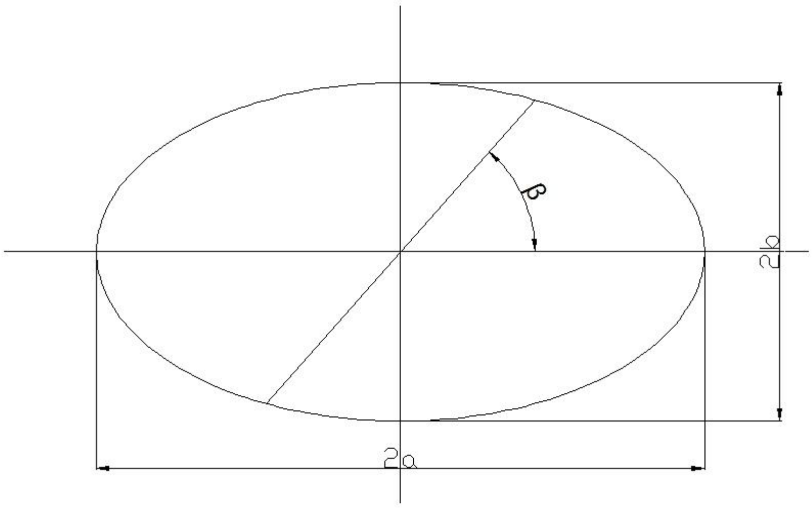

Fig 7. The area of the toll plazaDerive a, b, c, d, the relationship is as follows.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$$

$$x=\frac{d}{2}\cos\beta$$

$$y = \frac{d}{2}\sin\beta$$

$$b = \frac{ad\sin\beta}{\sqrt{4a^2 - d^2\cos^{2\beta}}}$$

Get the area expression.

$$S = \pi ab = \frac{\pi a^2 d\sin\beta}{\sqrt{4a^2 - d^2\cos^{2\beta}}}$$

By changing the value of β we can find a reasonable point, making the toll plaza smallest and on the basis of ensuring the use of performance to save cost.

5.1.2. Facilities

Facilities costs are mainly reflected in the maintenance of facilities and power consumption, facilities are the basis of toll stations, and electricity is a prerequisite for the operation of various facilities, and to ensure the normal operation of facilities must be regular maintenance and repair work, so the use of these two Part of the cost and facilities operating costs as toll stations.

$$C = \frac{M + W}{30}$$

Where: C is the operating costs of the facilities, yuan / d; M is the average monthly electricity charges toll stations, yuan / month; W is a variety of facilities monthly maintenance costs, yuan / month.

5.1.3. Staff

Labor cost is human consumption costs to ensure the normal operation of the toll station, toll station staff can be divided into toll booth staff and other staff. The number of tolls changes with the number of toll lanes opened. The number of other staff changes with the number of toll lanes opened, while the number of other staff must be a toll station operation of the labor costs should be for all the toll stations to meet the normal operation of the average daily wage of employees.

$$C_1 = \frac{C}{30}(r + n)$$

C is the average monthly wage of employees (yuan / month); r is the number of other workers; n is the number of lane opening.

Costs of per facility and staff are not changed, but the overall cost of personnel and facilities is optimized as the proportion of different charging methods is optimized.

5.2 Security

5.2.1. Gradient

As can be seen from the figure,cars who want to enter the station A will go through a large steering process.Considering a number of safety factors, blind spots and steering radius should be optimized.In order to ensure that the driver can see the toll station as a whole when they reach the top of the slope, the toll gate entrance must have a reasonable gradient.

We can get the correlation model between traffic accident and square entrance gradient by regression analysis：

$$Y = 1.4231e^{8.0664x}$$

The coefficient of association of the model is R2 =0.8621. It is indicated that the correlation coefficient of the model is high.From the correlation curve and the correlation model, it can be seen that the overcharge of the square of the toll plaza leads to the safety requirements of the toll plaza vehicle deceleration and the lane-changing, and leads to the rear-end collision of the vehicle in the toll plaza and the accident of the collision charging facilities, so the ramp rate should be considered according to the local conditions.

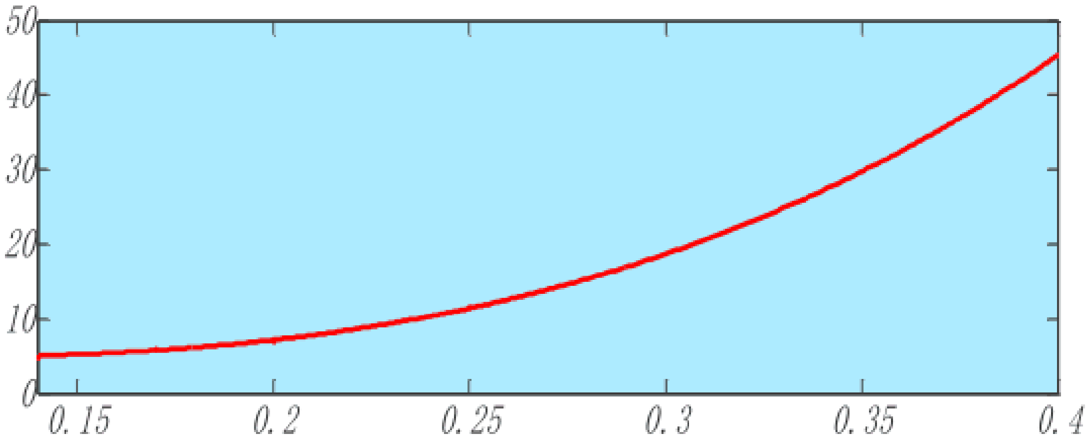

Fig 8.Curvature of the regression model of expressway toll plaza entrance gradient and the corresponding accident-related curvature

5.2.2. Motorists

In less traffic, the driver can be freer to choose charging entrance, the less formation of congestion and less likely to cause accidents, toll stations can be more smooth work. When the traffic flow increases, the toll booth will increase the number of toll booths, after the drivers get into the square the lane will be selected according to the queuing situation of the lane. However, there is also a follow-up phenomenon, which will lead to some toll booths lining up longer, which led to a number of security factors.

5.3 Service intensity

5.3.1. Queue length

Apply M/M/S to solve the length of the team.In the Hypothesis model, $X\left(t\right)$ is the number of the vehicles that come between $\left(t,t+\Delta t\right)$.

$P\left\{x_{(t)}=k\right\}=\frac{\lambda^k}{k!}e^{-\lambda},k=0,1,2\cdots$ So, is the average,m is the number of the toll booths,the service strength is:

$$\rho=\frac{\lambda}{m\mu}$$

Average queue length:

$L_q=m\rho+\frac{(m\rho)^m\rho}{m!(1-\rho)^2}P$ Average waiting time:

$$W_q=\frac{L_q}{\lambda}$$

The probability that all attendants are idle:

$$P_0=\left[\sum_{k=0}^{S-1}\frac{(mp)}{k!}+\frac{(mp)^m}{S\left(1-\rho\right)}\right]^{-1}$$

L_q is a number of vehicles in a queue, the length of each car is L_1, the distance between cars is L_2 , so the total length of the queue:

$$L=L_q\left(L_1+L_2\right)$$

5.3.2. Number of toll booths

For M / M / m / model, in the steady-state case, the average total cost of loss per unit time is:

$$F(m) = C_1\bar{N}(m) + C_2 m, m \geq 1$$

C_1 for each customer is the cost per unit time in the system stay, \$; $\bar{N}(m)$ is the average number of customers in the system, C_2 is the cost of time in each service unit.Because C_1 、 C_2 re given.M is the only possible change in the number of service stations, so F is a function of m.Now m^* is the optimal solution, making $F(m^*)$ the smallest.Because m only value positive integer . $F(m^*)$ is not the function of continuous variable, So we can not use the classical differential method to find the minimum value.But the marginal analysis method can be used.According to $F(m^*)$ is the characteristics of the smallest, can be:

$$\begin{cases} F(m^*) \leq F(m^*+1) \\ F(m^*) \leq F(m^*-1) \end{cases}$$

$F(m) = C_1 N(m) + C_2 m$ can be obtained:

$$C_1 m^* + C_2\bar{N}(m) \leq C_1\bar{N}(m^*+1) + C_2\bar{N}(m^*+1)$$

$$C_1 m^* + C_2\bar{N}(m) \leq C_1\bar{N}(m^*-1) + C_2\bar{N}(m^*-1)$$

by simplifying can be the following formula:

$$N(m^*) - N(m^*+1) \leq \frac{C_1}{C_2} \leq N(m^*-1) - N(m^*)$$

m=1,2,3, …, since C_1/C_2 has the L value, since C_1/C_2 is known, it is only necessary to determine the m^* value which can be determined by the inequality interval in which the number is located.

5.3.3. ETC location

Middle-place ETC

Middle-place ETC is located in the toll plaza which is next to the object compartment on the road. Generally, set up one enterclose in each two-way traffic .And you only need to rebuild the new ETC channel successively outward.

Advantages: This setting is consistent with the general rule of the vehicle passing , you can give full play to the superiority of ETC channel to improve the efficiency of traffic, and the impact to the toll station is also small.

Disadvantages: When the traffic flow is large, it will be very difficult for vehicles to change process before they go through the toll plaza. "Illegal vehicles" easily go into the ETC channel, leading to channel congestion.

External ETC channel

External ETC channel is set in the outermost lane.When is time to increase the number of channels, you can rebuild one ETC channel from the MTC channel from outside to inside in proper order.You can also directly open up a new lane for the ETC channel outside the outermost lane.

Advantages: the vehicles which stray into the normal way become less,the degree of special use of the channel can be higher.

Disadvantages: the capacity of the traffic lanes is small, ETC’s advantage is difficult to play.Especially when the flow is large, it is inconvenient for the ETC vehicles to travel.And is not conducive to guide and evacuate a large number of MTC vehicles.

In our improved design, we recommend using more ETC channel in the middle.When the traffic volume is small, the inner lane arc length is shorter than the outer lane, which improve the traffic efficiency.When the traffic volume is large, the ETC lane is in the innermost entrance , which can also prevent "illegal vehicles" traveling into the ETC channel..

5.3.4. The proportion of different lane types

Toll stations are the bottleneck of expressway traffic flow.Today,the toll stations adopt the mixed charging of MTC and ETC.Therefore,the proportion of ETC and MTC in this model makes a great influence on the service capacity of toll station.Based on the previous studies and the characteristics of this model,ETC can be located in the center of the driveway .According to previous studies,As the total number of lanes changing,the proportion of ETC lanes is different.For example:a main toll station has seven toll booths .Before the ETC vehicles reach 40％ an ETC can be used to meet traffic requirement.With the increase in the proportion of ETC vehicles(40％-60％), we need to open two ETC lanes in order to achieve the optimal traffic capacity, followed by increasing.[5]

Table 3.Simulation Results of integrated capacity of mixed toll stations with different ETC Lane Numbers

		Total lane capacity(pcu/h)							
		3	4	5	6	7	8	9	10
Capacity of different ETC lanes	1	1472	1736	1897	2042	2384	2529	2606	2720
	2	2182	2350	2505	2704	3092	3103	3271	3338
	3	2741	2926	3141	3382	3572	3746	3944	4064
	4	—	—	3725	3917	4134	4329	4414	4566
	5	—	—	4264	4508	4699	4744	4861	5092

5.3.5. Throughput

When the traffic is heavy , there are not many changes to travel freely.So the Binomial Distribution is used to describe the mode of arriving traffic,and Gaussian distribution describes the time of pulling out and severing time.

$$PK = C_k^n \left[\frac{\lambda t}{n}\right]^k \bullet \left[1-\frac{\lambda t}{n}\right], k = 0,1,2\cdots,n$$

So we can choose the multichannel’s M/G/K Model. The following is the statistical parameter computational formula of M/G/K Model.

$$W_q = \frac{D(S+G)+\left[E(S+G)\right]^2}{2E(S+G)\left[K-\lambda E(S+G)\right]} \bullet \left[1+\sum_{i=0}^{k-1}\frac{(k-1)!\left[K-\lambda E(S+G)\right]}{i!\left[\lambda E(S+G)\right]^{K-1}}\right]$$

The average stop time:

$$w = E(S+G)+W_q$$

The average length of the queue:

$$L_q = \frac{\lambda D(S+G)+\lambda\left[E(S+G)\right]^2}{2E(S+G)\left[K-\lambda E(S+G)\right]} \left[1+\sum_{i=0}^{k-1}\frac{(k-1)!\left[K-\lambda E(S+G)\right]}{i!\left[\lambda E(S+G)\right]^{K-1}}\right]$$

Because the Gaussian distribution describes the time of pulling out and severing time,the following formulas are established:

$$E[S+G] = E[S]+E[G]$$

$$D[S+G]=D[S]+D[G]$$

According to the M/G/K queuing theory model,we take advantage of the expectation and variance of toll service time and departure time to calculate the maximum number of vehicles that various toll stations are in the circumstances where there are different toll lanes and different queues .

5.4 Slope

5.4.1. Angle

The vehicle run in a high speed in the high way.The speed of the vehicle is slowed down by a ramp deceleration stage and then entered at the toll plaza at a low speed.The deceleration acceleration is composed of the acceleration of the gravitational acceleration in the slope direction and the acceleration of the vehicle's own braking:

$$V_2^2 - V_1^2 = -2\alpha L_J$$
$$\alpha = \alpha_1 + g\sin\varphi$$

V_2 is the speed of vehicles in the highway, m / s; V_1 is the speed of vehicles after they go by the deceleration area, m / s.

6. Model Ⅱ:Merging pattern

We have designed the pattern so that vehicles traveling at the same time from the A, B, C, and D toll booths (assuming four toll booths in this pattern) can travel at a certain distance from the lanes and naturally keep in a row to ensure that they can enter the lanes in order. In practice, there is no congestion in the case of small traffic, so we only consider the state of the toll plaza at the time of large traffic (saturation). When the traffic is saturated, each toll booth has been in working condition. We may be through the radio or the central control system to regulate the passing status so that every four vehicles leave the toll booths at the same time.Add unbroken guiding lane lines between adjacent lanes to guide the vehicles along the desired route to merge the roads.The number of unbroken guiding lane lines is determined through the relationship between toll booths and lanes.(For example: four toll booths corresponding to two lanes,there is uneven distribution of the priority allocation for medial and high-speed lanes).By this way,we can ensure that on the every stage of accelerated merging the vehicles do not collide with each other.To a certain extent, solve the problem of traffic congestion.

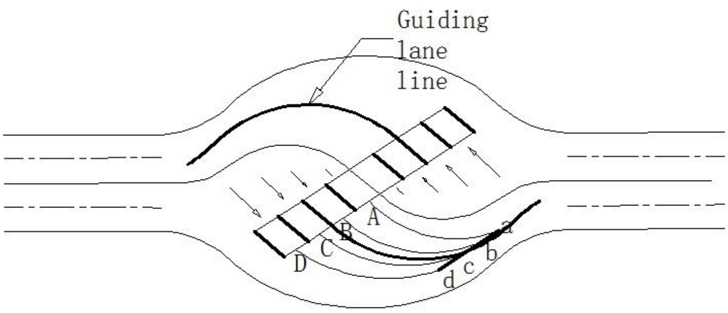

Fig 9. Merging Schematic.

7. Discussion

7.1 Model I

7.1.1. Strengths

This model uses a way different from the usual toll station design approach. The toll booth layout is optimized, The innovative use of inclined layout make the land use of the toll station greatly improved.Tall kiosk tilt makes the outbound Mouth area increased significantly, which is further some for vehicle safely merge .What's more, install the entrance and exit slope design with logo prompts, which makes the vehicle in the import and export to achieve acceleration and deceleration.

7.1.2. Weakness

This design also makes the vehicle go through a process to the specific after they go into the toll station, which requires practical applications to be based on the actual situation of a reasonable gradient design.In addition ,the slope angle of the export and import disturb the straightness of the highway, so a reasonable angle should also be considered.

7.2 Model Ⅱ

7.2.1. Strengths

This kind of vehicle release rule combines the shape advantages of the designed toll booths well.As shown in the model,when traffic is particularly large,four toll booths release vehicles at the same time .The inner lanes are high-speed lane and the distance from the exit is short.They can use less time and reach the booths first.In turn,the lane on the outward arrival later.Therefore,when the four vehicles reach to the intersection, naturally arranged in an order.They merge in order ,reducing the incidence of accidents.Arrangement of vehicles leaving toll booths is relatively compact,improving the utilization of time.And the separation between lanes makes that the vehicles in the outer lane can not be squeezed to the other lanes,ensuring merging in order and improving security

7.2.2. Weakness

The designed lane has a certain arc.In the rain and snow, the vehicles may slip and other security issues.In addition,after the vehicles exit the toll booth,the problem of volatility has not been resolved.Speed The speed of the vehicles is greatly affected by the driver's subjective factors .

7.2.3. Impact of autonomous vehicles and self-driving on design

When more autonomous (self-driving) vehicles are added to the traffic mix, the types of vehicles on the expressway will become more complex, so the function of the toll station should be subdivided. You can set up the independent unmanned ETC to meet the requirements of unmanned vehicles. Based on the intelligent design of the unmanned vehicle, the security of the security is improved.So the population gradient rate and the slope angle of the entrance and exit can be adjusted to save the cost. At the same time, the toll booth Tilt angle can be optimized to adapt to traffic changes.

7.2.4. Impact of design on proportion of toll station type

Toll Station is the bottleneck of the traffic flow of highway additionally, ETC lanes have been designed on both sides of the road In the case of traffic congestion, Vehicles on the ETC lane can not travel to either side and be forced to drive on the artificial lane, which increased the pressure of the manual toll lanes, resulting in unnecessary congestion.while in this model, we set the ETC lane in a central location.Because the distance of the central lanes is shorter , which is beneficial for driver on the ETC lanes to choose the toll gate.By this way, we can reduce the pressure on the manual toll lanes.At the same time, ETC lanes's utilization has been improved to avoid unnecessary waste of resources.Considering the problem that vehicles accounted for a proportion on the ETC lanes, the number of ETC lanes can be reduced or increased on demand.As the utilization rate is higher and traffic flow is denser, the proportion of ETC lanes opening can be optimized.

7.2.5. Performance of solution in light and heavy traffic

The innovative design of this model have advantages in the export of parallel flow.When the traffic light,is feasible to open the central lane, and rationally arrange the proportion of ETC and MTC .When the traffic is heavy,increase the number of the toll booths and do the route planning.If the vehicles travel by the route in a strict way , at the exit will naturally they will form in a queue naturally at the exit. The lanes are stipulated roughly for the vehicle in the exit.Drivers choose the exact lanes between a small number of lanes.However, the design makes the entrance space becomes smaller, so it is easy for rear-end scratches and other accidents to happen. In the latter development it can also be considered that the toll booths can be made apart .So the toll booth tilt angle can change in order to adapt to different traffic.

8. A Letter to the New Jersey Turnpike Authority

Dear New Jersey Turnpike Authority,

Hello, We surveyed the New Jersey highway and the Garden State Expressway in New Jersey, and found some problems.

First of all, when the highway was constructed traditionally, the design of toll plaza shape makes the land occupied.Secondly, when the traffic flow reaches a certain value, the processing capacity of the toll station seriously affected the use efficiency of the expressway.Thirdly, the proportion of ETC lanes, manual toll lanes and traditional MTC lanes is not appropriate, which will lead to waste of resources in varying degrees.Finally, because of the driver's behavior, the driver’s behavior also has some impact on the use of the toll station.For the United States, the time and resources are huge assets.Wasting the time of the masses by the toll station processing capacity is worth the candle.And the waste of resources caused by the unreasonable configuration can be optimized and designed to avoid, making a variety of resources to be efficiently used.

In view of the above problems,our team has redesigned a toll plaza program and some plans corresponding to the program.We hope that the above problems can be resolved.Our programs takes the cost、traffic、configuration between ETC and others and other issues into account.The exit of the curved toll stations is beneficial to the co-current way.At the same time, the tilt of the toll booths placed on the land makes land using efficiency large, saving construction costs.At the exit and entrance of toll station, we designed deceleration ramps and signs.When the vehicles get into the toll station , speed is controlled in a range, increasing safety.In the leaving process, there is the man-made road planning.And with the central control system and the relevant rules vehicles in the export can place in a queue naturally, avoiding the crowded situation.

In the late development of the model, there is a consideration that making toll booths detached.In the process of changing traffic flow, making a reasonable layout of toll booths angle.responding to different flows.In this way, the toll station place is variable and human.And be improved in terms of security,cost and practicality.

There are many areas where the model needs to be improved and improved.With the changing of traffic condition and driver awareness, new model will be developed.Hopefully our efforts will help.

9. Summery

By making key assumptions, we establish the model of toll plaza’s shape, size and area by queuing theory, and innovatively formulate the internal merging pattern in the toll plaza.

Firstly, the Toll Station Area Optimization Model is built based on the Queuing theory. The geometry of toll plaza is simplified to ellipse. The toll booth is not perpendicular with the direction of traffic flow, but with a deflection angle. The corresponding traffic ways of vehicles in and out of the plaza have a certain radius. With the combination of queuing theory and elliptical model, we can determine the smallest amount of area within the safety range of deflection angle, which can minimize the land use and cost.

Secondly, in order to avoid accidents, we develop a man-made control strategy based on the advantages of the S-shaped plaza. The speed limit in different channel is different, and also the distance to the merging end point is also different.Then the vehicles can form a queue naturally. In addition ,the matchup between the lanes and the toll booths should be stipulated ,which makes vehicles pull out from one certain toll booth can only travel in a certain way.And the accident can be prevent.

Thirdly, the autonomous (self-driving) vehicles can only pass through the ETC. If the number of these vehicles increases, the proportion of ETC should be increased. We implemented corresponding optimization by discussing the different proportion of ETC and MTC. When the traffic flow changes, there can also be a better response by adjusting the location and type of open toll booths.

Finally, the angle between the toll booths and the traffic flow direction can be adjusted to adapt to different traffic flow. This design not only in toll booth layout has certain advantages, but also make the number of toll booths more flexible.

We analyze the results of each of these models, performing sensitivity analysis on the input parameters and demonstrating their flexibility.

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