Design of a new type of toll plaza on the highway

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Abstract : Based on the Queuing theory and Cellular Automaton model, we design a three-dimensional toll plaza model that has two decks to reduce the congestion and increase the throughput. In order to describe its structure more clearly, we draw the stereo model and plans of it by using Pro/E and CAD. VISSIM has similar principle models, Car Following and Lane Changing, to Cellular Automaton. Therefore we use VISSIM to simulate our DTP model. The result of the simulation shows that the throughput increases by 12.4%.

1. Introduction

Multi-lane divided limited-access toll highways use “ramp tolls” and “barrier tolls” to collect tolls from motorists. A ramp toll is a collection mechanism at an entrance or exit ramp to the highway and these do not concern us here. A barrier toll is a row of tollbooths placed across the highway, perpendicular to the direction of traffic flow. There are usually (always) more tollbooths than there are incoming lanes of traffic. So when exiting the tollbooths in a barrier toll, vehicles must “fan in” from the larger number of tollbooth egress lanes to the smaller number of regular travel lanes. A toll plaza is the area of the highway needed to facilitate the barrier toll, consisting of the fan-out area before the barrier toll, the toll barrier itself, and the fan-in area after the toll barrier. For example, a three-lane highway (one direction) may use 8 tollbooths in a barrier toll. After paying toll, the vehicles continue on their journey on a highway having the same number of lanes as had entered the toll plaza (three, in this example).

Consider a toll highway having L lanes of travel in each direction and a barrier toll containing B tollbooths (B > L) in each direction. How to determine the shape, size, and merging pattern of the area following the toll barrier in which vehicles fan in from B tollbooth egress lanes down to L lanes of traffic? Important consideration to incorporate in the model include accident prevention, throughput (number of vehicles per hour passing the point where the end of the plaza joins the L outgoing traffic lanes), and cost (land and road construction are expensive). In particular, this problem does not ask for merely a performance analysis of any particular toll plaza design that may already be implemented. The point is to determine if there are better solutions (shape, size, and merging pattern) than any in common use.

2. Model of Double-deck toll plaza(DTP model)

We design a toll plaza that can reduce congestion and save time upon departure from the toll plaza. Our toll plaza has two decks: the upper deck and the lower deck. The stereogram of our double-deck toll plaza is shown in Figure 1. The top views of the upper deck and the lower deck are shown in Figure 2 .

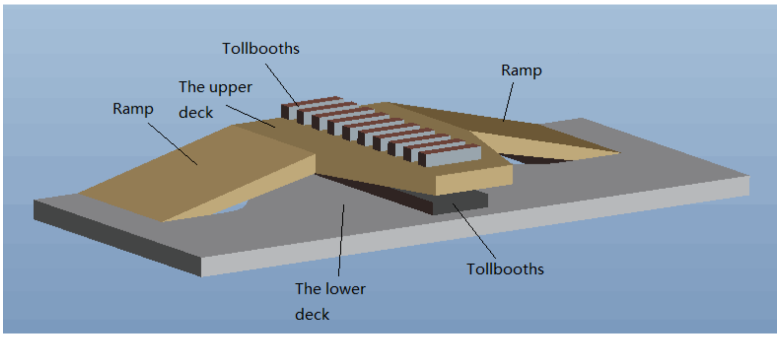
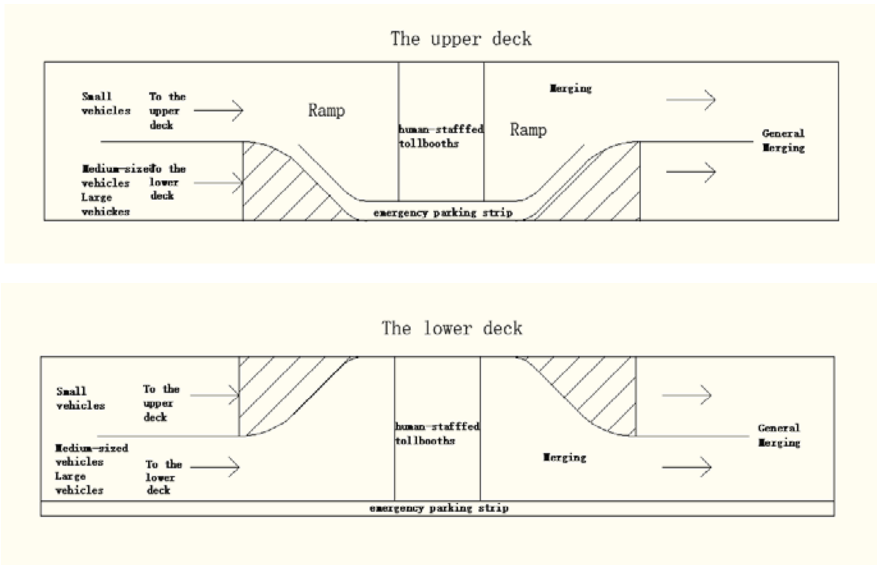


Figure 1: The stereogram of DTP model



Figuer2: The top view of the upper and the lower toll plaza

3. The simulation of our DTP model.

VISSIM is traffic simulation software. It is a microscopic, time-driven modeling tool based on driving behavior. The software system can be used to analyze the traffic operation status under the conditions of lane type, traffic composition, traffic signal control, stop control and so on. VISSIM has the function of analyzing, evaluating, optimizing traffic network and comparing different design schemes. It is an effective tool for evaluating traffic design.

The simulation system adopts Wiedemann Model :

$$d = a_x + b_x$$

$$b_x = (b_x\_add + b_x\_mult * z) * \sqrt{v}$$

a_x : Vehicle standstill distance

b_x : Vehicle safety distance

b_x_add : Additive part of desired safety distance

b_x_mult : Multiple part of desired safety distance

z : Coefficient in [0, 1], normal distribution value of 0.5, with 0.15 standard deviations

v : Vehicle speed

We use VISSIM to build the simulation model.

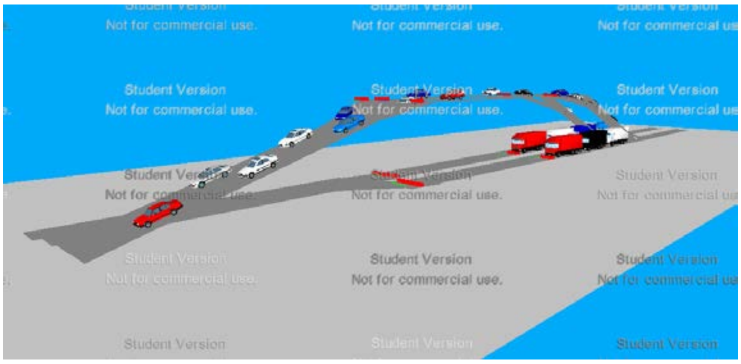


Table 1: The result

Speed(km/h)	Traffic flow	T_1	N_1	T_2	N_2	S_1
40	700/300	56.6	85	34.7	41	923

T_1: The average time for a vehicle to pass Lane 1

N_1: The number of vehicles passing Lane 1 during the interval time t_1

T_2: The average time for a vehicle to pass Lane 2

N_2: The number of vehicles passing Lane 1 during the interval time t_2

t_x x=1,2,$\cdots$: The time for VISSIM to test

$T \equiv 3600$

The calculation of throughput :

$$S_1 = \frac{T}{t_x} \times (N_1 + N_2)$$

In order to prove that our solution is better, we simulate the traditional toll plaza model based on VISSIM. Settings of link data, routs, and vehicle compositions are the same as the DPT model.

Table 2: The result of the simulation

Speed(km /h)	Traffic flow	T_1	N_1	T_2	N_2	S_2
40	700/300	56.6	85	34.7	41	808

$$m = \frac{S_1 - S_2}{S_1} \times 100\% = 12.4\%$$

S_2 : The through put of the traditional toll plaza

m : The growth rate of throughput

4. Summary

1) We design a three-dimensional toll plaza model that has two decks to reduce the congestion and increase the throughput..

2) We use VISSIM to simulate our DTP model. The result of the simulation shows that the throughput increases by 12.4%.

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