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# An analysis of tollbooth in Huludao City

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#### Keywords: tollbooth, highway, road safety, toll plaza

**Abstract.** Unreasonable road design and disordered traffic conditions may trigger accidents. As a part of highway design, tollbooth has close relationship with road safety, and there are many security problems in actual operation and management. It's necessary to establish a security model that can assess the safety of a car passing the toll plaza. Here we propose an index to evaluate the safety of a car passing the toll plaza and verify the effectiveness of the chosen index and analyze the effectiveness of the index.

#### 1. Introduction

It is well known that unreasonable road design and disordered traffic conditions are important factors in triggering accidents. As a part of highway design, tollbooth has close relationship with road safety, and there are many security problems in actual operation and management [1]. Time is equally important and N.Gans et al. [2] emphasized the importance of service time. Therefore, making the vehicles efficiently and orderly go through the tollbooths can reduce people's waiting time and the occurrence of road accidents.

A toll plaza consists of the "fan-out" area before the barrier toll, the barrier toll itself, and the "fanin" area after the toll vividly. The "fan-in" area after the toll is easy to cause traffic jams since the vehicles entering less lines, more seriously, accidents occur sometimes.

So determine the shape, the size, and the merging pattern of the area following the toll barrier scientifically is very important and necessary. There are some previous studies on establishing tollbooths. Many scholars have established models for optimizing the number of tollbooths.[3] But they can not consider the shape, the size, and the merging pattern of the area following the toll barrier.

In this paper, we establish an index to evaluate the safety of a car passing the toll plaza and verify the effectiveness of the chosen index and analyze the effectiveness of the index (Table 1).

| Table 1. Notations |  |  |
|--------------------|--|--|
| Symbols            | Definition                                     |  |
| n                  | Tollbooths                                     |  |
| $X_{\mathbf{q}}$   | Throughput                                     |  |
| Xb                 | Proportion of large vehicles                   |  |
| $\lambda_{re}$     | the number of rear-end accidents prediction    |  |
| $\lambda_{lc}$     | the number of land-change accidents prediction |  |
| f                  | accidents per hundred vehicles                 |  |
|                    |  |  |

#### 2. Assumptions

• The toll plaza system state is stable, otherwise the queuing system is not stable, and the vehicle queue will become longer and longer.

• Whether it is conventional tollbooths, exact-change tollbooths or electronic collection booths, the service efficiency is certain, regardless of the impact of human and machine damage.

- In different regions, ETC is compatible.
- The data collected from the paper and database is accurate and reliable.
- The service efficiency of exact-change tollbooths and electronic toll collection booths is equal.

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## 3. The Total Accident Prediction Model

### 3.1 Pre-Analysis of The Model

According to Z.Z. Zhang's literature, the most frequent traffic accidents are caused by rear-end collisions of the vehicles traveling in the same lane and the land-change accidents caused by vehicle changing lanes. Five factors are chosen to be the traffic accident variables. [7]

• Throughput  $(x_q)$ : Under a certain traffic capacity, when the traffic throughput is relatively small, the vehicle can pass freely, and the vehicle clearance is relatively large, so the probability of accident is relatively small.

• Proportion of large vehicles  $(x_b)$ : The impact of large vehicles on the traffic flow is very prominent because of its start is slow and brake is difficult so its impact on the adjacent vehicles is more obvious.

• Average difference between running vehicles  $(x_v)$ : Merging vehicles entering the main line may cause the speed deceleration of the vehicles driving in the main lane. To a certain extent, the differences between running vehicles may cause rear-end accidents easier.

• Average headway between vehicles  $(x_h)$ : Headway refers to the time difference of the vehicles before and after running through the same cross-section in the freeway same lane. The smaller the headway, the greater the probability of traffic accident.

• The ratio of the combined traffic to the total traffic  $(x_m)$ : When the ratio is large, a large number of vehicles need to decelerate due to the confluence and there are a lot of lane behavior, which is easy to cause abnormal vehicle operation, increasing the probability of traffic accident.

#### **3.2 The Establishment of The Model (Table 2)**

| Table 2. Symbols and explanation |  |  |
|----------------------------------|--|--|
| Symbols                          | Explanation  |  |
| $x_{\mathrm{q}}$                 | Throughput (pcu/0.5h)  |  |
| $x_{\mathrm{b}}$                 | Proportion of large vehicles   |  |
| $\chi_{ m v}$                    | Average difference between running vehicles (km/h)                                 |  |
| $\chi_{ m h}$                    | Average headway between vehicles (s)   |  |
| Xm                               | the ratio of the combined traffic to the total traffic (i.e. the confluence ratio) |  |
| $\lambda_{re}$                   | the number of rear-end accidents prediction  |  |
| $\lambda_{lc}$                   | the number of land-change accidents prediction                                     |  |

#### **3.3 Rear-End Accident Prediction Model**

Z.Z. Zhang found that  $x_m$  has no influence on  $\lambda_{re}$  basically [7]. He established a rear-end accident prediction model (**Eq.1**) based on the statistical analysis on the rear-end collisions and the traffic flow parameters of the confluence area. (*A*, *B*, *C* and *D* are coefficients and  $\psi$  is a constant)

 $\lambda_{\rm re} = \exp(\psi + Ax_a + Bx_b + Cx_v + Dx_h)$ 

(2)

3.4 Land-Change Accident Prediction Model

Similarly, the land-change accident model can be listed by the follows,  $\lambda_{lc}$  has a relationship with all these five factors: [7] (*P*, *Q*, *R*, *S* and *T* are coefficients and  $\zeta$  is a constant)

$$\lambda_{lc} = \exp(\zeta + Px_a + Qx_b + Rx_v + Sx_h + Tx_m)$$

## 3.5 The Total Traffic Accident Prediction Model

According to the above analysis, the total traffic accident prediction model of freeway "fan-in" area is as follows: [7]

$$N_{\rm m} = \lambda_{\rm re} + \lambda_{lc} = \exp(\psi + Ax_q + Bx_b + Cx_v + Dx_h) + \exp(\zeta + Px_q + Qx_b + Rx_v + Sx_h + Tx_d)$$
(3)

Define the accident rate f as traffic accident index. [7]

$$f = 100 \times \frac{N_m}{q_1} \tag{4}$$

Where, *f notes* accidents per hundred vehicles (times/one hundred vehicles),  $N_{\rm m}$  notes the sum of the rear-end accidents and land-change accidents,  $q_1$  notes the throughput (pcu/h). Fig. 1 shows the relationship between the different factors.





Fig. 1 the relationship between the different factors

## 4. Results and Analysis

## 4.1 Two Most Important Factors

In order to verify the impact degree of the five factors in **Eq.4**, we get partial derivatives of each factor in **Eq.3** (specific formulas see [7]), finding that the throughput  $(x_q)$  and the proportion of large vehicles  $(x_b)$  factors have the greatest impact on the results. Therefore, we should focus on these two factors when consider the solutions later.

## 4.2 The Effectiveness of index F

Through the traffic statistics of Huludao city's toll station in Z.Z. Zhang' paper [7], we predict the rear-end accidents ( $\lambda_{re}$ ) and land-change accidents ( $\lambda_{lc}$ ), and find that  $\lambda_{re}$  and  $\lambda_{lc}$  relative error of each time period is all less than 4% (**Fig.2 and Fig.3**). Then we calculate the value *f* of each time period and find that the results followed the measured values well [7]. All these prove the effectiveness of index *f*.







#### 5. Conclusion

In this paper, a comprehensive evaluation model is proposed to determine. The effectiveness of the chosen indexes T and f is verified respectively by analyzing the relevant data of a reality plaza. We choose Huludao city's toll station in the Shen-Shan freeway as our research object. And we find the most important factors influencing the four indexes, in which, T is determined by the throughput q1 at all, and f is mainly influenced by the throughput q1 and the proportion of large vehicles xb factors, which are the basis of our solution. In addition, we design a merging solution with a dedicated lane and a multi-stage merging pattern, which is comprehensive. The Shape, the size and the merging pattern is given of the toll plaza. However, we hold that the possibility for vehicles going through each tollbooth is equal, but the possibility is not equal generally, which would decrease the accuracy of our model. And we also do not set accident lane and consider the exact-change tollbooths, which will be improved in our next paper.

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