ISSN : 0974 - 7435 Volume 10 Issue 2

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(2), 2014 [318-323]

Research of the traffic rules based on mathematical model

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ABSTRACT

As all know, the performance of traffic rules directly affect the traffic flow and personal safety, the paper is mainly aimed for highway traffic rules, and according to traffic flow and safety, the paper establishes a two-factor optimization model based on performance problems of a multi-lane freeway traffic rules0Under the circumstance of right driving: according to analysis, we know that traffic flow and traffic safety determine the performance of freeway traffic rules, both are related with driving speed (the average speed of the vehicle in the second lane take the average upper or lower speed limit of the second lane), and both are mutual restraint. And through utilizing mathematics and physics knowledgeÿwe build an overtaking model in the same lane and use area evaluation method to establish the safety factor evaluation system, which obtains the function relationship between speed and safety coefficients. Next, to establish a traffic flow model considering the traffic lane width, lateral clear width, vertical slope, sight, along conditions and other factors, and we obtained a function between driving speed and traffic flow. Finally, according to the function relationship between speed and safety factor η , traffic flow C .

KEYWORDS

Mathematical model;
Area of evaluation;
Traffic flow.

INTRODUCTION

Traffic rules directly affect the personal safety and traffic flow. In addition to driving on the right, traffic rules also include vehicle speed and safety distance between moving vehicles. Traffic flow, safety and other aspects are important indicators on evaluating traffic rules. Around the traffic rules, the following questions will be discussed.(1) Mathematical model is set up to measure the influence of traffic rules to the traffic flow and safety, to judge the performance of current traffic rules under sparse circumstance or traffic jam, which is to optimize the traffic rules and to improve traffic condition and security.(2) Whether the improved rules in the first problem can be used to the left-driving rule after being changed slightly, if not, what additional conditions should be required.(3) In consideration of the difference between intelligent system and the human body mainly depends on the reaction time as well as the execution degree to the rules of the rules, if vehicles are controlled by intelligent system, what should be changed to the rules?

ESTABLISHMENT AND SOLUTION OF THE MODEL

Model preparation

We target our research goal to the most widely used three-lane highway, as shown by Figure 1.

Figure 1 : Three-lane highway

The definition of lane: for the country driving at right side of the road, the middle lane is the first driving lane. The right lane is second, the left one is overtaking lane.

First, specific definition of traffic rules[1]:

(1). Speed regulation defines the left lane as overtaking lane, the middle one and the right one as driving lane. The overtaking lane highest speed limit is 120 kilometers, the lowest speed limit is 100 kilometers, the middle lane highest speed limit is 100 kilometers with lowest speed is 80 kilometers, and the outer lane highest speed limit is 80 kilometers with lowest speed limit is 60 kilometers.(2). Vehicles-between distance regulation, The vehicle with a speed of over 100 km per hour should maintain a distance of 100 meters or more with other vehicles in front in the same lane; the vehicle with a speed below 100 kilometers per hour can properly shortened the distance with the front vehicle in the same lane, but the minimum distance should be less than 50 meters.

Through above regulation, we know that current traffic rule do not give a clear limit to safety distance, so this article is to analyze the safety distance and find out specific calculation method. There are two kinds of safety distance: the following safety distance in the same lane, and the safety distance when overtaking vehicles.

The calculation formula of vehicle-following safety distance in the same lane:

$$\mathbf{x_1 = t_1 \cdot v + \Delta s`} \qquad \textbf{(1)}$$

In this formula, t_1 is brain response time, Δs is braking distance, the brain response time is about 1.5 seconds, which is the human response time between former vehicle emergency braking and latter driver's braking.

The braking distance[2] calculation method is as follow:

$$\mathbf{\Delta s = 0.1v_{11} + 0.01{v_{11}}^2 - 0.1v_{12} + 0.01{v_{12}}^{2}`} \qquad \textbf{(2)}$$

v_{11}, v_{12} stand for the overtaking speed and the overtaken speed in the same lane respectively.

The overtaking safety distance is calculated according to the overtaking model in the following.

The model for speed restriction and safety factor

The performance of traffic rules are mainly reflected in safety and traffic flow[3]. In order to make the solution clear and easy to be understood, the problem solving process has three steps: the first one is to build the model of speed limit and safety factor, which is to analyze the relationship between speed and safety; the second step is to build traffic flow calculation model[4] to analyze the relationship between speed and safety; the third step is to build a double-factor model for safety and traffic flow, and to optimize the rules.

Because the speed restriction and the safety factor are mainly interrelated through overtaking safety speed and vehicle-following safety distance[5], we build two models, which are: model of changing lane to accelerate without return to original lane, and model of overtaking by changing lane and return to original lane.

Model of changing lane to accelerate: vehicle B enters into the first lane from the second lane without return to the second lane, as shown by Figure 2:

In order to simply model, to assume the accelera-

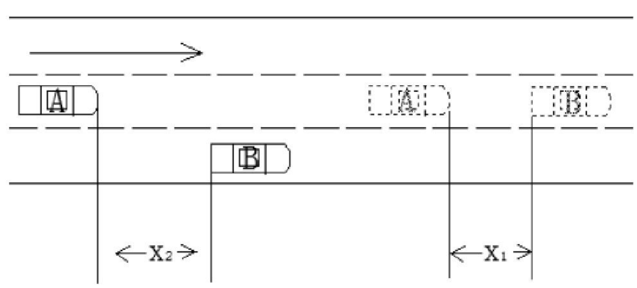


Figure 2 : Schematic plot of model 1 of changing lane to accelerate

FULL PAPER

tion value is not changed in the process of changing lane.

To assume the safety distance of changing lane for overtaking as x_2, the safety driving distance as x_1.

Defining $x_2 = \Delta x + x_1$, then:

$$\Delta x = v_2 t - (v_1 t + \frac{1}{2} a t^2) \quad (3)$$

$$t = \frac{v_2 - v_1}{a} \quad (4)$$

In this equation, v_1 is the original driving speed of overtaking vehicle, a is the acceleration speed of the vehicle, v_2 is the speed of vehicle A.

To sum up:

$$x_2 = \frac{(v_2 - v_1)^2}{2a} + 1.5v_2 + 0.1v_2 + 0.01v_2{}^2 - 0.1v_1 - 0.01v_1{}^2 \quad (5)$$

According to formula (5), the relationship between vehicle speed and safe overtaking distance, as shown by Figure 3

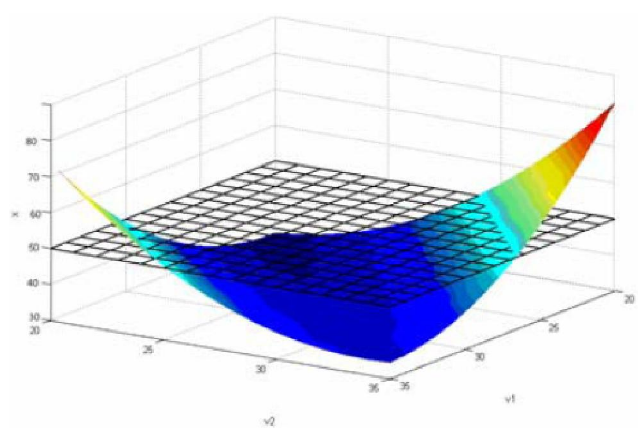


Figure 3 : Relationship between vehicle speed and safe overtaking distance

According to the highway speed restriction in this paper, the highest speed restriction in first lane is 100km/h with the lowest speed restriction of 80km/h. The lowest speed restriction in second lane is 60km/h with highest speed restriction of 90km/h.

According to Figure 3, within speed restriction, the faster the speed, the lower the driving safety. In order to evaluate specifically to the safety, 'safety factor η 'is introduced.

To assign $v_2 = 90$km/h. According to formula (5), the safety overtaking distance x is changed according to v_1. Figure shows that the faster the vehicle, the larger the overtaking safety distance, which surpasses standard vehicle distance. The Figure 3 is obtained from the changing curve of x and the 50 meters standard vehicle distance.

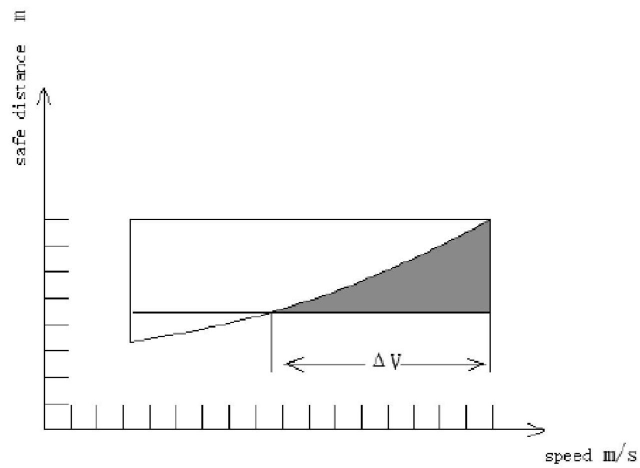


Figure 4 : Schematic diagram of shaded area

The larger the shaded area, the lower the safety.

We use 'area evaluation method' to calculate safety factor[6], which is to build the function relationship between shaded area and η, and combined with formula (5), the following (6) can be obtained by assuming shaded area as S

$$S = \int_{v_{min}}^{v_{max}} x_2 dv - 50 \times \Delta v \quad (6)$$

Δv is shown by Figure 4

According to Figure 3 and formula (5), we can work out the largest area to be 53, and we define the safety factor at this moment as the lowest 0.5, when area is 0, the safety factor is 1.

Then, the linear equation between safety factor and area is:

$$\eta_1 = -\frac{1}{106} S + 1 \quad (7)$$

From this model, a vehicle need to accelerate when overtaking, so $v_1 = 80$ kilometers/hour, that is $v_1 = 22.2$ m/s, at this time, the relationship between v_2 and the safety distance of overtaking by changing lane is shown by Figure 5. When speed is less than 100km, the distance between vehicles should not be less than

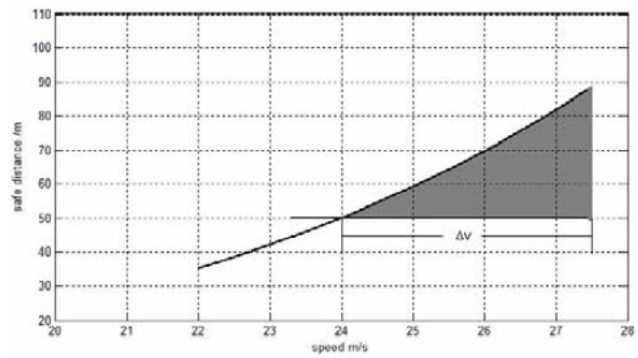


Figure 5 : Relationship between v_2

50m.

According to formula (6) and formula (7), we can work out that the area is 42 at this moment, so the safety factor is 0.61 under current traffic rules and the overtaking model.

① The overtaking model in the same lane

The vehicle overtakes from the rear side in the second lane, after overtaking from overtaking lane, and return to the second lane. This type of overtaking can be divided into two conditions on highway with three lanes:

(1) the vehicle in the second lane overtakes from the first lane and return to the second lane, as shown by ① Figure 6,

(2) The vehicle in the first lane overtakes from the overtaking lane, and return to the first lane, as shown by ② Figure 6:

In both cases due to the different lane speed limit, cars offset angle and distance will vary when overtaking.[7] Thus, safety factors η in both cases are different

In the process of changing lanes, the situation in which the former vehicle brakes in emergency before the rear vehicle changing line completely might occurs. Because the overtaking speed is faster than the driving speed. In order to prevent rear-end, an adequate response time and braking distance[8] should be given to the rear vehicle, the overtaking safety distance must be greater than vehicle-following safety distance.

In driving the process, if the vehicle in front brakes in emergency[9], there are two solutions: 1, to use emergency brake; 2, increasing the deflection angle of the vehicle when changing lanes. Known from the common sense is that it is not allowed to steer wheel too hard on the highway, so we do not consider the second solution.

For the overtaking model, its overtaking safety distance is calculated as following:

In the case of that the rear of the vehicle is not completely change lanes, to ensure the safety distance in formula (1). The overtaking safe distance[10] can be calculated as:

When overtaking, the vehicle shifted to the left lane, the lateral offset distance is y, assuming the vertical distance ahead as x then:

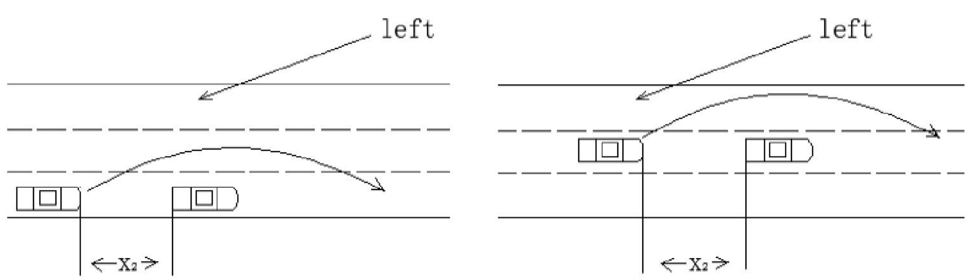
$$\mathbf{x = \frac{y}{\tan\alpha} + t_1 v_t + x_3 - x_4} \qquad \textbf{(8)}$$

In the formula, offset angle is α, when the speed of the vehicle when overtaking is v_t, brain reaction time for braking was t_1. The braking distance is $x_3 0 x_4$. According the physical knowledge:

$$\mathbf{2a\frac{y}{\sin\alpha} = v_{t1}^2 - v_3^2} \qquad \textbf{(9)}$$

$$\mathbf{v_5 = \cos\alpha\sqrt{2a\frac{y}{\sin\alpha} + v_4^2}} \qquad \textbf{(10)}$$

$v_3 and v_4$ stand for the driving speed in the first lane and the second lane. v_{t1} is longitudinal velocity when changing lane. v_5 is speed when changing lane to overtake.



① ②

Figure 6 : Overtaking by changing lane and then return to original lane

FULL PAPER

Put (9) into (8), we can obtain:

$$\mathbf{x}=\frac{\mathbf{y}}{\tan\alpha}+\mathbf{t}_1\cos\alpha\sqrt{2\mathbf{a}\frac{\mathbf{y}}{\sin\alpha}+\mathbf{v}_3{}^2}+\mathbf{x}_5-\mathbf{x}_6 \qquad (11)$$

In simplified form:

$$\mathbf{x}=\frac{\mathbf{y}}{\tan\alpha}+\mathbf{t}_1\mathbf{v}_4+0.1\mathbf{v}_2$$
$$+0.01\mathbf{v}_4{}^2-0.1\mathbf{v}_3-0.01\mathbf{v}_3{}^2 \qquad (12)$$

Based on our value of road length and clear width, to assign y, $y=1.8m$. In practical circumstance, the overtaking angle is very small, we should assign the overtaking angle as $\alpha=4^{\circ}$. We also know $t_1=1.5s$. And according to (9) (10) (11) (12), the relationship among safety speed x, v_4, v_3 is:

$$\mathbf{x}=26.0956-0.1\mathbf{v}_3-0.01\mathbf{v}_3{}^2$$
$$+0.01\mathbf{v}_4^2+1.6\sqrt{35.6+\mathbf{v}_4{}^2} \qquad (13)$$

According to (13), we can use MATLAB to simulate and get Figure 8:

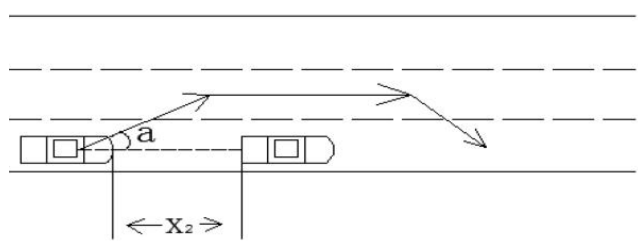


Figure 7 : The turning angle in the process of changing lane

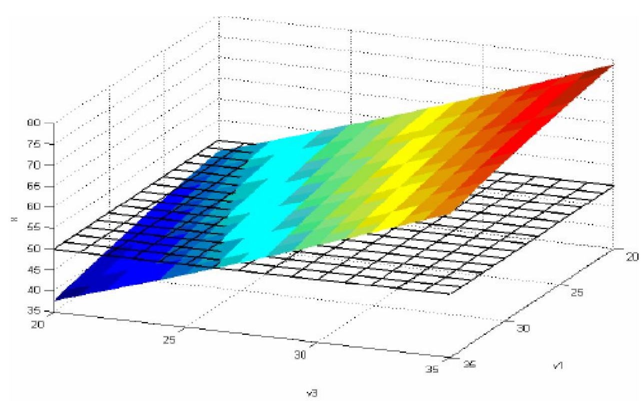


Figure 8 : The relationship between speed and overtaking safety distance

Like the model of acceleration through changing lane, according to (13) and Figure 8, the relationship between safety factor and area can be determined:

$$\eta_i=-\frac{1}{232}S_i+1, i=2,3 \qquad (14)$$

η_2 is the safety factor in ① of Figure 6, η_3 is the safety factor in ② of Figure 6.

It is known that the highest speed limit in the first lane is 100 kilometers/hour with the lowest speed limit 80 kilometers/hour. In the second lane, the lowest speed limit is 60 kilometers/hour with the highest speed limit 90 kilometers /hour. In this speed range, the driving speed is not evenly distributed. We assign value averagely. $v_4=90\text{km/h}$ $(=25\text{m/s})$, $v_3=70\text{km/h}$ $(=19.5\text{m/s})$. To put v_3 and v_4 into formula (14) respectively, we can obtain safety factor respectively: $\eta_2=0.69$, $\eta_3=0.72$.

Combined with the above three circumstances, the three overtaking types are random, so their weight functions are the same with a value $\frac{1}{3}$. So in combination with formula (7) and (14), we can obtain that the general safety factor calculation formula of the highway is:

$$\eta=\frac{\sum_{i=1}^{3}\eta_i}{3} \qquad (15)$$

To put η_1, η_2, η_3 into this formula, we can obtain 0.673 as the safety factor for current traffic rules.

CONCLUSION

In summary, by considering the safety factor and the traffic flow, this paper conducted a study on multi-lane highway traffic rules performance.

ACKNOWLEDGEMENTS

This paper is supported by the Scientific Technology Research and Development Plan Project of Tangshan (2012cx-11;12140201B-3;12140201B-7), Hebei Province Natural Science Fund Project (E2013209215).

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