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The Study About Stopping Distance of Vehicles

Zhao Chun-xue

School of Mathematics and Statistics, Anyang Normal University, Anyang, China

Email address

zhaochunxue66@163.com

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Abstract: With the surge in the number of motor vehicles and private cars, urban road traffic pressure increases, and rear end collision accidents are increasing day by day. The implementation of the "two seconds" rule and keeping the safety car distance can be effective in preventing the occurrence of rear end collision event. In this paper, we mainly study "two seconds" rule in normal driving conditions through establishing corresponding mathematical model. Results show the "second" law is quite applicable to actual when the vehicle speed is lower than 36 m/s, which provides theory basis for the traffic studies.

Keywords: Mathematical Modeling, Vehicle Stopping Distance, "Two Seconds" Rule

1. Introduction

With the rapid economic development, traffic conditions and improvement of automobile consumption environment, car ownership has increased dramatically. The growing tension between the growing demand for transportation and existing transportation facilities is becoming more and more serious, such as traffic congestion, traffic safety and energy waste.

Traffic safety, as an important factor in transportation, has got a lot of attention. It is an important task for the current transportation system to prevent and reduce traffic accidents and ensure the smooth and safe road traffic. A large number of studies show that reducing speed and increasing the distance of workshop can effectively prevent and reduce the occurrence of traffic accidents. For example, Niu et al. [1] researched on car-following distance detection system of bus based on CCD camera technology; Wender et al. [2] collected a large number of car shape information as matching template database of image recognition, compared the image of the detected car with the template in the database, obtained the performance data of the front car, and then made a reasonable judgment about the relationship between the forward vehicle and the car; Huang et al. [3], [4] proposed the two-dimension reconstruction algorithm and distance measurement algorithm based on the single-ocular vision. Zhao et al. [5], [6], [7] introduced the process of applying monocular vision technology to the acquisition of multiple information of the forward vehicle, used the symmetry measure to detect the presence of the forward vehicle, and estimated the tracking target. Zhang et al. [8], [9] analyzed the spacing of stable car-following state and the car-following state of acceleration and deceleration; Zheng et al. [10] studied the safety driving distance of different car-following states in highway. Xia et al. [11] studied the influence of vehicle spacing on load effect. Kui et al. [12] discussed the effect of lateral wind and longitudinal spacing on the two trucks in tandem. Gao et al. [13] studied the adaptive cruise control aimed to achieving the control for maintaining safe inter-vehicle distance. Jiang et al. [14] established a mathematical model of rear-end collisions through the calculation of distances traveled by the front vehicle and the rear in different phases of the braking process after the brake lamp of the front vehicle lights. Zhai et al. [15] studied the feedback control of a class of coupled-map fuzzy time-delay car-following system. Ning et al. [16] built a model based on intelligent control of vehicle following distance.

At present, all kinds of algorithms have their advantages and disadvantages, but there is very little research based on the two-second rule. The "two-second" rule proposes it is necessary to properly increase the spacing of the workshops. The "two-second" rule can prevent collision crashes by maintaining proper safety car spacing. On the road, the driver can choose a fixed content of the road for reference, the front car passed through the fixed reference of the road, the after driver starts reading seconds, "for a second, two seconds," if counted, the after car did not arrive at the reference object, which explains it is safe and suitable for distance. On the other hand, if the driver does not count a couple of seconds, the vehicle has reached the reference, which explains the gap between the two cars is not safe enough, it should slow down immediately. Therefore, the time interval between the front car and the after car passing through this reference is more than two seconds, then the distance is suitable. It is the so-called "two second" rule. Based on the two-second rule, we establish a model to verify the validity of the two-second rule in the paper.

2. Models

2.1. Model Analysis

Assuming that car total stopping distance L is divided into reaction distance L_r and braking distance L_b. The reaction distance is the driving distance from the driver aware of parking time to really start braking vehicle moment; The braking distance is the sliding distance from the moment when the driver starts braking to the moment the vehicle stops. That is

$$L = L_r + L_b$$

We first study the reaction distance L_r. To simplify the operation, assuming L_r is influenced by reaction time t_r and speed v, that is,

$$L_r = f(t_r, v)$$

The reaction time t_r is affected by driver's personal driving factors, vehicle operating system factors, traffic environment and natural weather [11]. When the driver brakes, the vehicle operating system needs corresponding time, it is called the system time, which is defined the time elapsed from the driver contacts the brake pedal to the brake. However, the system time is relatively negligible to modern vehicles because the role of the system time is very small relative to the people themselves. the driver's reaction time depends on the sensitive degree of unexpected circumstances, the instinct of the reflection and visibility etc. In the paper, we study its general rule, so we take the mean values of the above variables. In the model, the mean value of detail factors is chosen. At the same time, we choose general motor vehicle speed and vehicle length. Assume that a driver's reaction time is normal, and there are not any accident happened in the process of braking.

Then we discuss the braking distance L_b. The driving speed of the vehicle and its own quality are important factors in the study of braking distance. In actual driving, of course, it is necessary to consider the braking efficiency of the vehicle, the type and state of the tire, the road condition and the weather conditions at that time. In the paper the effects of the factors are also ignored, and assume the average condition of the factors is satisfied. So in the sub-model, we assume that L_b is a function of the quality m and speed v of the vehicle. That is

$$L_b = h(m, v)$$

2.2. Build Models and Tests

For the reaction distance, suppose the vehicle is traveling at a constant speed at the time interval from that the driver is determined to stop until the braking action, the vehicle is traveling at a constant speed, namely the response distance L_r is the product of reaction time t_r and velocity v:

$$L_r = T_r * v \tag{1}$$

To verify the rationality of the reaction distance model, we use the data about the actual observed distance and braking distance of the driver that the U.S. highway administration provides on table 1, and give the relation graph about reaction distance and speed as shown in figure 1, the driver's reaction distance is proportional to the speed. The proportional relationship is as follows:

$$L_r = 0.75 * v \tag{2}$$

Table 1. *The reaction distance and braking distance observed.*

v(m/s)	*L_r(m)*	*L_b(m)*		*L(m)*	
		Observations	**Average**	**Observations**	**Average**
9	7	5-7	(6)	12-13	(12.5)
11	9	8-10	(9)	16-18	(17)
13	10	11-14	(12.5)	21-24	(22.5)
16	12	14-18	(16)	26-30	(28)
18	13	20-24	(22)	33-38	(35.5)
20	15	25-31	(28)	40-47	(43.5)
22	17	32-40	(36)	49-57	(53)
25	19	40-50	(45)	59-69	(64)
27	20	49-62	(55.5)	69-82	(75.5)
29	22	60-75	(67.5)	82-97	(89.5)
31	23	72-90	(81)	96-113	(104.5)
34	25	86-107	(96.5)	112-133	(122.5)
36	27	102-127	(114.5)	127-154	(140.5)

There may be the corresponding error between the result and the actual situation. In this paper we assume it is an ideal situation.

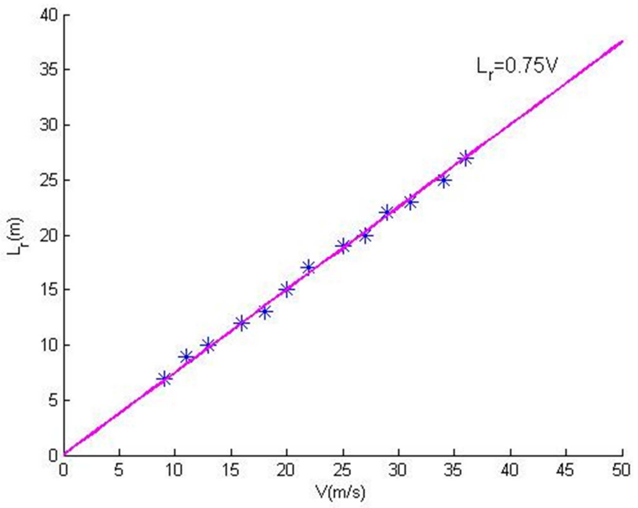

Figure 1. *The relationship between the reaction distance and the speed.*

For the braking distance, we assume that the maximum braking force F is used during the braking process. The work during the braking distance traveled L_b under the action of the maximum braking force F is FL_b. During the process, the speed of the vehicle is changed from V being to 0. From the law of conservation of energy, the change in kinetic energy is equal to the work done by the maximum braking force in the braking process, namely:

$$FL_b = \frac{1}{2}mv^2 \quad (3)$$

In addition, when the maximum braking force F is applied to the vehicle, the maximum acceleration of the vehicle a is fixed. Therefore, from the Newton's second law, we can get

$$F = ma \quad (4)$$

From (3) and (4), the following proportions are obtained：

$$Lb \propto V^2 \quad (5)$$

In this paper, we assume $L_b = kv^2$. Then we use the data in table 1 to test the equation (5) and get the value of k.

To verify the rationality of the braking distance model, based on table 1, we give the value of braking distance and speed squared in table 2.

Table 2. *The speed squared v^2 and braking distance L_b.*

$v^2(m/s^2)$	L_b (m)	
	Observations	**Average**
81	5-7	(6)
121	8-10	(9)
169	11-14	(12.5)
254	14-18	(16)
324	20-24	(22)
400	25-31	(28)
424	32-40	(36)
625	40-50	(45)
729	49-62	(55.5)
841	60-75	(67.5)
961	72-90	(81)
1156	86-107	(96.5)
1296	102-127	(114.5)

Based on table 2, the relation graph about braking distance and speed squared is shown in figure 2, the image is a straight line through the origin. Especially at lower speed, the ratio between the braking distance and the speed squared is more obvious, which verifies the rationality of our hypothesis. The proportional relationship is as follows:

$$Lb = 0.08V^2 \quad (6)$$

Then we can get $k = 0.08$. At a higher speed, however, the ratio needs to be further tested.

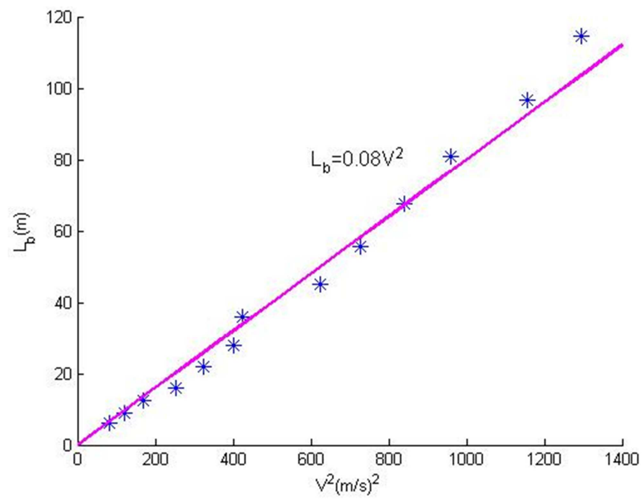

Figure 2. *The relationship between the braking distance and the speed squared.*

From formula (2) and (6), we can get the car total stopping distance L as follows:

$$L = 0.75V + 0.08V^2 \quad (7)$$

To verify the rationality of the the car total stopping distance, based on table 1, we give the mean value of the observed data from the total stop distance of the vehicle $L_{Observation}$ and the predicted data from the model (7) $L_{Prediction}$ in table 3.

Table 3. *The speed total distance observed $L_{observation}$ and total distance predicted $L_{Prediction}$.*

speed (m/s)	$L_{observation}$ (m)	$L_{Prediction}$ (m)
9	12.5	13.23
11	16.5	17.93
13	22.5	23.27
16	28	32.48
18	35.5	39.42
20	43.5	47
22	53	55.22
25	64	68.75
27	75.5	78.57

speed (m/s)	$L_{observation}$ (m)	$L_{Prediction}$ (m)
29	89.5	89.03
31	104.5	100.13
34	122.5	117.98
36	140.5	130.62

Consider the roughness of the data mentioned in the hypothesis and the incomplete accuracy of the data, and the result is shown in figure 3 according to table 3, we can get, when the vehicle speed is less than or equal to 36 m/s, $L_{Observation}$ and $L_{Prediction}$ are consistent, which indicates the feasibility of the model. However, when the vehicle speed exceeds 36 m/s, the total stopping distance of the vehicle predicted is significantly underestimated. It remains to be seen.

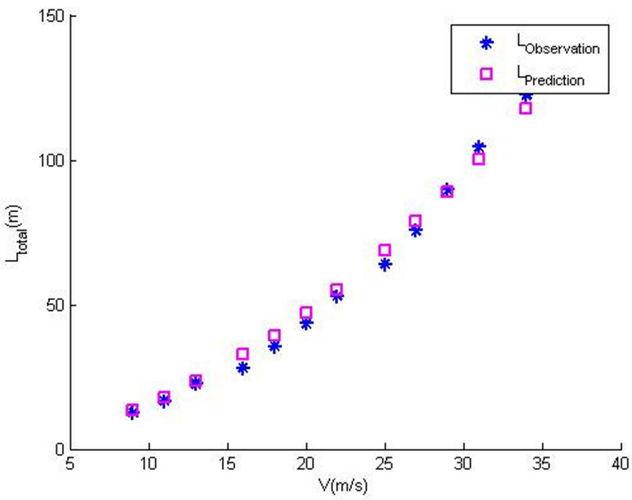

Figure 3. *The car total stopping distance.*

3. Model Applicability Analysis

Based on analysis and inspection of the reaction distance, braking distance and total stop distance for the driver, it can be found that the vehicle speed is lower than 36 m/s, the "second" law is quite applicable to actual; When the speed of the vehicle exceeds 36 m/s, the "two-second" rule greatly understates the total stopping distance of the vehicle because we lower estimate the vehicle stop distance during the process of solving the driver reaction distance and braking distance before the vehicle speed reaches 36 m/s. After that, we also overestimated the stopping distance of the vehicle. In addition, we ignore a lot of influence of natural and human factors in the model, such as individual drivers driving conditions, brakes, road pavement condition and visibility of gravity, etc., which provides a direction for future research on traffic safety issues.

4. Conclusions

In this work, we study the applicability of the "second" law through building the model of the reaction distance, braking distance and total stop distance. Results show the "second" law is quite applicable to actual when the vehicle speed is low, but the speed of the vehicle exceeds 36 m/s, the "two-second" rule greatly understates the total stopping distance of the vehicle. In future research, more influential factors need to be considered during the process of building the model.

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