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Calculation and Analysis of the Amber Interval in Traffic Flow

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Authors' contributions

This work was carried out in collaboration among all authors. Author MX designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ZJ and ZW managed the analyses of the study. Author MZ managed the literature searches. All authors read and approved the final manuscript.

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Abstract

According to the relationship between the speed of vehicle and the amber light, we establish the differential equation model of the amber light duration. And based on the relevant conditions given in the title, three differential equation models of amber light duration under different conditions are obtained. Considering the traffic condition and driver's habit, we calculate a value that is most suitable to the actual demand. The sensitivity and stability of the model and its related factors are analyzed. We improve the model for the problem of difficult area.

Keywords: Difficult area; sensitivity analysis; differential equation; image rendering.

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1 Introduction

When you are in the traffic lights, are you noticed how long the amber light is on?

In fact, the setting of the amber light duration has many limitations and plays a crucial role. So, have you ever thought about how long the amber light should be on? What are the restrictions on the length of the amber light? In traffic management, amber lights are set up to allow vehicles that are driving at or too close to an intersection to pass safely through an intersection. Therefore, amber lights at traffic lights must be on long enough to prevent drivers approaching intersections from being caught in a dilemma. So the setting of amber light has a lot of restrictions, and it is important to optimize the road condition.

There are many relevant factors to be taken into account when establishing the time model of yellow light. In this paper, we consider the factors in the problem and consult the relevant data [1], then conclude that the decisive factors in the calculation of the amber light duration are the speed of the vehicle, the width of the intersection, the length of the vehicle, driver's reaction time and braking distance.

First of all, according to the actual situation, we simulate the situation of the intersection, using Visio software to draw the image of the intersection as follows:

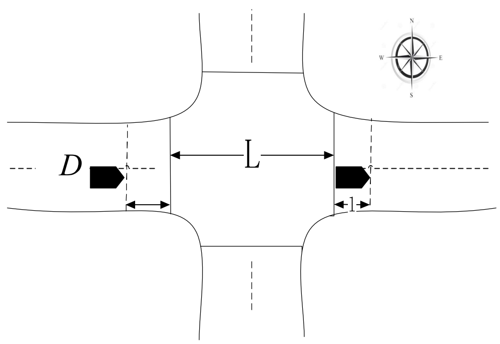

Fig. 1. Crossroads

According to the above image (Fig. 1), we can clearly see the situation at the crossroad, in which the length of the car is l and the width of the intersection is D. For this model, we have a more intuitive understanding by combining with reality.

Then, according to the known conditions, we establish a mathematical model of the length of the amber light which is related to the above factors (or part of the factors), and the length of the amber light is expressed as a function of the above factors (or parts of the factors). The model of the minimum distance vehicles can stop before the stop line is as follows [2].

$$L=v_0 t_1+\frac{v_0^2}{2\mu g}. \tag{1.1}$$

Here, v_0 represents the initial speed of a vehicle near the parking line, its unit is m/s. t_1 is reaction time, its unit is s. μ is , L represents braking distance, its unit is m.

Amber light duration is

$$t=\frac{L+D+l}{v_0}. \tag{1.2}$$

According to the formulas (1.1) and (1.2), we finally get the function calculation model of amber light duration as follows:

$$t = t_1 + \frac{v_0}{2\mu g} + \frac{D}{v_0} + \frac{L}{v_0}. \tag{1.3}$$

Here, the amber light duration is t, the unit is s, the width of the crossing is D, the unit is m, l is the length of the vehicle, and the unit is m.

2 Vehicle Speed and Amber Light Duration Model

On the basis of the above problems, we add the known conditions. Assuming that the reaction time is 1s, the average length of the vehicle is 4.5 m, the width of the intersection is 15m, and the friction coefficient is 0.2. Then, we analyze the relationship between the speed of the vehicle and the length of the amber light [3,4].

First of all, we replace the $t_1 = 1\text{s}$, $l = 4.5\text{m}$, $D = 15\text{m}$, $u = 0.2$, $g = 9.8\text{m}/\text{s}^2$ with the original amber light time function model. Then, the function expression we get is as follows:

$$t = 2 + \frac{v_0}{1.96} + \frac{15}{v_0}. \tag{2.1}$$

So we got a model of the relationship between the length of the amber light and the speed of the car. According to this model, we use MATLAB to draw the relationship between speed and time as follows:

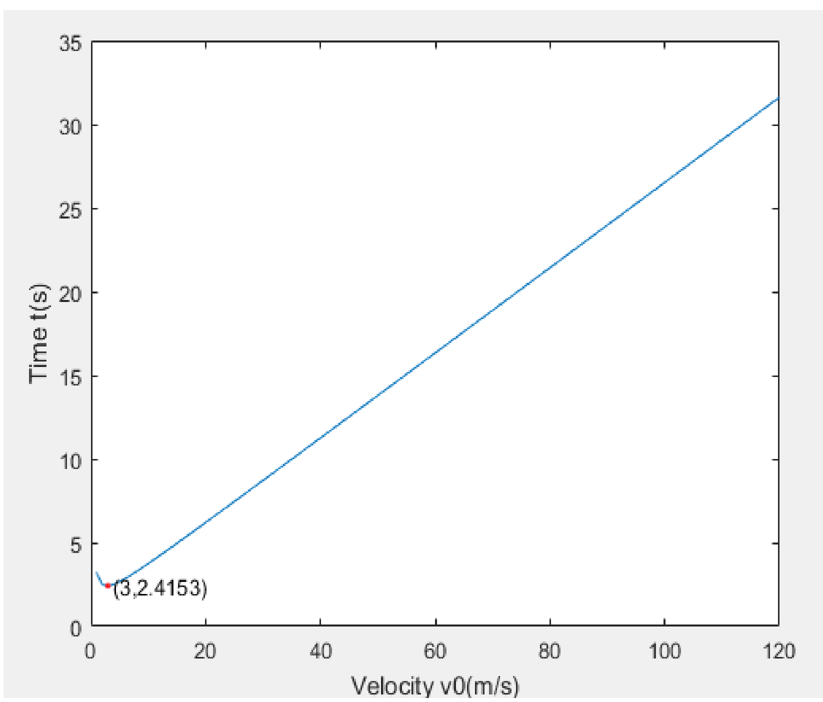

Fig. 2. Relationship between speed and amber light duration 1

From Fig. 2, it can be seen that amber light duration decreases with the increase of speed when $0 \le v \le 3$, and increases with the increase of speed when $v > 10$. So we conclude the two are positively correlated.

Here, we think more deeply about this result. In actual life, the amber light duration should be increased with increasing speed, and there is no negative correlation in theory. After we find this, we deduce that the lowest speed of the car is 10 km/h when the automobile runs normally through common sense, and according to the actual life and observation, the speed range of the car passing through the traffic light is about 10 km/h ~ 30 km/h.

3 Amber Light Duration Discussion

3.1 Amber light duration calculation I

We assume that the speed of the vehicle is 20km/h, 30km/h, 40km/h and 50km/h, respectively. Friction coefficient μ is not a definite value because of friction coefficient. Many factors, such as weather, tire quality, will affect μ. Assuming that the friction coefficient is increased from 0.2 to 0.4, we use the MATLAB to obtain the relationship between the driving speed of the vehicle and the time length of the amber light as follows in Fig. 3:

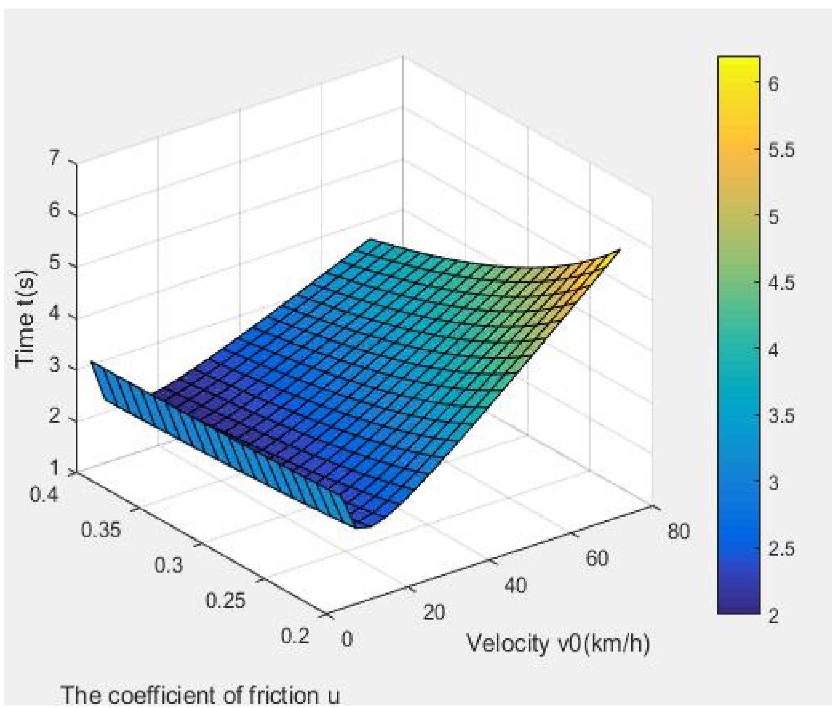

Fig. 3. Relationship between μ, speed and amber light duration

In Fig. 4, the 3D coordinates are vehicle speed v_0, friction coefficient μ and amber light duration t. The depth of color in the picture represents the length of the amber light. The three dimensional images show the general trend of the three: amber light decreases first and then increases with the increase of velocity. It decreases with the increase of friction coefficient. There is a general negative correlation.

Since the relationship between the friction coefficient and the length of the yellow light cannot be seen visually when the vehicle speed is small in the above image, we selected some representative points and obtained the following Table 1:

Table 1. Amber light duration

μ / t v	**20**	**30**	**40**	**50**
0.2	2.7682	3.3599	4.0100	4.6835
0.25	2.4848	2.9347	3.4431	3.9749
0.3	2.2958	2.6512	3.0651	3.5025
0.35	2.1608	2.4488	2.7952	3.1650
0.4	2.0596	2.2969	2.5927	2.9119

Compared with Fig. 4, Table 2 shows more clearly the relationship between μ and amber light duration. With the increase of μ, the duration decreases gradually.

3.2 Amber light duration calculation II

In the course of the study of the above model, we calculate some factors according to the given values, such as the width of the crossroads, which is not a fixed value. In addition to objective conditions some subjective conditions such as different traffic conditions and drivers' habits will have a greater impact on the calculation of amber light duration. After these factors are taken into account, the amber light duration is further solved and a final average value is calculated.

Here, we assume that the speed of the crossing is between 20 km/h and 50 km/h, with uniform distribution. And according to the existing research results, we know that: The perceptual time of 85% drivers is between ls and 1.8s, and for some older drivers, the reaction time is not less than 2.5s. According to the American Association of Highway and Transportation Workers, we take the reaction time as 2.5s. Therefore, in this question, we set the reaction time to 2.5s, the length of the vehicle to 4.5m, the width of crossroads to 25m in general, and the dynamic friction factor of dry asphalt and concrete pavement to 0.7. The average amber light duration is:

$$\bar{t} = \frac{\sum_{k=1}^{n} t_k}{n} = \frac{\sum_{k=1}^{n} t_1 + \frac{v_{0k}}{2\mu g} + \frac{D+l}{v_{0k}}}{n}, 1 \le k \le n. \tag{3.1}$$

The above data are substituted into the formula and solved by MATLAB, and the average amber light duration is 3.4231s.

4 Sensitivity and Stability Analysis

In the above process, we solve the establishment of the model and the solution of the amber light duration, and obtain the theoretical value of the final amber light duration, and then analyze the sensitivity and stability of the model.

In order to solve the problem in practice, we divide the orthogonal test optimization method into five small steps, and do a systematic and rigorous study on sensitivity analysis, which is to define the purpose of the experiment, to select the factors and the level, to exclude the test plan table, to analyze the test results by statistics, and to draw a conclusion [5].

For the purpose of the experiment, we want to obtain two aspects. One is the sensitivity of the factors such as friction coefficient μ and other factors in a certain range of changes to the amber light time, that is, the sensitivity of the factors. The factors of high sensitivity need to be considered in practical engineering setting.

Next, we need to select the influential factors that cause the change of the index. The factors in the experiment are called the level of factors. Select the factors that are suitable for artificial control and adjustment, and list the level of factors. We select the influencing factors which are suitable for artificial control and adjustment, list the factor level table, and replace the different numbers of each column in the selected orthogonal table with the corresponding level of the corresponding factors to form the test scheme [6]. Through MATLAB, we obtain 243 groups of representative data, and here we take the first five groups of data to make the following table:

Table 2. Experimental scheme and experimental results

	t_1(s)	v_0(km / h)	μ	D(m)	l(m)	t(s)
1	1	30	0.2	10	3	4.686
2	1	30	0.2	10	4	4.806
3	1	30	0.2	10	5	4.926
4	1	30	0.2	15	3	5.286
5	1	30	0.2	15	4	5.406

In summary, we can obtain sensitivity and stability information based on the above table.

In terms of sensitivity, according to the known mean square of each factor, we know that the sensitivity of several factors is not very high, and the stability of the results obtained from the corresponding model is good. Among several factors, the most important influencing factors are μ , t_1 and D , the sensitivity of the three factors is high. The sensitivity of l and v_0 is small, and the two have little effect on the result of the final amber light duration, so the selectivity should be considered or even ignored in real life.

In terms of stability, the mean square of each factor is less than 100, so the stability is high. In order to analyze the stability of the results more intuitively, we further process the data by using the method of control variable and MATLAB.

We already know that the three variables, μ , t_1 and D , have a great effect on the amber light duration. In actual engineering construction, the width of crossroads is certain, so there is no situation that amber lights do not meet the actual requirements due to its change. The variation range of t_1 is 1 ~ 2.5s, and the most reasonable value of t_1 has been obtained when the time of amber light is determined. Therefore, under normal conditions, it can meet the practical requirements. Therefore, we only need to study the friction coefficient μ , which is the most important factor, and take the other factors as invariants, and use MATLAB to draw the figure of the relationship between sliding friction coefficient and amber light duration as follows:

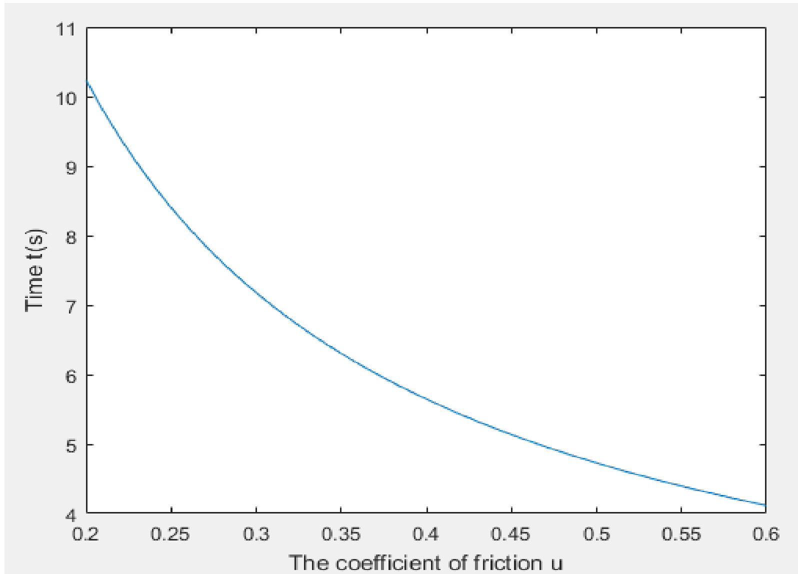

Fig. 4. Friction coefficient and amber light duration 1

From Fig. 5, we can see that μ varies from 0.2 to 0.6 when $t_1 = 1$ s、 $v_0 = 10$ km/h、 $D = 15$ m、 $l = 4.5$ m. By MATLAB, the duration difference of the corresponding amber light is 6.1224s. In this image, we take the $v_0 = 10$ km/h, which takes into account the decrease in speed when the snowy road slides, and the normal speed is about 30km/h, and μ is relatively larger than the snowy day. Without changing the other conditions, we will change the speed to 30km/h and redraw the relationship between the sliding friction coefficient and the amber light duration as follows:

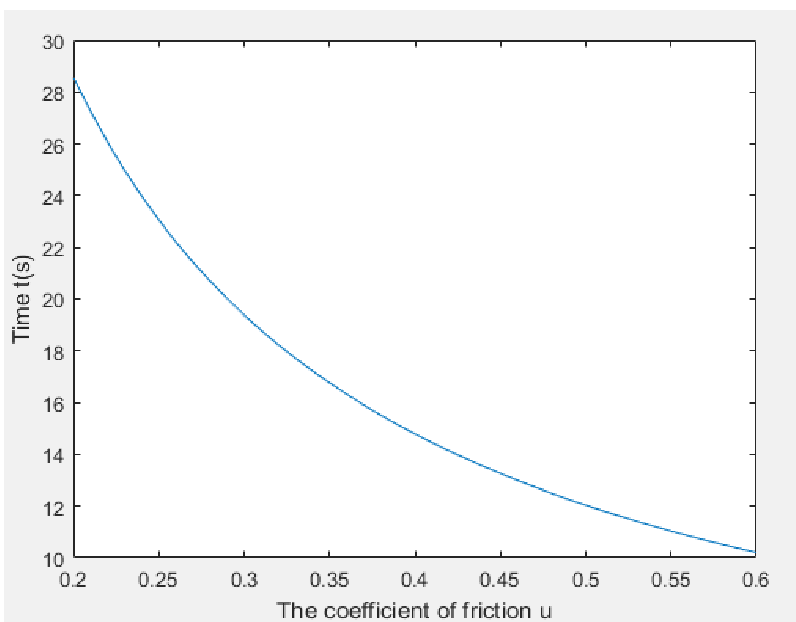

Fig. 5. Friction coefficient and amber light duration 1

From Fig. 6, we can see that μ varies from 0.2 to 0.6 when $t_1 = 1$ s、 $v_0 = 30$ km/h、 $D = 15$ m、 $l = 4.5$ m. The duration difference of the corresponding amber light is 18.3673s.

In calculating the actual amber light duration, according to the driving speed and μ of people in sunny and snowy days, we obtain the duration of 10.2366s and 10.320 7s, respectively. The difference between them is only 0.0841s. We get the conclusion that the amber light duration calculated by our model has strong stability in real life and can meet the needs of different weather, speed and other actual road conditions.

5 Model Improvement

Because our model is relatively simple to take into account various factors and idealized, especially for the problem of "difficult area", which is often encountered in the amber light duration, there is not a proper consideration. Here, we will analyze the situation from the point of view of the difficult areas. A more rigorous calculation model of yellow lamp time is obtained.

At the crossroads, when the amber light is on, the driver either chooses to pass through the intersection or chooses to slow down to stop. If the vehicle can neither speed through the intersection nor slow down in front of the stop line, the vehicle is in a difficult area. To show the problem in the difficult area more visually, we used Visio to draw a crossroads map as follows:

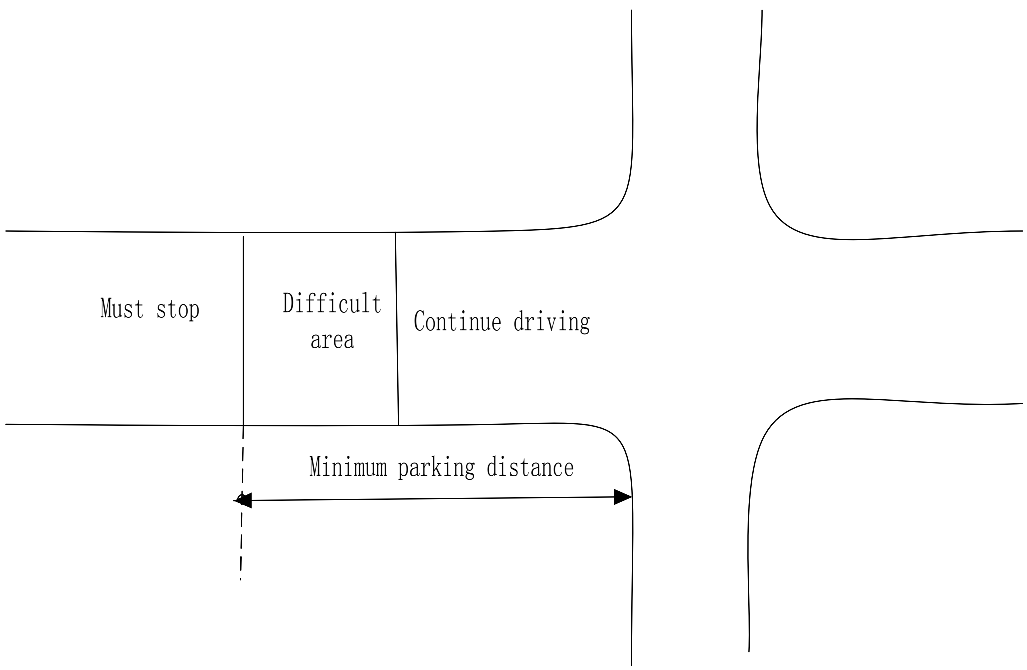

Fig. 6. Difficulty area at crossroads

From the figure above, we can see the difficult area between the parking area and the continuing area. Next, we will solve the problem of the difficult area based on the minimum parking distance and other data. Assume that t_1 is the driver's reaction time, and that the car runs to full stop at maximum acceleration during t_2. The following formula can be listed:

$$X_1 = v_0 t_1, \tag{5.1}$$

$$X_2 = \frac{v_0^2}{2a_{\max}}. \tag{5.2}$$

The minimum stopping distance is

$$X_c = X_1 + X_2 = v_0 t_1 + \frac{v_0^2}{2a_{\max}}. \tag{5.3}$$

When the yellow light lights up, the driver thinks he can pass through without slowing down, and the maximum distance from the parking line through and away from the intersection is the maximum distance:

$$X_O = v_0 t - D - l \tag{5.4}$$

The width of the difficult area by formula (8) and (9) is

$$X = X_c - X_o = v_0 t_1 + \frac{v_0^2}{2a_{\max}} - v_0 t + D + l. \tag{5.5}$$

When a vehicle is in a difficult area, difficulties can arise. When the vehicle encounters a amber light in the area, it will park outside the parking line, and the vehicle will not be able to cross the intersection safely during amber light duration. In a difficult area, the driver does not intend to run a red light or can not cross the intersection safely.

In order to solve the problem of difficult area, assuming that the vehicle is approaching the intersection at the initial speed of v_0, when X_c and X_o are equal, the difficult area is a line, that is, the difficult area does not exist, thus the model of amber light duration can be deduced as follows:

$$t = \frac{v_0 t_1 + \frac{v_0^2}{2a_{\max}} + D + l}{v_0} = t_1 + \frac{v_0}{2a_{\max}} + \frac{D + l}{v_0}. \tag{5.6}$$

Formula (5.6) concluded that the calculation model of difficult area amber light duration. The model can be used as a reference for the calculation of the amber light duration at all intersections in the city. In the use of the model, we need to know the speed limit and the width of the vehicle at the target intersection. Other parameters can be selected according to the model composition of different sections of the vehicle flow when the reference data mentioned in the paper are used.

Competing Interests

Authors have declared that no competing interests exist.

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