Journal of Mathematics and Informatics
Vol. 2, 2014, 38-46
ISSN: 2349-0632 (P), 2349-0640 (online)
Published 18 November 2014
www.researchmathsci.org

Journal of Mathematics and Informatics

Study on the Impact of Urban Traffic Capacity due to the Lane Occupation

***Liuxin Chen*[1], *Xiangqian Li*[2], *Fang Fang*[2] and *Yansheng Huang*[2]**

[1]Schoolof Science, Chongqing University of Posts and Telecommunication
Chongqing-400065, Chongqing, China. E-mail: chenliux@cqupt.edu.cn

[2]School of Automation, Chongqing University of Posts and Telecommunication
Chongqing-400065, Chongqing, China
E-mail: 1548573746@qq.com; chenliux@cqupt.edu.cn

Received 10 October 2014; accepted 2 November 2014

Abstract. We aim to investigate the problem of the impact of lane occupation on urban road traffic capacity and vehicle queuing length.We successfully solve the degrees of impact of different lane occupation on the actual road capacity, the relationship among the vehicle queuing length and the cross-section actual capacity and traffic flow on upstream by the theories of speed-flow model and improved traditional cumulative reach-leaving model.Through the analysis of examples, we conclude that the model presented in this paper is reasonable and can be used in practice to solve the relevant problems.

The lane occupation means the cross section of the traffic road becomes narrow because of the traffic accident, temporary roadside parking, work and other factors, which always lead to traffic jams.Because of the characteristics of traffic flow density, strong continuity on the city road, if a lane is occupied, it may reduce the road all the lanes of traffic capacity.Even though the time is very short, it may also be caused by traffic jams. If it is treated inappropriately, traffic jams would become terrible.

In China, lane occupation is very common.To estimate correctly the influence degree of the city road traffic capacity due to the lane occupation, it will provide a theoretical basis for the traffic administrative department, on the correct guide vehicle, reasonable examination and approval work, set the curb parking and setting non harbor shaped bus station etc.

Keywords: Traffic capacity; speed-flow model; cumulative reach-leaving model

1. Introduction

In this paper, we have established a mathematical model accordingto the video of the CUMCM-2013 Problem A. First, we define the calculation formula of the actual capacity, and collect traffic-flow data in the videoⅠand the VideoⅡ, so as to obtain the change process of the accident to evacuate during the actual capacity of the cross section.Through the test of variance, we show that there is different actual capacity influence when a traffic accident happens on the different lane in the same section of traffic accidents.Then we build the model about road capacity loss rate by using the relationship between road traffic capacity and road space, and get the degree of influence on the actual capacity owing to the different lane occupation.Second, we improve the traditional reach-leaving model.Through the improved traditional reach-leaving model, we analyze the influence of road traffic accident vehicle queue length and cross section of the actual capacity of accident, accidentduration, the relationship between the upstream sections of vehicle flow, vehicle queue length estimation model is established.Finally, we apply this model to calculate queuing length and queuing disappear duration in the two kinds of traffic accident cases.

2. Assumptions

1. The ratio of vehicle flow in each lane doesn’t change because of the traffic accident.
2. Once the lane occupied, we believe no vehicle can go through the lane.
3. We believe that only the four wheel vehicle and above vehicle, battery car on the road.
4. We believe that the vehicle queue length relate to the actual traffic capacity of the cross section, and accident duration,and sections upstream traffic flow, no other factors are involved.

3. Model building and solving

3.1. Analysis the actual traffic capacity of different lane

3.1.1. Calculate the actual traffic capacity

We can calculate the road capacity under the overload traffic conditions by use of the common highway speed-flow model.We hope get a function relation of speed and flow under any traffic load conditions.We obtain the average speed and traffic load through the following model given byWang[1].

$$\begin{cases} U = \dfrac{\alpha_1 \cdot U_s}{1+\rho^{\tau}} \\ \tau = \alpha_1 + \alpha_2 \cdot \rho^3 \\ \rho = \dfrac{V}{N} \end{cases} \quad (1)$$

where U is the average speed, U_s is that the design speed of the highway, ρ is the traffic load, V is vehicle flow, N is the traffic capacity, α_1 is 1.133, α_2 is 1.88 and α_3 is 4.90.

Further, we need to learn the maximum traffic capacity on every road which can pass in a unit of time under the ideal traffic conditions. According to the model given by Li [2], we can get the maximum traffic capacity.

$$N_{\max} = \frac{3600}{t_0} = \frac{3600}{l_0 / (U / 3.6)} = \frac{1000V}{l_0} \quad (2)$$

Because the vehicle front minimum interval l_0 is relate to the safety distance l_s between it and the front vehicle andit usually take as 3 to 5 meters, the average length of the vehicle l_c,the driving distance l_f within the driver's reaction time of vehicle and braking distance l_z.From the above, we get the formula $l_0 = l_s + l_c + l_f + l_z$.

According to Gong's research [3], we learn the driver's reaction time t_1 is generally one second or one second and a half. Let μ is the coefficient of friction between the wheel and road surface.Under the ideal conditions, we can get the basic traffic capacity as follow:

$$N_{\max} = \frac{1000U}{\frac{U}{3.6}t_1 + \frac{U^2}{254\mu} + l_s + l_c} \quad (3)$$

However, the traffic capacity in the actual situation is influenced by the lane width, the traffic conditions, the number of lanes and other factors.In order to get the actual situation of the traffic capacity, we improve the model, by additional consideration lane width correction coefficient of traffic conditions, the correction coefficient of correction coefficient, the number of lanes correction coefficient.The model is given by

$$N_P = N_{\max} \prod_{j=1}^{n} \beta_j \quad (4)$$

Finally, we put the service traffic volume multiplied by a given level of service and the traffic capacity with the ratio, and then can get the actual traffic capacity as follow:

$$N_s = \frac{N_P \times service\ \ traffic\ \ volume}{traffic\ \ capacity} \quad (5)$$

We collected traffic flow data from the videol, and convert the traffic flow volume into a standard vehicle equivalent number based on the vehicle conversion factor in table 1.

Tape of vehicle	minibus	Large bus	Large trucks	Hinge for vehicle
conversion factor	1.0	2.0	2.5	3.0

Table 1: Vehicle conversion factor

By formula (1) - (4), we can get the average speed, the basic traffic capacity and the actual traffic capacity.We draw a graph to show the actual capacity changes over time by using matlab software, as in Figure 1 (a).

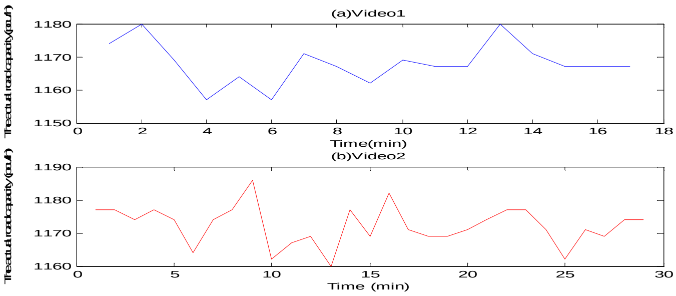

Figure 1: The actual traffic capacity curve

According to figure 1(a), we learn thechanges of the actual traffic capacityafter the accident occurred.By recording the traffic flow within a minute before the accident occurred, we can obtain the traffic capacity is 1686 pcu/h.Compared with the actual traffic capacity, the traffic capacity dropped by 30.72% after the accident.During the whole accident to evacuate, we learned that the cross-sectional actual traffic capacity changes little, about 1168 pcu/h.

3.1.2. Effect of occupying different lane on the actual capacity

Through the analysis of the videoⅠ, videoⅡdata and figure 1, during the whole accident to evacuate, we can know that there is a different effect on the actual capacity of the same cross sectiondue to the lane different occupied. Through the test of variance (see Table 2), it further illustrates the different lane occupied is an important factor affecting the average traffic capacity.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
VAR00001	17	1157.00	1180.00	1168.0000	6.34429	40.250
VAR00002	29	1160.00	1186.00	1172.2414	5.90191	34.833
Valid N (listwise)	17					

Table 2: The statistical results of traffic flow form videoⅠand video Ⅱ

Based on the relationship between traffic capacity and the share of road space, Xu [4] put forward a calculated method and model of lane-changing about it's effected to additional road space, and calibrated the parameters, the correction factor is calculated. Therefore, we define the road capacity loss rate to show the actual traffic capacity influence degree because of the different lane's occupying.

In a certain period of time, the vehicles in the unregulated state, the actual traffic capacity because of the lane-changing behavior of influence is relate to the number of lane-changing vehicles.It can begiven by

$$Q_c = (Q - Q_s)\cdot q_i \cdot (V_f \cdot t / l_g) \quad (6)$$

where Q_s is the road capacity loss.

We consider the effect of shunt accounted for traffic flow ratio φ_k, and deduces the total occupy extra space due to the lane changing behavior within in time t.

$$l_\Delta = (Q - Q_s)\cdot q_i \cdot (V_f \cdot t / l_g)\cdot |\Delta V| \cdot t_c \cdot \varphi_k \quad (7)$$

where q_i is the probability of the lane-changing behavior occurrence, l_g is the vehicle traveling distance in free flow speed V_f in a unit of time, ΔV is the difference between the speed after the lane-changing behavior occurrence and the free flow speed V_f.

We need to know the road space of every car occupancy to get the additional space occupation caused by traffic volume loss. We can get it through the formula given by

$$l_D = \frac{t \cdot V_f}{Q} \quad (8)$$

Under ideal traffic capacity of road conditions, the traffic volume loss per unit time is the ratio given by

$$Q_s = \frac{l_\Delta}{l_D} = \frac{(Q-Q_s)\cdot q_i \cdot (t\cdot V_f / l_g)\cdot |\Delta V| \cdot t_c \cdot \varphi_k \cdot Q}{t \cdot V_f} \quad (9)$$

where

$$Q = \frac{t\cdot V_f}{l_D} = K_j \cdot V_f / 4 \quad (10)$$

and K_j is the jam density.

The road capacity loss rate is defined as the ratio of total loss of traffic volume Q_s and traffic volume Q .Therefore the formula for calculating the traffic capacity of the road loss rate is

$$\alpha_c = \frac{Q_s}{Q} = \frac{K_j \cdot V_f \cdot q_i \cdot |\Delta V| \cdot t_c}{4l_g + q_i \cdot |\Delta V| \cdot t_c \cdot \varphi_k \cdot (K_j \cdot V_f)} \quad (11)$$

Let V_f is 60 km/h , K_j is 111.1 $pcu/(km.\ln)$ .We use the formula (11) and can get the effect ofthe traffic capacity because of different lane occupation.The results of the calculation are shown in the following table.

Conditions of lane occupation	The loss of traffic flow ratio	The road capacity loss rate
1,2,3	1	1
1,2	0.65	0.6199
1,3	0.56	0.5871
2,3	0.79	0.6788
1	0.21	0.487
2	0.44	0.5485
3	0.35	0.5227

Table 3: The different effects on the actual capacity of different lane occupied

According to table 3, we can see that the influence degree on the actual capacity due to the different road lane occupied is different. If the first lane is occupied, the impact of the actual capacity is the minimal. Though the same number of lanes is occupied, because traffic flow ratio of every lane is different, and the traffic capacity loss rate is also different. When all the 3 Lanes are occupied, the actual capacity is reduced to 0, that is, the road to traffic. Because the large the road capacity loss rate is, the bigger the degree of influence holds the behavior of vehicle actual capacity is.It shows that the traffic flow and the traffic capacity of the road loss rate is negative correlation.

3.2. Vehicle queue length estimation model

Becausetraffic accidents happen on the upstream road, it leads to a reduction of the section of the actual traffic capacity, and results in traffic congestion, and causesvehicle queuing situation. In order to estimate the vehicle queue length, weselect the traditional cumulative reach-leaving model. The model can be used to calculate the flow, and the actualflow of the traffic network is relatively easy to obtain, and the model is convenient to be improved according to the characteristics of urban road [5].

There are some defects in the traditional cumulative reach-leaving models, such as the actual traffic capacity of the original model is a constant, and the arrival traffic flow of the car is a monotonically decreasing function.In fact the actual traffic capacity is not a fixed value and the traffic flow is a monotonically decreasing function, it may be a fluctuating curve with the time.

In order to aviod the above problem, we improve the original model by considering the dynamic changes of the actual traffic capacity and a function of the arrival traffic flow which is obtained according to the signal periodic fitting.Then we use the improved cumulative reach-leaving model to estimate the length of the vehicle queue, and obtain the relation among vehicle queue length, the actual traffic capacity of the cross section, accident duration and theupstream traffic flow.

3.2.1. The relationship among the length of vehicle queue and the actual capacity and upstream traffic flow

Due to the two different cycle of the intersection traffic signal and random arrival, we get the arrival flow diagram according to the data of the vehicle in videol. The arrival flow diagram as follow:

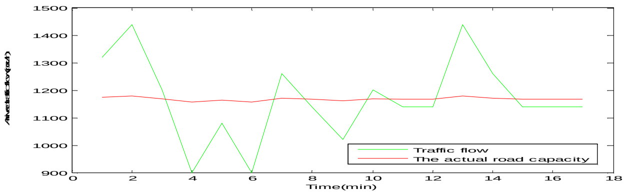

Figure 2: The arrival flow diagram

Using the arrival flow diagram, we can get the formula to calculate the vehicle number of the cumulative arrival.The formula is given by

$$Q_J(t) = \int Q(t)dt \quad (12)$$

Similar, we can get the vehicles number of the cumulative leaving by the follow formula.

$$N_J(t) = \int N_s(t)dt \quad (13)$$

Therefore, the vehicle numbers of the accumulative arrival and of the leaving are monotonically increasing with the time.

3.2.2. The relationship between the actual traffic capacity and the accident duration

The actual traffic capacity is constantly changing in the traffic accident duration.With the actual traffic capacity to gradually return to normal levels, the actualcumulative traffic capacity will be increased linearly with the increase of time. The length of queue vehicles will shorten to zero with the increase of time.

Based on the above analysis, we establish the model by considering the relationship among the number of accident vehicle queue, the actual capacity, the upstream traffic flow and the accident duration.The model is

$$B(t) = Q_J(t) - N_J(t) = \int N_s(t)dt - \int Q(t)dt = \int [N_s(t) - Q(t)]dt \quad (14)$$

Then we can get the length of the vehicles queue by the follow formula.

$$L(t) = \frac{B(t)\cdot l_p}{number\ \ of\ \ lanes} = \frac{l_p \cdot \int [Q(t) - N_s(t)]dt}{3} \quad (15)$$

With the continuouschange of arrival traffic flow, the queue length may be lengthenor shorten.When $Q(t) = N_s(t)$, the number of vehicles queuing reaches to the local maxima of this moment.During the period of the traffic accident, the number of extreme point means how many times queuing occurs, only difference of the queue length. The maximum queue length is the maximum value of the extreme point.Therefore, we can get the maximum vehicle queue length from the below formula.

$$L_m = \max_{t_j}[\max(L(t_j))] \quad (16)$$

where $L(t_j)$ is the extreme value of the time t_j .

3.2.3. The calculation

Variablein the modelinvolvedis continuous, such astraffic flow, the actual traffic capacityand so on.But wegetthe value ofthe variablefrom the video, which are discretevalues.Therefore, wefitthe discretevaluesto obtain avariation ofthe variablesover time. Here wediscusstwo cases:

Case 1: We get the standard vehicle equivalent numberfrom video Ⅰ, and we obtain the cumulative standard vehicle equivalent number. Then we fit a cubic regression model.

$$Q_J(t) = 3.926 + 19.629t - 0.371t^2 + 0.025t^3 \quad (17)$$

Similar, we can get the linear regression equation to calculate the cumulative actual traffic capacity value.

$$N_J(t) = \begin{cases} 0.978 + 19.238t, & 0 \le t \le t_x, \\ 339.182 + 28.1(t - t_x), & t > t_x, \end{cases} \quad (t_x = 17.58\,\text{min}) \quad (18)$$

From the formula, we get the model to calculate the queue length before and after the accidente vacuation. The formula is given by

$$L(t)=\frac{l_p\times B(t)}{3}=\begin{cases}\frac{l_p}{3}(0.025t^3-0.371t^2+0.382t+2.948), & 0\le t\le t_x\\ \frac{l_p}{3}(0.025t^3-0.371t^2-8.471t-335.222), & t>t_x\end{cases} .(19)$$

Case 2: It is 140 metersfar from upstream ofthe intersection to the roadtraffic accidents, and the accident does n't evacuate, and reach the traffic flow at the detection section changes, and the traffic capacity of down stream doesn't change.

Original N_J	17	24	22	12	18	14	21	20	15
Cumulativenumber	17	41	63	75	93	107	128	148	163
Original N_J	21	19	16	25	20	18	17	16	
Cumulativenumber	17	203	219	244	264	282	299	315	

Table 4: VideoⅠ accumulated leave and turn the cumulative number of vehicles

By using the data of Table 4, we get the regression model.

$$N_J(t)=18.566t+0.257 \quad (20)$$

Because the up stream traffic volume traffic is $1500pcu/h$. So we have

$$Q_J(t)=\frac{1500t}{60}=25t \quad (21)$$

From the formula, we get the length of the queue which is given by

$$L(t)=\frac{l_p}{3}[Q_J(t)-N_J(t)]=\frac{l_p}{3}(6.434t-0.257) \quad (22)$$

If $L(t)=140$, the length of the vehicle queue wills reachto the upstream intersection after 220 seconds, i.e. oncean accidentoccurs, thevehicle queue length will reach the upstream intersection after 220 seconds.

4. Conclusion

In this paper, focusing on CUMCM-2013 Problem A, we have established the actual capacity model due to different lane occupied and the vehicle queue length estimation model. Then we correct the actual traffic capacity gradually and get an improved reach-leaving model which can be more reasonable to solve practical problems.

Acknowledgements

This work is supported by the Natural Science Foundation of Chongqing (No.CSTC, 2011jjA00021), the Graduate Teaching Reform Research Program of Chongqing Municipal Education Commission (No.YJG143010) and the Natural Science Foundation of Chongqing University of Posts and Telecommunication (No.A2011-38).

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