ABSTRACT

In order to realize the reasonable planning, design and management of expressway, the modified cell transmission model is proposed considering the limitation of equal cell length of traditional cell transmission model, improving the mode of traffic transmission on expressway. The capacity and jam density is calculated and the relationship between traffic speed and density is calibrated by using the vehicle detector data. Meanwhile, the traffic speed-density relationship is refined by adopting the weighted least square method, enhancing the practicality of the model. When the modified cell transmission model is applied in the expressway, the mean percentage error of cell traffic flow can be controlled at around 12 percent, which shows that the simulation result is satisfactory.

INTRODUCTION

Expressway transport occupies a large proportion of transportation, in recent years, with the rapid growth in the number of motor vehicles, it is the main means of transport in the short and long passenger and freight transport. However, with the increase of expressway utilization, a series of traffic congestion problems on high occurrence rate of traffic accidents and environmental pollution. In order to solve the problem of traffic congestion, the traffic flow simulation technology is
used to get the output parameters, which can reflect the traffic status on the expressway intuitively and efficiently.

Traffic flow simulation model can be made up of macroscopic and microscopic model. Compared with the microscopic model, the macroscopic model is easier to calibrate the parameters and is more suitable for real-time traffic management. The most widely used model is Cell Transmission Model (CTM), which is proposed by Daganzo in 1994[1],[2] and it is clearly to describe the physical effects of queuing and can be better to simulate the traffic dynamics such as shock wave, queuing formation, queuing dissipation and interaction between multi-channel cells. However, the road is divided into equal length cells in the Cell Transmission Model, limiting the application of CTM in the actual traffic simulation. Ajith Muralidharan[3] proposes Link-Node Cell Transmission Model (LN-CTM) based on the Cell Transmission Model and adopts the least squares method and quantile regression algorithm to calibrate the traffic flow parameters, which completes the whole freeway network traffic simulation. Although LM Muñoz[4] raises Modified Cell Transmission Model (MCTM) to achieve non-equal length of the road division, which increases the applicability of the CTM, the model still not takes the impact of traffic density on speed into account when calculates the traffic flow.

This paper illustrates the modeling and simulation of the expressway. The expressway is divided into non-equal length cells, the toll station and vehicle detector is as the data source, this paper analyzes the traffic flow transmission form of the expressway, the calibrated the parameters and finally constructs the dynamic traffic flow simulation model on expressway, reflecting the expressway traffic status dynamically.

MODIFIED CELL TRANSMISSION MODEL

In order to establish cell transmission model of non-equal length cell, this paper makes the following assumption: (a) the expressway is divided into non-equal length cells according to the direction of the vehicles; (b) each cell contains at most one on- or off-ramp; (c) the traffic status of each cell is considered to be homogeneous; (d) if there is an exit or entrance ramp in the cell, it must be located near the downstream boundary of cell; (e) the first and last cell contain neither an one on- and off-ramp.

On the basis of the CTM, considering the principle of non-equal length division, the functional relationship between the traffic flow \( q \) and traffic density \( k \) is:

\[
q = \min(q_{\text{max}}, k \cdot v_e(k), w(k_j - k))
\]  

(1)
Noting that the traffic speed is a function of density in the above equation, which it is no longer assumed that the traffic speed is a constant in the traditional CTM. Owing to the law of flow conservation that the traffic flow transfer meets, the flow transmission formula between adjacent cells is:

\[ N_i(t + 1) = N_i(t) + f_{in,i}(t) - f_{out,i}(t) \]  \hspace{1cm} (2)

\[ f_{in,i}(t) = f_{out,i-1}(t) \]  \hspace{1cm} (3)

Where \( w \), \( q_{max} \) and \( k_j \) represent traffic flow back propagation speed when the traffic is congested, the maximum traffic flow and the jam density respectively. \( v_e(k) \) represents the function of traffic speed and density in the equilibrium condition. \( N_i(t) \) is the number of vehicles on the cell \( i \) during the \( t \)th time interval. \( f_{in,i}(t) \), \( f_{out,i}(t) \) respects the input and output flow on the cell \( i \) during the \( t \)th time interval respectively.

**CALIBRATION**

Like most macroscopic models of traffic flow, the modified cell transmission model must calibrate the traffic flow parameters by the vehicle detector data. The traffic flow parameters include the cell capacity, the cell jam density and the equation of cell traffic speed and density. The calibration procedure involves the following.

**The Calibration of Cell Capacity, \( Q_i \)**

The capacity is defined as the maximum flow of the road or a crossroad in the unit time, in a certain road and traffic conditions. This deterministic notion of capacity has been challenged lately by stochastic approaches[5]. So according to the traffic flow theories, the capacity of each cell is obtained by analyzing the relationship between traffic flow and traffic speed. Firstly, the observation interval we choose is 5min. Consequently, the analyses below are all based on 5-minute volume and speed values.

The relationship between traffic flow and speed of each cell can be made in scatter plot. As is shown in Figure 1, speed-flow data for 5 minutes counts across all lanes obtained from vehicle detector throughout one whole year, and a threshold speed of 70km/h is found, which can be as the boundary between
non-congested status and congestion. Therefore, the capacity of each cell can be calibrated as the traffic volumes when the speed is 70km/h.

The Calibration of Cell Jam Density, $K_j$

The cell critical density $K_m$ can be counted by the formula:

$$K_m = \frac{Q}{V_m}$$

(4)

Where, $Q$ represents the cell capacity and $V_m$ represents the threshold speed, which is equal to 70km/h. The jam density can be considered as twice of the critical density.

The Traffic Speed-density Relationship

Similar to the calibration of capacity, the equation of each cell is obtained by analyzing the vehicle detector data of a whole year that are aggregated every 5 minutes. In particular, a total of 700,600 samples of speed and density from 001 to 013 vehicle detector are collected from the freeway, of which 512,241 out of 700,600 samples (73.11%) are at low densities (<20veh/km). Therefore, compared to the least square method (LS), the parameters of the speed-density relationship are calibrated by the weighted least square method (WLS)[6] (Figure 2)

The value of the weight is depended on its density. The speed-density samples can be presented as: $(v_1, k_1), (v_2, k_2), (v_3, k_3), ..., (v_m, k_m)$. Firstly, rank the speed-density samples in terms of density. And then make sure the weight $\omega$, the equation is:
The speed-density relationship of each cell can be obtained through drawing the speed-density scatter plot of detector data (Figure 3), thus the basic format that can be adopted is:

a. Linear format: \[ v = \beta_1 + \beta_2 k \]
b. Parabolic format: \[ v = \alpha_1 k^2 + \alpha_2 k + \alpha_0 \]
c. Negative exponential format: \[ v = \eta_1 + \exp(-k) \times \eta_2 \]

Where, \( \beta_i (i=1,2) \), \( \alpha_i (i=0,1,2) \) and \( \eta_i (i=1,2) \) are the calibrated parameters. The speed-density relationship of each cell is got by choosing the best fitted form of the three formations, which the parabolic formation is chosen.

**APPLICATION**

The imputation procedure and calibration detailed in the previous sections are used to simulate the traffic flow parameters of a 9-kilometer long expressway. The expressway has a total of 2 on-ramps and 3 off-ramps and 7 toll stations. Meanwhile, the expressway can be divided into 13 cells from the assumption of modified cell transmission model. In order to improve the accuracy of the simulation results, the 10sec time interval is carried out.

The simulation traffic flow results of expressway can be aggregated every one
hour, which can be presented as: \( \{y_1, y_2, ..., y_{24}\} \). Meanwhile, the real flow data collected by vehicle detector summarizes every one hour, which can be presented as: \( \{y_1, y_2, ..., y_{24}\} \). For the purpose of verifying the accuracy and reliability of the modified cell transmission model, comparing the simulation traffic flow \( \{y'_i\} \) with the measurements \( \{y_i\} \), which the following figures summarize the results of the simulation and compare them to the corresponding observations (Figure 4), and then calculating the mean absolute percentage error \( E_{mpe} \), which the formulation is:

\[
E_{mpe} = \frac{1}{M} \sum_{k=1}^{M} \left| \frac{y_i(k) - y'_i(k)}{y_i(k)} \right|
\]

(6)

In conclusion, according to the equation (6), the mean absolute percentage error of the traffic flow volume is 12.33%.

CONCLUSIONS

This paper specifies the modified cell transmission model and the calibration of expressway, realizing the simulation of traffic state evolution of expressway and estimation of the traffic parameters.

The expressway is divided into several cell of unequal length, and then establishes the simulation function of the expressway. The vehicle detector data aggregated every 5 minutes is used for calibrating the capacity, jam density and the speed-density relationship of each cell. Taking an example of expressway, the simulation traffic flow volume of the cell is closely to the measurements obtained by summarizing the vehicle detector data, which the mean error is less than 15 percent.

REFERENCES