INITIAL INVESTIGATION ON TRAFFIC FLOW

CHARACTERISTICS OF BEIJING NO.3 LOOP HIGHWAY

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Abstract
The purpose of this work is to investigate the relationship among speed, flow and density based on the actual traffic data collected from Beijing No.3 Loop Highway. Principal findings related to the shapes of the three curves are presented. Through observation of traffic flow, a new modeling approach is proposed in this paper.

Keywords
Macroscopic traffic model, Beijing loop highway, drivers' behavior

1 Introduction

A solid understanding of the way in which three basic aggregate traffic parameters of speed, flow and density varies with one another is a prerequisite for the development of traffic data processing and estimation, design of traffic models, and testing of control strategies via simulation and field works. Especially, for many applications it is critical to know the relationship between traffic speed and flow.

In this paper we presents the initial results of investigation on the speed, flow and density relationship in a representative metropolitan freeway in China, Beijing No.3 Loop Highway during three successive days in May 2001. Our goal is to develop an accurate traffic model that can be used to describe traffic situations in Chinese Urban freeway systems, such as Beijing's Loop Highways and Shanghai's Highpass Highways.

2 Conventional fundamental diagrams

As an introduction to the measured data set, let us first consider the conventional fundamental diagram shown in Figure 1 and Figure2 [1] [2] [3]. The speed-flow relationship shown in Figure 1 is not based on any data set but is a heuristic result from the conventional wisdom. However, this curve is not entirely correct. The upper branch of the speed-flow relationship cannot have a negative slope at all points but must be horizontal at very low flows. It would also seem to be obvious that the speed does eventually drop. What is not obvious, however, is how the flow changes before the drop begins or how far the speed drops.

We can ask similar questions to the flow-density relationship. So far, four kinds of flow-density relationships have been reported in the literature[4] that is, inverted “U”, discontinuous inverted “U”, reverse lambda and inverted “V”, as shown in Figure 2. Which one is more accurate for Beijing's metropolitan highway system? And particularly, which one is more suitable for Beijing No.3 Loop Highway?

One can always address those questions through modeling and simulation, but ultimately they must be answered through the field measurement.

3 Traffic data available

Parameter estimation and validation of basic models requires availability of adequate
Figure 1 Traditional flow-speed relationship

Figure 2 Typical flow-density relationship

real traffic data, and this section presents the data utilized in the present study for the speed-flow-density investigation.

Figure 3 presents the road geometry of North Shuangang segment of Beijing NO.3 Loop Highway. Traffic data were collected from a four-lane street with a length of 1000m including an on-ramp, an off-ramp and a bottleneck. There are four measurement stations (A, B, C, D) in total. Traffic data were collected on three successive days so that available traffic data cover the whole range of possible traffic conditions (fluid, dense and congested).

4 Scattered point plot

Figure 4, Figure 5 and Figure 6 show scattered plot of v-q, q-p and v-p respectively based on the measured traffic data for every 30 seconds.
5 Data analysis

(1) From Figure 4, we can see the mean space speed \( v \) seems to be constant until flow reaches at least 500 veh/(lane.h). Clearly, the classical curve of \( v-q \) shown in Figure 1 does not reflect this situation accurately. However, speed in Figure 4 turns out to be lower than the expected partly because of the large proportion of trucks and buses on the highway in Beijing. In addition, the traffic flow capacity which is only 1500 veh/(lane.h) in Figure 4 seems to be lower than the standard traffic flow capacity 1900 veh/(lane.h)[5]. Therefore, some measure should be taken to improve the urban highway condition in Beijing.

(2) Looking into the \( q-r \) relationship shown in Figure 5, while the classic relationship is an inverted “U” or an inverted “V” or a converse “\( \lambda \)”, we find none of them can be the suitable choice for our measurement. It is obvious that when the flow is lower than the 40 percent of capacity, which is 1500veh/h.lane), the mean speed always can be kept as a constant. So the lower part of the left branch of the \( q-r \) is a straight line with the slope as the mean speed, when flow varies between the 40 percent of capacity to full capacity, there will be a drop down of the mean speed gradually. So the whole curve between \( q \) and \( r \) is neither an inverted “U” nor an inverted “V”, but some irregular shape. Here we have two methods to model the \( q-r \) relationship. In the first method, we can use two different functions such as linear function and exponential function to represent the two branches respectively. In the second method, we can model it by taking account of drivers’ behavior. Here we mainly discuss a possible second method.

As we all know, traffic flow is greatly affected by drivers’ behavior under both uncongested and congested conditions. There are three classes of drivers such as conservative, normal, and aggressive types. Under uncongested traffic conditions, each class of driver would drive at its desired “free-flow” speed, so that the observed uncongested flow-density relationship is a weighted average of the desired speeds[6]. Equation 1 illustrates this relation:

\[
q_a = \sum_i v_{free,i} p_i \rho
\]  

(1)

\( v_{free,i} = \text{free flow speed for driver type } i \)

\( p_i = \text{proportion of driver type } i \).

Under congested traffic conditions, each class of drivers is able to control the spacing at which it follows the preceding vehicle \( \text{(6)} \). Equation 2 shows the basic relation:

\[
s_i = a_i + b_i v
\]  

(2)

\( s_i = \text{Car front-to-front distance of previous vehicle} \)

\[
\rho_i = \frac{p_i}{\bar{s}} = \frac{p_i}{\sum_i p_i \bar{s}_i} = \frac{p_i}{\sum_i p_i (a_i + b_i v)}
\]

\( v = \frac{p_i}{\rho_i} - \sum_i p_i a_i \times (\sum_i p_i b_i) \)

\( p_i = \text{proportion of drivers of type } i \)

\[
q_e = v \rho = \frac{v}{\bar{s}} = \frac{v}{\sum_i p_i \bar{s}_i} = \frac{v}{\sum_i p_i (a_i + b_i v)} = \frac{v}{a + b v}
\]

\[
\frac{p_i}{\rho_i} - \sum_i p_i a_i \times (\sum_i p_i b_i \times \sum_i p_i \frac{1}{\rho})
\]

\[
(1 - \rho \sum_i p_i a_i) / (\sum_i p_i b_i)
\]

(3) During the measurement, we found that sometime the right lane is dense while left lanes are fluid, therefore in those situations it is not correct or at least not accurate to consider
the traffic flow as homogeneous fluid. To model the traffic situation more accurately, we can consider the overall traffic flow as two fluids, the right lane fluid \( q_r \) and left lane fluid \( q_l \), and describe them separately to get a more precise reflection of the real traffic situation. Equation 3 specifies this consideration.

\[
q = r_l q_l + r_r q_r
\]  

\( r_l \) = weighted coefficient for right lane

\( r_r \) = weighted coefficient for left lanes

Finally, Equation 4 summaries our new model of \( q - \rho \) relationship.

\[
q = \begin{cases} 
q_l + q_c \quad &\rho_l < \rho_{crit}, \quad \rho_r > \rho_{crit} \\
q_l + q_u \quad &\rho_l \leq \rho_{crit}, \quad \rho_r \leq \rho_{crit} \\
q_c + q_r \quad &\rho_l > \rho_{crit}, \quad \rho_r > \rho_{crit} 
\end{cases}
\]

\[
q_u = \sum_i v_{free,i} p_i \rho
\]

\[
q_c = \left( \frac{p_l}{\rho_l} - \sum_i p_i a_i \right) / \left( \sum_i p_i b_i \sum_i p_i \frac{1}{\rho} \right)
\]

\[
= (1 - \rho \sum_i p_i a_i) / \left( \sum_i p_i b_i \right)
\]

(4) In order to get the full range of the traffic condition (fluid, dense, congested), several observation stations have been selected. As shown in Figure 2, there are four observation stations (A, B, C, D) and each of them having its own specialty. In section BC, which is a bottleneck, if it is controlled, the traffic situation can be anywhere on the upper branch of the curve of \( v-q \) as shown in Figure 4, but never on the lower branch (unless an accident or other incidents occurred downstream). Conditions in section CD, on the other hand, can be on either branch, depending on whether the point observed is within or behind the queue caused by the bottleneck. But it can never lie to the right of three forth capacity on the lower branch, since it is physically impossible for the average total flow within the queue to exceed the bottleneck capacity. It is of course possible to observe average lane flows between three forth and full capacity behind the queue in section CD, but not for very long period, since the queue would then grow and the condition at the observation station would abruptly change to the lower branch of the curve as soon as the queue ends. Then it is very difficult to obtain enough data at any single observation point to plot the entire \( v-q \) curve, so several observation stations must be selected and used.

(5) Figure 7 presents the vehicle speed distributing diagram of the selected segment of Beijing loop freeway. From the this figure, we find that 8% are at the speed of 40km/h to 50km/h, 20% are from 50km/h to 60km/h, 60% from 60km/h to 70km/h, and 12% from 70km/h to 100km/h. It is obvious that the overall vehicle speed is much lower than that in urban freeways of other countries. Clearly, there is a gap between Chinese traffic condition and foreign traffic condition, although it is becoming smaller gradually.

**Figure 7 Vehicle speed distributing diagrams**

(6) Through our measurements, we found that most of the congestion is due to having no on-ramp control and no coordination between the highway control system and conjunctural arterial intersection control system. Since it is difficult to add on-ramp control according to the current situation, coordinating control might be the best choice to decrease congestion on
6 Conclusions

Through measurements, relationships of the traffic parameters are given to combat the conventional idea, and based on the new basic model a new modeling method for Beijing Loop Highway is introduced. Finally, on the basis of the data analysis, some advice are presented to improve the Urban Highway situation in Beijing to shorten the gap of Urban Highway condition between China and foreign countries and then make a good preparation for the application of Olympic Games.

References