The “car-following method” and its application in Nanjing traffic control

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Abstract

The so-called “car-following speed-measuring method” (CFM) is a traditional method for surveying vehicle speed. It is mainly used for surveying vehicle running speeds, delays due to stopping, and queuing length while waiting to pass on a road (including at junctions). Improvement to the traditional surveying method by combining a car sensor with a computer greatly simplifies the surveying operation, and enhances convenience so that the surveying work becomes a day-to-day process. Furthermore, the cost of such a surveying method is less than other methods. The method has been widely used in traffic control of the urban roads in Nanjing since 2001. This includes surveys of the speed of motor vehicles on roads and control of traffic signals. In addition, design and checks of the “green wave” effect, and the distribution level of auto-exhaust pollutant sources, can be known if vehicle flow information is available. Increased amounts of surveying data may allow greater control over urban road traffic performance.

Keywords: “car-following method”, URTME, sensor, signal control, vehicle speed survey, auto-exhaust.

1 Introduction

In China, privately owned vehicles have increased dramatically in recent years, which put great pressure on the city’s transportation system. In order to improve traffic efficiency, transportation management department must collect the traffic data regularly to support transportation decision making. Usually, in addition to traffic volume, the vehicle operation data on the road reflects the road network
condition the best. However, these data are difficult to collect due to some restriction.

In 2000, Nanjing Research Institute of Traffic Science & Technology adopted a new speed survey method - “Car-following speed-measuring method” (CFM). This method enables people to collect many vehicle operation data such as speed on the road, stop delay (include traffic signal and other abnormal stops) and length of waiting queue. This article will explain the “Car-following speed-measuring method” (CFM) and its application in Nanjing transportation management.

2 A brief introduction to the “car-following method” computer aided surveying system

The working principle of the traditional “car-following method” is that the full length of a road and the lengths of various road sections between each two junctions on the drawings are measured, and marked. For measuring vehicle speed the test car, with two operators, follows the fleet on a road, and one measures times with a stopwatch while the other records the times. Such a method is time and labor consuming in preparation for the survey, the survey process and later processing of the data, and it is often difficult to carry out.

When the CFM Computer Aided Surveying System is used, a car sensor collects relevant data and transmits it to a computer, the surveyor identifies the running status of the vehicles shown on the computer, and the majority of jobs in the surveying task are completed by storing, calculation, classification, and statistical analysis of data in the computer system. In such a way, the work
intensity of the traditional method is reduced, and the precision of the surveying result is improved. This, however, is not all; the system is applicable for large-area surveys of vehicle speed on roads.

- **Sensor**
  A special taxi dry reed sensor is adopted here. It is a passive sensor, and only requires to be connected to the transmission shaft of the odometer in series; no additional power supply is required in use.

- **Parallel interface**
  The parallel interface to guide the signal from the sensor into the computer for processing.

- **Computer**
  A portable notebook computer is adopted here. The main software is Visual C++ 6.0, and the database used is Access 2000, which may be used for real-time recording of surveyed data and storing of the system parameters.

### 2.1 Working principle of the system

The CFM Computer Aided Surveying System uses the car sensor to detect starting and stopping signals of the vehicles, and continually sends the pulsing signal of wheel rotation. Its working principle is similar to that of the taximeter and the sensor sends the data to the computer via a parallel interface. The computer calculates the distance passed using the pre-determined wheel diameter in the following equation:

\[
d = \phi \pi p
\]

- \(d\) — Running distance of the vehicle
- \(\phi\) — Diameter of the wheel
- \(p\) — Pulse number of the wheel rotation

If the car sensor fails to send a pulse signal of the wheel rotation when the vehicle is moving, the system will judge this to be a stop signal and a man-machine dialog window automatically pops-up. A manual intervention is then necessary; that is, the operator inputs the reason for the vehicle’s stop. The system provides two choices for this; one is a red traffic light, defined as normal stop, the other is some other interference factor, defined as an abnormal stop. Suppose the vehicle stops for \(m\) times in total between two junctions, \(t_2(j)\) represents the time of the \(j\)th stopping, so the total stop time will be \(\sum_{j=1}^{m} t_2(j)\). If running of a vehicle is completed on \(n\) road sections, \(t_1(i)\) represents the time of the \(i\)th running, so total running time will be \(\sum_{i=1}^{n} t_1(i)\). The equation for calculating the running speed of the vehicle on the road section
between the two junctions is \( V = \frac{d}{\sum_{i=1}^{n} t_1(i)} \). The equation for calculating the average running speed is \( V = \frac{d}{(\sum_{i=1}^{n} t_1(i) + \sum_{j=1}^{m} t_2(j))} \).

Where, \( v \) —— Average speed;  
\( d \) —— Distance between two junctions;  
\( t_1(i) \) —— Running time in the \( i \)th section;  
\( t_2(j) \) —— Stopping time in the \( j \)th section.

2.2 Hardware structure

The system structure block diagram is as follows.

![Hardware structure block diagram of CFM system.](image)

Figure 1: Hardware structure block diagram of CFM system.

![Data flow of the URTME system.](image)

Figure 2: Data flow of the URTME system.

3 Application of CFM in traffic control

Nanjing Urban Road Traffic Management and Evaluation System (or URTME for short) adopts CFM for acquiring relevant traffic information. URTME is a road evaluation system integrating the urban road network and traffic survey and analysis. By building a set of data including those on junctions, roads, and road sections and the relationship between them, it generates a static urban traffic network; and perfects a dynamic urban traffic database with the help of traffic survey in traffic flow and direction, vehicle speed, delay, and the rate of dispatch.
of vehicles. Therefore it is a platform to be used for analyzing the data on urban road traffic control. For the network data flow, see the following figure.

CFM uses the data, such as those on roads, road sections, and junctions, provided by the URTME system, in a road network. The result obtained in the survey conversely provides distances of road sections, average speed of the vehicles on the road sections, running speeds of the vehicles on the road sections, delayed time of the vehicle due to stops and the queuing length for waiting to pass the URTME. The URTME generates and uses data based on the survey carried out using CFM.

<table>
<thead>
<tr>
<th>Road name</th>
<th>No.</th>
<th>Width (m)</th>
<th>Lane (p)</th>
<th>Length (m)</th>
<th>Direction</th>
<th>Class</th>
<th>Design speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Model Road</td>
<td>1000</td>
<td>30</td>
<td>0</td>
<td>1386</td>
<td>W→E</td>
<td>major road</td>
<td>50</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>4</td>
<td>3.5</td>
<td>3867</td>
<td></td>
<td>4</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>290</td>
<td>4</td>
<td>3.5</td>
<td>3867</td>
<td></td>
<td>4</td>
<td>5.5</td>
</tr>
<tr>
<td>3</td>
<td>387</td>
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<td>3.5</td>
<td>3867</td>
<td></td>
<td>4</td>
<td>5.5</td>
</tr>
<tr>
<td>4</td>
<td>272</td>
<td>4</td>
<td>3.5</td>
<td>3809</td>
<td></td>
<td>4</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Figure 3: Road section parameters and “Green Wave” control parameters.

3.1 Setting and checking of the traffic signal “green wave” control scheme

URTME contains the parameters related to the design of road “green wave”, for example, number of junctions, distances between each pair of junctions, running speeds of the vehicles in various road sections, hourly traffic flows in various road sections and other traffic information on a road. URTME may give “green wave” schemes in a certain algorithm. For instance, the New Model Road is a road on which there are 5 junctions, in other words, 4 road sections in total (for lengths of the sections see the left side of Figure 3). Suppose that the direction of the “green wave” is from west to east, the average speed on the road is within the range from 15 to 30km/hr according to the vehicle speed survey (Figure 3). The system provides the offset for signal control at various junctions on a “green wave belt” of the road according to the “green wave” speed of 30km/hr selected.
by the traffic engineer (Figure 3). Based on the data above, a “green wave” scheme may be designed by taking traffic flows at various points into account, as shown in Figure 4.

![Figure 4: A sample of “green wave” scheme of New Model Road.](image)

<table>
<thead>
<tr>
<th>Name of road</th>
<th>Road class</th>
<th>Distance (km)</th>
<th>Design speed (km/h)</th>
<th>Starting time</th>
<th>Average speed (km/h)</th>
<th>Running speed (km/h)</th>
<th>Travel Delay (s/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yangtze Bridge</td>
<td>Urban artery</td>
<td>1.619</td>
<td>50</td>
<td>2003-6-18 9:53:45</td>
<td>39.11</td>
<td>41.62</td>
<td>20</td>
</tr>
<tr>
<td>New Model Road.</td>
<td>Urban artery</td>
<td>15.724</td>
<td>50</td>
<td>2003-6-27 14:56:18</td>
<td>40.22</td>
<td>40.22</td>
<td>17.5</td>
</tr>
</tbody>
</table>

### 3.2 Travel delays of the vehicle on a road

Average travel delays may be calculated in such a method that the difference between the practically measured running time $t$ and the design running time on a road of $l$ long is divided by the road length $l$. that is, the average travel delays

$$\frac{t - \frac{l}{v_0} \times 3600}{l} = \frac{1}{v_1} - \frac{1}{v_0} \times 3600.$$  

$v_1$ and $v_0$ mean average speed and
design speed. Table 1 is a sample to calculate average travel delays by using the survey data provided by CFM.

**Average speed on road section**

![Average speed of the motor vehicle in the road network.](image)

Figure 5: Average speed of the motor vehicle in the road network.

### 3.3 Emission of exhaust from motor vehicles on the road section

Auto-exhaust, which mainly contains carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOₓ) and lead compounds, is one of the important sources contributing to atmospheric pollution. Pollution produced from auto-exhaust is affected by the average running speed of the vehicle and, to a certain extent, the temperature. The running speed of the vehicle on a road and the temperature is recorded in the vehicle speed database of the URTME system when the survey is carried out; it provides basic data for the analysis of auto-exhaust pollution on the road. The system provides a parameter, which is an auto-exhaust discharge mean combination of vehicles at different temperatures and at different speeds. An auto-exhaust emission factor is used to calculate the auto-exhaust pollution source on a road. The initial values in the table originate from the auto-exhaust discharge of the mean combination of vehicles at different temperatures and at different speeds in United States in 1980 issued by U. S. Environmental Protection Agency (EPA), and they may be adjusted by users.

The equation for calculating the intensity of traffic pollution source on a road section is:
where \( Q_i \) — Intensity of traffic pollution source of a pollutant in Category \( i \), mg/s.m

\( E_{j,k}(i) \) — Discharge of exhaust in Category \( i \) at the temperature and at the running speed \( k \) km/hr, g/km.veh

\( A \) — Hourly flow

3600 — a factor used to convert hour into second

**Average travel delays on the road section**

![Average travel delays on the road section](image)

Figure 6: Average travel delays of the motor vehicle in the road network.

### 3.4 Evaluation of traffic performance of an urban road network

URTME generates documents on evaluation of the traffic load on the corresponding road network based on the data in the survey using CFM, and illustrates them. The following figures provide examples of run charts, average speed distribution charts, and so on, in the Nanjing Road Network. Figure 6 is a chart of travel delays and the distribution of CO emission from motor vehicles on the road sections, shown in URTME. Some road sections are indicated by two different colors, meaning there is discordance in the two directions.
Having a population of about 6 million, Nanjing, as the capital of Jiangsu Province, is located in the Southeast of China, about 400km form Shanghai. The metropolitan area of the city is 438.63 square kilometers and the main artillery density is 4.41 kilometers per square kilometers. Nanjing Traffic Administration is responsible for city’s traffic safety sign, traffic survey, traffic control and traffic planning. Nanjing Traffic Administration has surveyed more than 100 main roads in Nanjing using the CFM computer aided surveying system. The total surveyed distance is over 3000km since early 2001. The surveyed data provide the basis for decision-making in road traffic control in Nanjing.
Table 2 shows the average vehicle speed on some of the Nanjing roads. These data provide the decision support for the Nanjing city transportation management.

4 Conclusion

Nanjing Local Traffic Administration has adapted CFM System into routine traffic survey (including vehicle speed survey, signal timing, traffic organizing system design, one-way system design, local traffic annual report and "Expedite transportation system" investigation data, etc.). CFM system was approved by the National Police Bureau in October of 2003. The CFM system will be improved at the project of pollution survey, such as sensors of climate data collecting, automatically data collection of temperature, wind direction, atmosphere pressure etc.

References