Application Study on Urban Road Volume-Time Function Based on RFID Data

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Abstract. Radio Frequency Identification (RFID) plays an important role on road traffic management and basic data could be collected from automotive electronic registration identifications, which could be applied for road traffic management and planning. Firstly, road section volume-time function was discussed in the paper, and then urban road RFID data collected from the city of Nanjing were analyzed with mature methods on identifying redundant and wrong data based on license plate number. Then the function from Bureau of Public Road (BPR) was calibrated to get the basic volume-time function with RFID data, and the basic function was improved based on the time periods, and the improved functions were used to describe relationships between volume and travel time in weekdays and weekends, and the fitting effect is compared with the basic function. It was indicated that the fitting effort $R^2$ was increased by 40% at least. The results can provide reference and support for urban road traffic planning.

1. Introduction

In the process of road traffic data collection and detection, due to the inherent superiority, radio frequency identification (RFID) technology is receiving more and more attention in traffic management. There is a significant advantage that it is not affected by environmental conditions when collecting the identity information of the identified vehicle, which could be applied to performing traffic demand characteristics identification and traffic flow parameter analysis. By further utilizing the detection records of the identified vehicle, the location information and time stamp information can be quickly extracted, thereby there are more and more studies and applications in the travel time and travel speed of the vehicle characteristics [1-2], travel demand analysis [3-4], dangerous road cargo transportation [5], traffic control [6], and so on.

Some cities in China have completed the coverage and application of RFID readers. Under this background, in-depth study of urban traffic operation characteristics and vehicle travel rules based on RFID data is of great significance to traffic planning and management, especially in road networks. In order to achieve a reasonable spatial and temporal distribution of traffic demand, a reasonable route impedance function should be constructed from the perspectives of minimum travel time or minimum energy consumption. Combining with mathematical methods such as graph theory, it can be known that a route in a road network is composed of a set of road segments, and the travel time of a route is obtained by adding the travel time of each road segment element in the set and the travel time of the intersection...
between road segments. In the application and theoretical studies of road traffic planning, the BPR (Bureau of Public Road) function is a widely used mathematical model to calculate route impedance [7-8]. Considering that the model is established based on the characteristics of the highway condition, it lacks considering and quantifying the delay caused by urban road intersections, there will be differences when using this model to analyze urban road traffic operation. To solve this problem, improvement studies are carried out, and scholars have also separately analyzed the BPR function from the model perspective [9] and the data perspective [10]. In order to describe the relationship between the travel time and urban roads flow volume, this paper starts with the RFID data from urban roads, and the basic BPR function is improved (such as the model and parameters recommended by the US Highway Administration, $\alpha = 0.15$, $\beta = 4.0$), travel time and flow data between road detection sections are extracted, the BPR function framework is further used to improve the model form and perform parameter calibration, and the improved functional model between travel time and flow is obtained in the analysis area in different periods. The analysis results can be used for urban traffic demand management, and scientific reference could be provided from road operation characteristics analysis.

2. Methodology
According to the basic form of the BPR model, the travel time is proportional to the flow volume, as shown in equation (1).

$$ t = t_0 \left(1 + \alpha \left(\frac{q}{c}\right)^\beta \right) $$  \hspace{1cm} (1)

The Equation 1 can be transformed as shown in equation (2) and equation (3).

$$ \frac{t}{t_0} - 1 = \alpha \left(\frac{q}{c}\right)^\beta $$  \hspace{1cm} (2)

$$ \log \left(\frac{t}{t_0} - 1\right) = \log \alpha + \beta \log \left(\frac{q}{c}\right) $$  \hspace{1cm} (3)

Equation 3 can be simplified as shown in equation (5) based on equation (4).

$$ y = \log \left(\frac{t}{t_0} - 1\right), x = \log \left(\frac{q}{c}\right) $$  \hspace{1cm} (4)

$$ y = \beta x + \log \alpha $$  \hspace{1cm} (5)

3. Data analysis
3.1 Data quality analysis
The data used in this paper is collected from the city of Nanjing local roads for one month in December 2015. The data fields mainly include the station code, lane number, record time, license plate number, license plate color, and vehicle speed. Before further using the data to calibrate the model, data quality analysis of the original data is needed. There are many researches and applications of data quality analysis and processing methods for RFID data features [11-12]. In this paper, the redundant data and error data are mainly processed, results as shown in table 1.
Table 1. Example of one station record data processed

| Record No. | License plate No. | Record time | License plate color | Lane No. | Vehicle speed (km/h) | Type     |
|------------|------------------|-------------|---------------------|----------|----------------------|----------|
| 1          | “Su A**129”      | 2015-12-9 6:39:00 | blue               | 1        | 35                   | repeat   |
| 2          | “Su A**129”      | 2015-12-9 6:39:00 | blue               | 2        | 24                   |          |
| 3          | “Su A**401”      | 2015-12-9 6:39:16 | yellow             | 1        | 32                   | similar  |
| 4          | “Su A**401”      | 2015-12-9 6:39:23 | yellow             | 1        | 32                   |          |
| 5          | “unrecognized”   | 2015-12-9 6:40:34 | -                  | 1        | 22                   | unrecognized |

In this paper the wrong license plates are classified according to the standards of motor vehicle number plates in the collected data of 21 stations in the study area, mainly three types of wrong license plate data are included. The error of no Chinese characters in provinces, autonomous regions, and municipalities is classified to the first type of wrong license plate. The error of no serial number or digital identification is classified to the second type of wrong license plate. The error of the code including “O” or “I” is classified to the third type of wrong license plate.

By counting the data from 21 stations throughout the day on December 1, 2015, a total of 219,456 entries were obtained, and the statistics were identified according to the wrong license plate classification. The results are shown in Table 2.

Table 2. Statistical characteristics of wrong license plate data

| Error type          | Quantity (items) | The proportion (%) |
|---------------------|------------------|--------------------|
| First type of error | 556              | 0.25%              |
| Second type of error| 1746             | 0.80%              |
| Third type of error | 161              | 0.07%              |
| Correct license plate| 216993         | 98.88%             |
| Total               | 219456           | 100%               |

It is analyzed that the proportion of license plate error rate is low in Table 2, but the total amount of error data is 2463, of which the second type of incorrect license plate data is the main error. It can be seen that in the identification process, license numbers are incorrectly recognized as letters. As the license plate is the unique identification, the vehicle cannot be uniquely verified by wrong license plate, so it should be deleted. In addition, when analyzing the rationality of vehicle travel time characteristics between neighbor stations, the spatial distance and speed characteristics of vehicles passing through neighbor base stations are mainly considered.

3.2 Traffic flow characteristics

Based on the erroneous data and redundant data process in the data set, the traffic flow volume characteristics of the stations and the travel time characteristics between the stations can be extracted. The local path (path 1 and path 2) and the distribution characteristics of base stations are shown in figure 1. Taking the characteristics of the base station 6292's all-day traffic volume as an example, the characteristics of the traffic flow volume are shown in figure 2, where solid line stands for weekday and dot line stands for weekend.
Taking the travel time of two path during peak hours as an example, the route starts at station 6292 and ends at station 6255. The license plate data is analyzed to obtain the traffic flow volume characteristics and average travel time characteristics of the route within a single week, statistical characteristics results are shown in table 3.

| Period  | Path | Volume (veh) | Lane No. | Travel time (s) | Ratio |
|---------|------|--------------|----------|----------------|-------|
| Weekday | 1    | 307          | 3        | 496            | 47%   |
|         | 2    | 345          | 3        | 325            | 53%   |
| Weekend | 1    | 94           | 3        | 435            | 54%   |
|         | 2    | 82           | 3        | 305            | 46%   |

4. Calibration and analysis

The data from December 1st to 20th, 2015 is taken as sample data, the scatter diagram of the traffic and travel time of the station pair 6292-6290 is shown in Figure 3. From figure 3 it can be known that the data corresponding to the exponential form does not have a high fitting degree. The BPR function is directly calibrated using sample data, and the result is shown in figure 4.

In order to improve the accuracy, according to the traffic volume analysis requirements at 8-12 a.m. in the area, the traffic flow data is divided into two categories, of which four hours in the 8-12 a.m. time period per day are regarded as a type, and the data of the remaining periods are regarded as a type. The BPR models are constructed and fitted separately, and the fitting conditions for weekend are compared and analyzed.

This paper uses the station pair 6292-6290 as an example. There are many non-motorized vehicles and pedestrians in the surrounding area, which have a large impact on the traffic flow, then the road capacity in the model uses the empirical value of 680 pcu/h for one lane and 2040 pcu/h for three lanes.
(1) The fitting situation on weekdays (not 8-12 a.m.) is shown in figure 5, and the fitting formula is shown as equation (6).

\[ y = 0.4307x + 0.5764 \]
\[ R^2 = 0.8481 \]

Figure 5. Fitting on weekdays (non 8-12 a.m.)

(2) Function of station on weekday (8-12 a.m.)

Weekday (8-12 a.m.) fitting situation is shown in figure 6, and the fitting formula is shown as equation (7).

\[ y = 1.2522x + 0.5321 \]
\[ R^2 = 0.7093 \]

Figure 6. Fitting on weekdays (8-12 a.m.)
The weekend (non-8-12 a.m.) fitting situation is shown in figure 7, and the fitting formula is shown as equation (8).

\[ y = 0.4158x + 0.5573 \]  
\[ R^2 = 0.8084 \]  
(8) Weekend function (non-8-12 a.m.)

The weekend (8-12 a.m.) fitting situation is shown in figure 8, and the fitting formula is shown as equation (9).

\[ y = 0.47x + 0.3723 \]  
\[ R^2 = 0.6063 \]  
(9) Weekend function (8-12 a.m.)

The fitting of each function is shown as equation (10).

\[
\begin{align*}
\text{weekday (non 8-12 a.m.)} & \quad y_1 = 0.4307x + 0.5764 \\
\text{weekday (8-12 a.m.)} & \quad y_2 = 1.2522x + 0.5321 \\
\text{weekend (non 8-12 a.m.)} & \quad y_3 = 0.4158x + 0.5573 \\
\text{weekend (8-12 a.m.)} & \quad y_4 = 0.4700x + 0.3722
\end{align*}
\]  
(10)

The impedance function for the four cases is shown as equation (11).

\[
\begin{align*}
\text{weekday (non 8-12 a.m.)} & \quad t_1 = 60 \times \left( 1 + 2.70 \times \left( \frac{q}{c} \right)^{0.4307} \right) \\
\text{weekday (8-12 a.m.)} & \quad t_2 = 60 \times \left( 1 + 3.41 \times \left( \frac{q}{c} \right)^{1.2522} \right) \\
\text{weekend (non 8-12 a.m.)} & \quad t_3 = 60 \times \left( 1 + 3.61 \times \left( \frac{q}{c} \right)^{0.4158} \right) \\
\text{weekend (8-12 a.m.)} & \quad t_4 = 60 \times \left( 1 + 2.36 \times \left( \frac{q}{c} \right)^{0.4700} \right)
\end{align*}
\]  
(11)

The comparison of function parameter calibrations and the fitting conditions between BPR function and its improvements are shown in table 4 and table 5.
Comparison results show that the impedance model obtained from the RFID in Nanjing is significantly different from the recommended parameters by the U.S. Highway Administration, which is caused by the calibration data collected from urban roads with many intersections and small distance, it will bring greater disturbance to the traffic flow continuity, which is inconsistent with the highway condition. Therefore, applying the actual data to fit the impedance model is more practical for urban road traffic planning and management.

5. Conclusion
This paper starts with urban road traffic impedance model calibration, travel time is selected as route impedance, urban road RFID station data is collected and used. Based on the redundant data, license plate error data, and travel time error data processing, basic BPR model is calibrated for local area of urban road. Combined with the demand of multi-period analysis, the models are calibrated separately, and the fitting effect is compared with the basic model. The comparison results show that the model calibrated by using the period data has better fitting effect, and further comparison and analysis are performed on weekday and weekend respectively. The results can provide effective support for urban road traffic planning.

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| Table 4. Comparison of calibration results of BPR function |
|---------------------------------------------|
| BPR model | Improved BPR model |
| Data type | α | β | t₀ | α | β |
| weekday (non 8-12) | 60 | 2.70 | 0.5764 |
| weekday (8-12) | 60 | 3.41 | 1.2522 |
| weekend (non 8-12) | 2.96 | 0.3345 | 60 | 3.61 | 0.4158 |
| weekend (8-12) | 60 | 2.36 | 0.47 |

| Table 5. Calibration and fitting |
|---------------------------------|
| Comparison of fitting | R² |
| BPR model | weekday (non 8-12 a.m.) | 0.8481 |
| | weekday (8-12 a.m.) | 0.7093 |
| Improved BPR model | weekend (non 8-12 a.m.) | 0.8084 |
| | weekend (8-12 a.m.) | 0.6068 |
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