A Calculation Method for Bus Running Index

Jing Teng
Associate Professor
Key Laboratory of Road and Traffic Engineering in the Ministry of Education
Tongji University, 4800 Cao’an Road, Shanghai, China
TEL: 86-21-6958-3001
E-Mail: teng.jing@tongji.edu.cn

Xiong-fei Lai*
Master Student
Key Laboratory of Road and Traffic Engineering in the Ministry of Education
Tongji University, 4800 Cao’an Road, Shanghai, China
TEL: (86-21)188-0178-5212
E-Mail: m18801785212@163.com

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* Corresponding Author
ABSTRACT
Public transit services should be fast and reliable. Complex road conditions, however, make them slow and fluctuate. Taking reliability into consideration, increasing planning travel time reasonably will help to overcome fluctuations. Therefore, to reflect the impact of road traffic conditions for buses running, we should take both fast and reliable into consideration. This paper uses GPS data of buses, raises a bus running index (BRI) calculation method, based on bus planning travel time (BPTT) and facing bus main roads. In order to verify the effectiveness, this paper selects a bus main road on Yan’an Road between Shimen Road No.1 (SM) Stop to Kaixuan Road (KX) Stop in Shanghai, China as a case. Through this case study, this paper verifies that the proposed bus running index (BRI) can objectively and sensitively evaluate bus running conditions. Meanwhile, by contrast with the traditional single-line bus reliability evaluation method, the proposed bus running index (BRI) calculation method has an advantage in the sample volume size and calculation effectiveness.

KEYWORDS
Bus running index (BRI), bus planning travel time (BPTT), reliability, bus main road, GPS
1. INTRODUCTION

Planning has a great effect on bus running, bus operating environment is important for bus planning and managing. Therefore, it requires an effective evaluation method to evaluate and optimize bus operating environment. With the wide application of traffic performance index (TPI), bus running index (BRI) has also been proposed. Bus running index, also known as public traffic congestion index or public traffic cost index, was used to measure the traffic congestion in an area with extra time than original. Because the reasons of public traffic jams or wasting time also depend on the road and signal designing in this area, so it also reflects the region’s transportation cost index.

Traditionally, bus travel time is the key indicator of bus running index, its length is directly related to the smooth operation of buses. Nowadays, with the growing popularity of ITS philosophy and applications, as advanced public transportation system (APTS) develops rapidly, bus travel time becomes much more important. Moreover, as a significant part of advanced traffic information system (ATIS), dynamic and real-time bus arrival information plays a significant role on decreasing passengers’ waiting time, improving service level, attracting people traveling by bus and so on (1).

Besides rapidity, reliability is also an important factor in the evaluation of public transport services. Through city’s development, travelers consider not only the length of travel time, but also the reliability of travel time. Since the environment of buses running is very complex, however, it’s very difficult to improve bus running reliability. Current researches and practical applications on the reliability of public transport always focus on a single bus line, but the previous studies have shown that operating environment is the main factor which affects the reliability of bus running (2-8). The main measures to enhance bus running reliability, such as setting up bus lanes and providing bus priority signal, are all based on sections of road, not a bus line. Meanwhile, this reliability evaluation based on multi-lines, has advantage on increasing the amount of data samples, improving result’s adaptability, reducing costs, optimizing for determining new line’s bus running time.

A bus main road is the sections of road which have a number of bus lines covering. These roads have more buses running through, are suitable for bus running environment evaluation. This paper focuses on bus main roads, develops a bus running index calculating method based on rapidity and reliability, to evaluate bus running environment. This paper uses GPS data from buses as data sources to analyze bus running processes, excludes error from artificial survey data, expands effective sample size without increasing the cost of data collection.

2. LITERATURE REVIEW

In theoretical research, index is a special relative number to measure comprehensive changes in different occasions for multiple projects, which has comparable, convenient and many other advantages in the evaluation process. Index is a concept in economics originally, researchers raised traffic performance index (TPI) by using index evaluation method. TPI is the combination of traffic congestion index and traffic operation index, is a conceptual index value which comprehensively reflect whether road network is smooth.
TPI makes traffic congestion digitized. The calculation method of traffic congestion evaluation is based on some data like road speed, road traffic density, traffic flow and travel time. Among them some methods are typical, like INRIX Index which calculates traffic congestion index based on road speed (9), and Roadway Congestion Index (RCI) which calculates it by road traffic density (10).

Compared with widely research progresses on TPI, bus performing index (BPI) is in its infancy, especially bus running index (BRI) hasn’t been maturely applied in practice. In urban road system, bus system has many particularities, mainly refer to the public target for planning services, compared with personalized goal of private cars. Since buses’ running process has many parts such as bus stops, reasons which cause buses’ travel time not stable are more complex than private cars. Travelers’ requirements for buses’ travel time reliable, however, are much more than private cars’. Therefore it is necessary make a separate study on bus running index. Traditionally, evaluation of public transport index reflects mainly buses running time or delivery time (2-8).

Bus travel reliability means that buses could travel between bus stops within a certain time frame in a certain running environment and road conditions. As a basis for public transport vehicle scheduling management and bus dynamic information services, bus travel time reliability plays an important role on public transportation services, this makes bus travel time reliability evaluation becomes an important indicator of bus operation. Herbert S. Levinson reviewed transportation service reliability studies (11). In the traditional sense, indexes which characterize bus travel time reliability can be divided into three categories: statistical measures, buffer measures and tardy trip indicators (12-15). Besides, probability indicators are also used to describe travel time reliability. In recent years, Supported by data from AVL and IC card system, Researchers have proposed much more methods and a broader perspective of bus system reliability analysis (16-24).

In application research, TPI applications have many successful experiences at home and abroad. For example, the US publish “City Patency Report” annually, selects traffic congestion index and other indicators, periodic assesses and releases to the public. With the continuous advance of China's traffic information, many cities have defined their own TPI and received good results. Among them, Beijing took congested mileage proportion as basis, Shanghai based on speed and load degree, Shenzhen considered the ratio of travel time. With the development of urban public transport and the maturity of urban transport index, urban public transport index has been proposed and introduced into practical application. Shenzhen uses passenger questionnaires, complaints and other ways to collect data, issues public transportation service index based on three kinds of public transit ways including bus, subway and taxi. It faces to regularity authorities of urban public transportation system, is used to improve public transport quality of service. Chicago released public attraction index based on travel time, walking time, waiting time, etc. Beijing released crowded subway index using real-time passenger data. Beijing University of Technology raised the concept of bus travel index from convenience and rapidity.

At present, there are very few evaluation method for bus running, and they always focus on a single-line. The calculation results for other lines as well as higher levels of
evaluation (road, network, etc.) have limitations. Proposing an evaluation method based on multi-lines, considering both travel time and reliability has a strong practical significance.

3. BUS RUNNING INDEX CALCULATION METHOD

Bus running index (BRI) in this paper faces a bus main road, involves a number of bus lines within the road. Taking travel time and reliability indicators in the traditional sense into account, combining with the actual operation of bus system, this paper proposes Bus Planning Travel Time (BPTT) based on Buffer Index (BI). Its calculation method is as follows:

\[
BPTT = \frac{M \times (1 + \frac{\sum N_i \times BI_i}{\sum N_i})}{d}
\]

Where,

- \( N_i \) is the sample volume of line \( i \)
- \( d \) is the distance between bus stops

By this equation, considering both travel time and reliability, using planning travel time per kilometer to characterize bus running environment, this paper then proposes BRI.

BI is buffer index, an important indicator to calibrate buffer time. Buffer time allows travelers to add an additional time value based on the average travel time, to ensure that travelers can reach their destination on time. It partly reflects the unreliability of travel time for consideration, is an important indicator of travel time fluctuation analysis. Meanwhile, for public transport enterprises, buffer time is also an important factor for them to consider their operating plans. The calculation method for buffer time (BI):

\[
BI = \frac{TT95 - M}{M}
\]

Where,

- \( TT95 \) means the 95th percentile travel time
- \( M \) is the mean travel time, calculated by this formula:

\[
M = \frac{\sum_{i=1}^{N} TT_i}{N}
\]

Where,

- \( TT_i \) is a travel time of the observed sample
- \( N \) is the number of samples in a given time

This calculation method for the average travel time is in line with general practices for reliability analysis. Meanwhile, in support of large amounts of data, the deviation of distribution from different conditions can be balanced efficiently, so the calculation result has statistical analytical significance.

Based on the results above, the definition of BRI:
\[
BRI = \begin{cases} 
\frac{BPTT - BPTT^*}{BPTT^*} - 1 \times k & \text{if } BPTT \geq BPTT^* \\
0 & \text{else}
\end{cases}
\] (4)

Where,
BPTT* is the bus planning travel time under the ideal operating environment, k is the conversion factor.

Statistical analysis can characterize the travel time distribution within a certain time frame. Therefore, the index libraries of BRI in this article also include the following statistical indicators:

- Standard deviation (STD) of travel time:
\[
STD = \sqrt{\frac{\sum_{i=1}^{N} (TT_i - M)^2}{N-1}}
\] (5)

- Coefficient of variation (COV):
\[
COV = \frac{STD}{M}
\] (6)

4. DATA ACCURACY AND CREDIBILITY

Compared with a single-line bus running reliability analysis, BRI calculation method in this paper faces a bus main road including a series sections, has a stronger credibility. TPi’s data acquisition are generally based on thousands of floating taxis, which can be seen as continuous flow. When we take bus into consideration, data sample size becomes a problem. With bus departure intervals ranging from two to more than thirty minutes, data from a single-line is very limited. At present, buses in Shanghai upload their GPS data every 10 seconds, according to different operating plan every single-line collects about 10,000 to 150,000 pieces per day. The following table compares the data sample size between traditional a single-line reliability evaluation method and multi-line BRI evaluation method in this paper.

<table>
<thead>
<tr>
<th>Modules / procedures</th>
<th>Effective sample size (per day, one direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-line (line No.936) Multi-lines</td>
</tr>
<tr>
<td>Original database (GPS data)</td>
<td>30,000</td>
</tr>
<tr>
<td>Arrival time matching</td>
<td>1,600</td>
</tr>
<tr>
<td>Travel time between stops matching</td>
<td>800</td>
</tr>
<tr>
<td>Complete trips</td>
<td>30</td>
</tr>
<tr>
<td>Trips based on one section</td>
<td>30</td>
</tr>
<tr>
<td>BRI per day</td>
<td>1</td>
</tr>
</tbody>
</table>

*can calculate more than one BRI per day (for peak hours and not-peak hours)

According to the actual calculation and analysis, each compute cycle requires at least 30 pieces of complete trips for 1 corresponding section and 1 direction, in order to make the results statistically significant. Taking the situation that the level of bus departure...
interval is generally different in peak hours and not-peak hours into consideration, to
calculate BRI for different time periods in one day requires more than 200 pieces of
complete trip data in one direction per day. Because of the different processes of GPS
data cleaning and processing, corresponding GPS effective sample shall be more than
150,000 pieces for one day in one direction.

The following table uses data from the section between Yan’an Road Jiangsu Road
(JS) intersection to Yan’an Road Zhenning Road (ZN) intersection on February 10 as an
example, compares the data accuracy between traditional one single-line method and BRI
evaluation method in this paper.

| TABLE 2 BRI index comparison analysis based on one single-line and multi-lines |
|---------------------------------------------|--------|--------|--------|--------|
| A single-line/section | 127    | 71     | 936    | Section |
| Distance between bus stops (m) | 700    | 700    | 1500   | -       |
| Departure interval (min)       | 6-8    | 4-10   | 30     | -       |
| GPS data sample size (per day) | 57585  | 68500  | 29138  | 155223  |
| Travel time sample size (per day) | 125    | 56     | 32     | 213     |
| BRI and its deviation with five-days’ mean | 2.296  | 4.816  | 1.18   | 2.82    |
|                                    | (-0.186) | (+0.708) | (-0.582) | (0)     |

As we can see, since each line’s data sample size is small, if we only use its data to
make reliability evaluation, there will be a wide range of variation in the other line, so it
can not be used to make bus running environment evaluation for a section.

BRI calculation method in this paper has a great advantage on data sample size
compared with traditional one single-line evaluation method, so its actual suitability and
data credibility have improved. For example, if we use traditional one single-line
evaluation method, we could hardly evaluate the bus running environment of bus line
No.936 in a 3-hours-long time period (such as evening peak hours), since there are only 6
trips in one direction during evening peak hours per day, the 95th percentile travel time
will lose its significance. BRI calculation method in this paper meets this requirement.

5. CASE STUDY

5.1 Basic situation of this case

Different from previous research which focused on a single-line, this paper focuses on a
bus main road which has multiple bus lines covering. This paper selects a series of
sections of bus lanes on Yan'an Road, Shanghai as the case to study, focuses on several
bus lines which cover it. Through BRI and its evaluation system in this paper, we analyze
bus operating environment based on rapidity and reliability.

Yan'an Road bus lane starting at Zhongshan Road, ending at Gubei Road, with a
total length of 10.00 km. It was built in about 2,000, and is Shanghai's first bus lane put
into use. The scope for consideration in this paper is from West Yan’an Road Kaixuan
Road (KX) bus stop to Mid Yan’an Road Shimen No.1 (SM) bus stop. The basic
situation of the sections of bus lane and passing bus lines in this case are shown below.
Data acquisition process uses automated collection system and related equipment based on AVL. This paper extracts upstream direction (east to west) data from 5 working days including February 5, February 6, February 9, February 10, February 11 in 2015.

Basic package includes the following sections:

Vehicle-line data: vehicle ID, line ID, line name.

Bus stop data: stop ID, stop name, stop longitude, stop latitude.

Line-stop data: line ID, line name, operating direction, stop number.

GPS data: line ID, vehicle ID, time point, longitude, latitude, speed, direction angle, operating direction.

Compared with traditional artificial data collecting, automatic data collecting system in this paper can collect a large amount of valid data within decreased cost. Moreover, it excludes artificial errors arising in artificial data collection.

After the above basic data obtained, this paper divides these sections into three parts: the west side from KS stop, KS stop to SM stop, east side from SM stop. Then, this paper calculates BRI and some corresponding indicators, analyzes the influence from these sections to bus running based on rapidity and reliability.

By applying the proposed bus operating condition evaluation system, we obtained a series of bus operating condition evaluation results. Meanwhile, this paper also describes this method’s practical significance and credibility.

5.2 Evaluation result

(1) Indicators effectiveness, sensitivity and road traffic condition evaluation

In this case, the minimum BPTT for each section in the 5 days is considered as BPTT*. Considering some corresponding cases in TPI calculating, BPTT and BRI usually correspond by this rule: in a 10 score index evaluation system, the initial value of BRI is 0, with BPTT 0.3 times larger than normal, BRI plus 2, so we let k be 6.67. We divided this 10 score index into 5 levels, corresponding to (A) smooth, (B) generally smooth, (C) a little bit congestion, (D) some congestion, (E) congestion.
TABLE 3 Results for BPTT* and corresponding indicators calculation

<table>
<thead>
<tr>
<th>Section</th>
<th>Speed (km/h)</th>
<th>Mean travel time (min)</th>
<th>Standard deviation</th>
<th>COV</th>
<th>BI</th>
<th>BPTT* (min/km)</th>
<th>Mean BPTT (min/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East side from SM</td>
<td>10.948</td>
<td>3.551</td>
<td>0.997</td>
<td>0.281</td>
<td>0.437</td>
<td>7.261</td>
<td>7.875</td>
</tr>
<tr>
<td>SM-SX</td>
<td>21.393</td>
<td>2.687</td>
<td>0.948</td>
<td>0.353</td>
<td>0.682</td>
<td>4.195</td>
<td>4.717</td>
</tr>
<tr>
<td>SX-TR</td>
<td>19.677</td>
<td>1.375</td>
<td>0.540</td>
<td>0.393</td>
<td>0.661</td>
<td>4.839</td>
<td>5.064</td>
</tr>
<tr>
<td>TR-HS</td>
<td>10.203</td>
<td>3.652</td>
<td>1.419</td>
<td>0.389</td>
<td>0.688</td>
<td>9.171</td>
<td>9.925</td>
</tr>
<tr>
<td>HS-ZN</td>
<td>15.542</td>
<td>2.529</td>
<td>1.069</td>
<td>0.423</td>
<td>0.594</td>
<td>5.594</td>
<td>6.153</td>
</tr>
<tr>
<td>ZN-JS</td>
<td>7.855</td>
<td>3.964</td>
<td>1.269</td>
<td>0.320</td>
<td>0.538</td>
<td>10.068</td>
<td>11.748</td>
</tr>
<tr>
<td>JS-DX</td>
<td>21.407</td>
<td>3.083</td>
<td>0.664</td>
<td>0.215</td>
<td>0.395</td>
<td>3.643</td>
<td>3.911</td>
</tr>
<tr>
<td>DX-KX</td>
<td>10.171</td>
<td>2.743</td>
<td>0.806</td>
<td>0.294</td>
<td>0.466</td>
<td>8.264</td>
<td>8.646</td>
</tr>
<tr>
<td>West side from KX</td>
<td>25.559</td>
<td>2.348</td>
<td>0.962</td>
<td>0.410</td>
<td>0.714</td>
<td>3.541</td>
<td>4.023</td>
</tr>
</tbody>
</table>

In this case, we use the BRI calculation method proposed by this paper, BRI and related results are shown in Table 3. Firstly, we calculate BPTT and select BPTT* for each section. As we can see, by comparing the BPTT* with the mean BPTT for each section, the fluctuations of BPTT in each section is much smaller than results from a single-line calculation, maintaining a good correlation. Meanwhile, by considering the contrast between BPTT and mean travel speed, we can find these two indicators show a very significant negative correlation, which is realistic.

Using BPTT and mean travel speed as the basic indicator to evaluate bus running conditions in each section, can effectively evaluate bus running facilities as well as bus lanes. From figure 1, we know that when bus lines pass this section of bus lane, the west side from KX is normal lane and the east side from SM is bus lane. Table 3 shows that when these three bus lines get into these sections in this case, BPTT* in DX-KX is much larger than SM-SX, which means mean travel time and fluctuation will increase under the condition that buses travel from normal lane to bus lane, and bus running condition is worse. In reality, with the complex road infrastructure and rule changing, the connection between bus lanes and normal lanes is usually a congestion point. When setting up bus lanes, management department set 2 bus lanes for 1 direction from SX to JS by considering traffic flow, and other sections have 1 bus lane for each direction. Through table 2, BPTT* between these 2 stops are higher (more than 5), and BPTT* in other sections are lower. So we can use BPTT to provide a reference for bus lane arrangement.

Since buses run on road, bus operating conditions and road traffic conditions connect closely. By improving the data system, adding some data such as the number of lanes, intersection and signal control program, we can evaluate traffic conditions comprehensively. What’s more, take BRI compared with TPI, we can evaluate transit priority measures (such as bus lanes and bus priority signal) from more angles.
(2) \textit{Sub-sections / sub-time bus operation conditions evaluating and mutation analysis}

From figure 2, we can found that there is a generally smooth section, it’s the BRI for ZN to JS on February 10. The BRI calculation method in this paper involves 3 bus lines in it, the sample size is sufficient to support a sub-period day bus run index change analysis. Compared with traditional bus running reliability evaluation method based on a single-line, BRI calculation method proposed in this paper can reach a realistic significant result even involves bus lines with large departure intervals (such as departure interval of bus line No.936 is 30 minutes). By using the data from this data system, we analyze the reason for the mutation in this case.

\textbf{FIGURE 2 BRI on these 5 workdays}

Through table 4, we can find that mean speed just has a minus change. If we only use travel time as an evaluation index, we can hardly find out the drop of bus running environment level. But through BRI in this paper, we can see that drop of reliability causes BRI’s increase. By finding out the time period which includes the most amount of high travel time, preliminary judgment says bus operating environment deteriorated because of evening peak congestion. Through figure 3 which involves sub-time period BRI, we verify this judgment.
Through figure 3, besides well performance of bus operating environment in not-peak hours, we can see that buses ran smoothly in the morning peak, which meant that the bus lane on it had a good performance with the traffic flow increasing in the morning peak. But bus operating environment deteriorated much in the afternoon, especially in the evening peak (16:00-19:00). In this time period, BRI of the section ZN-JS reached 7.89, which meant D (some congestion) level. BPTT reached more than 2 times from BPTT*, meets the judgment for the reason for BRI increasing on February 10 from table 4. This BRI has a strong sensitivity to changes in the operating environment of buses, changes of BRI can reflect changes of bus running environment. Meanwhile, analyzing figure 3 comprehensively, we can find that BRI increased in the evening peak in most sections, which meant that bus running environment would be worse in the evening peak, it needed to improve. To sum up, BRI and its data system can reflect the change of bus running environment based on sections or time periods.

5.3 Extension analysis
From figure 3, we know that BRI increased in the evening peak in this case. The bus lane management, however, was equal for the morning peak (7:00-10:00) and the evening peak (16:00-19:00). What caused BRI increasing in the evening peak?

In this case, we choose the direction from SM to KX, which is from the downtown side to the suburban side. So, traffic flow will be much heavier in the evening peak because of a large amount of commuter traffic. And figure 3 tells us that this bus lane cannot meet the bus running environment requirement with the evening peak’s heavy traffic flow. Through field research, we find that these bus lanes have many deficiencies in layout form and management measures:

- Due to cancel non-motorized vehicle lane on Yan’an Road and lax management for bus lanes, social vehicles and non-motorized vehicles traveling on or even stopping at bus lanes occur quite often, especially in the evening peak (see figure 4.a.).
- Yan’an Road bus lanes are provided in the roadside, simultaneously with the Yan’an Elevated Expressway collinear. Since the signs are not clear, some social vehicles get into bus lanes by mistake quite often. Social vehicles can not let out of bus lanes, and this causes congestion (see figure 4.b.).
With this analysis from field research, we can find that the proposed calculation method for BRI could be connected with the reality well, where we can find out a vast application prospect in.

6. CONCLUSIONS AND RECOMMENDATIONS

Instability of bus running time mainly causes by complex operating environment. This paper based on GPS data, facing bus main roads raises BRI calculation method. The evaluation object changes from a single bus line to a section of road including multiple bus lines, which is more realistic. This evaluation system has good stability and has sensitivity to abnormal conditions, shows a very good evaluation effect, can provide good support for the corresponding decisions. In the context of Big Data, data mining effect is particularly worthy of attention. Calculation method in this paper based on GPS data of multi-lines within the same section of road, significantly increases the effective sample size, provides a greater accuracy and flexibility for data processing and analysis.

With the improvement of the index data analysis system, we can also see that it has more research value, such as the previously mentioned convergence with TPI. Under the current method of calculation and data integration situation, combination between TPI and BRI is not sufficient. We can hardly combine these 2 indexes and take them into consideration. Obviously, there is a connection between TPI and BRI evaluation method, because social vehicles and buses are all running in the urban road network. On top of that, TPI and BRI are all focusing on sections of road. We can expect a lot of convenience by comparing these two indexes. For example, when we consider the effect of a bus priority method (such as bus lane or bus priority signal), and social vehicles run at an appropriate speed that buses can achieve, we can get the comprehensive results by comparing the performances of social vehicles and buses.

In future work, we will use this calculation method to combine each section of bus main roads in the city's public transport network to evaluate the performance of the network, and set up the BRI evaluation system for the whole network. Meanwhile, we will try to find out the correlation between BRI and TPI, then build an evaluation system for integrated urban transport performance level.
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