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Study of bus service reliability in Singapore using fare card data

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ABSTRACT: For public transportation service, schedule reliability is generally a central point in the service level agreement. However, bus bunching is a very common phenomenon of bus systems, resulting in more waiting time for passengers. Based on fare card data, this paper presents a case study analysis of the reliability of one typical service route in Singapore. Characteristics such as headway distribution and average velocity are obtained from fare card data and employed for measuring service reliability and developing optimization tools for reorganizing bus routes. More importantly, real information from fare card data about boarding time, origin and destination stops of the trips is available for formulating a simulation scenario to test the performance of different control strategies based on real passenger demand. Combining those two approaches, the proposed simulation approach is applied to compare bus service on the case route that is characterized with relatively frequent services and featuring more than 70 stops with reconstructing its route into segments.

KEYWORDS: bus service reliability, bus bunching, fare card data

INTRODUCTION

For public transportation service, schedule reliability is generally a central point in the service level agreement. Unreliable bus service can lead to longer waiting time and traveling time for passengers. However, bus services are born unstable due to many reasons. Generally, buses leave their departure station at regular intervals, namely the headway. But the intervals become irregular with buses traveling along the route [1]. Reasons can be summarized into two aspects, the first of which is the randomness of passengers’ arrival at certain bus stops. When a bus falls behind its schedule, the headway with the preceding bus will become longer while the one with the following bus will become shorter. In other words, this may cause more passengers waiting at the approaching stop then result in more boarding time and make the bus fall further behind [2]. The second reason is variability of travel time between stops due to traffic congestion, signal control and the difference of bus captains’ driving behavior.

The challenge of improving bus service reliability has been addressed by several researchers. In [1], a headway threshold based control strategy was developed, which aimed to minimizing the waiting time of the passengers at bus stops and the delay of the onboard passengers. When the bus arrives at the stop with headway less than the threshold, it will wait until the threshold is reached. Otherwise, the bus will depart immediately when the headway becomes greater than the threshold.

In terms of bus route services with high frequency, because of the acceptable expected average waiting time, passengers tend to arrive without a prearranged schedule. For this situation, headway based control strategies were implemented in [3-5]. However, in these models, normally instead of actual data on the distribution of travel time and passenger demand, generic distributions that do not account for potential spatial correlation are employed. With the development of Intelligent Transportation Systems (ITS), real time data are available to services’ operators from Automated Vehicle Location (AVL) systems, Automated Passenger Counting (APC) and Computer Aided Dispatching (CAD) systems [6-10]. A model based on historical AVL data was also proposed to improve the service level [11]. In [12] and [8], models were proposed assuming that buses can adjust their velocity to maintain equal headway. To give a better picture, bus route service is explained as a
Meanwhile, analytic studies and mathematical models are conducted by some researchers. Mathematical models based on random process trying to minimize passengers’ waiting time at stops and additional onboard waiting time caused by bus holding [13-15]. In [16], headway variance was analyzed to provide more reliable services. In the field of practical application, a distributed architecture of bus holding was built with real time coordination taken into account [7]. In [17], dynamic bus holding strategies were proposed to achieve schedule reliability and a comparison of different control methods was also conducted.

All the above control strategies and analytical studies can be summarized as holding strategies. To solve the problem on another aspect, stop-skipping strategies were implemented in [18-20]. Furthermore, a mixed model approach taking the bus capacity into account as well as holding and stop-skipping strategies was proposed in [21].

Simulation approaches are also conducted simultaneously. In [22-25], different strategies are simulated to see how the buses run along a certain route. Some of simulations were conducted based on real-life bus services to give a more intuitive explanation and more realistic recommendations.

In the remainder of this paper, the dataset used and the case service studied in this research are introduced briefly in the second section. In the third section, a case study analysis is conducted based on fare card data collected in Singapore, which aims to find out the characteristics of the route and the significant factors which impact level of service. Then, based on the fare card data, a method is proposed to get passenger demand profiles to support the following simulation, which focuses on how the route length influences the level of service in the fourth section. The last section highlights the conclusion of this study and suggests directions of future research.

DATA ANALYSIS

Data Preparation

EZ-link card was introduced in Singapore in April 2002 to provide simplified fare collection in public transportation as stored value contactless smart card. Today, EZ-link cards are used island-wide for various purposes, such as public transportation, parking and road toll payment, and retail transactions. However, the most frequent application is still the payment method for public transportation. Cash payment is still possible for public transportation users, but subject to a higher charge rate, wherefore the EZ-link payment covers 96% of all the public transportation trips in Singapore [26]. This makes the trip record data retrieved from EZ-link card a highly comprehensive data source for research purpose.

The fare charge for each public transportation trip is calculated on trip distance, trip modes and passenger types. There are different charge rate for children, students, senior citizens and adults. Passengers have to tap their EZ-link card on the reader when they enter or leave the MRT stations or boarding and alighting buses. When the passenger finishes a trip, a full record will be created which contains boarding time and alighting time, boarding station and alighting station, and the unique registration number of the bus taken by the passenger.

The analysis conducted in this paper is based on the EZ-link data recorded in one full week (from 11, April, 2011, Monday to 17, April, 2011, Sunday) in Singapore. The dataset has already been pre-processed by Land Transport Authority according to the definition of journey, which means one way travel from one activity to another.

Study of Case Service Route

In this paper, the case service chosen to analyze the reliability of bus services is the busiest service according to the dataset prepared. The service route under study, with 71 stops along the route and total length of 27.6 km, has the most trip records in the one week’s dataset.

The raw data in this study is based on single passenger trips. Generating detailed information of bus service like occupancy, velocity, arrival and departure time at each bus stop is not straightforward. To conduct the case study, the data needs to be processed in order to obtain bus-specific information such as arrival and departure time as well as occupancy.
ROUTE CHARACTERISTICS

Headway & Distribution

Considering the boarding and alighting process when the bus approaches and arrives at a certain bus stop, passengers will tap their card to leave before the bus arrives at the next bus stop. At the same time, the waiting passengers will board and tap after the bus’ arrival. Therefore, it is reasonable to consider arrival time of bus as the boarding time record of the first passenger who boards. The departure time is considered as boarding time or alighting time of the last passenger who boards or alights. However, if there is no passenger boards or alights at the stop which means the bus passes the stop, no information is recorded. Based on this assumption and the location of certain bus stop, the spatial temporal point is recorded for the bus as long as there are passengers boarding or alighting at the bus stop. For the bus stops without records, the arrival and departure time are obtained based on interpolation. Figure 1 shows the trajectories of the case route from 9 a.m. to 12 p.m. in the morning, of which Figure 1(a) presents the original trajectory while Figure 1(b) presents the processed trajectory with interpolation at unrecorded points.

As can be seen in Figure 1, the headways of buses passing certain bus stops are easily interpolated based on the trajectory. To have a more intuitive impression on how the headways change with the buses running along their route, the probability distribution of headways along the case route based on weekday records (11, April, 2011 to 15, April, 2011) are plotted in Figure 2. The buses were able to follow to keep headways stable at the beginning segment, but with the buses traveling further, the distributions become more and more widely distributed. The headways increasingly diverge from the origin schedule.
Figure 2 Headway distributions with stops along the route

Figure 3 Mean and variance of headways from the 2nd stop to the 60th stop

Figure 3 shows the change of mean and variance with the stop sequence, when considering the headway of each stop as a random variable. The mean values do not change substantially because of the scheduled operating time of the service. However, the variance almost continuously increases along the route, which means the headways become more irregular and passengers are facing more uncertainty of the service when the buses traveling forward. Assuming uniformly distributed arrival times of passengers at the bus stop, this pattern causes waiting times above the average mean value of headway as two buses arrive at the same time with one bus overcrowded and the other almost empty.

**Average Velocity**

Average velocity is another significant measurement of the service level, which can reflect the travel time spent on the bus. Figure 4 shows how the average velocity of the case route changes against time of day. The pattern of how velocity varies does not change very much from Monday to Friday. Therefore, it is reasonable to analyze the average velocity of weekdays together. The red line in Figure 4 summarizes the average velocity in 5 weekdays. It can be seen that the travel velocity remains fairly constant from early morning till 3 p.m., followed by a significant decrease of velocity till to 7 p.m. Afterwards, the velocity starts to increase again and reaches the highest value at midnight. Taken the real time traffic of Singapore into consideration, what has been shown in Figure 4 is correlated with the traffic condition, since 5 p.m. to 8 p.m. is the peak time of traffic in Singapore and there are so few passengers and cars in the night that the buses can travel at a very fast velocity. However, the morning peak of traffic seems not to influence the average speed of the service route under study.
In order to describe the passengers’ travel patterns comprehensively, additional information that cannot be derived from the EZ-link dataset needs to be imputed. Since the actual arrival time at the bus stop and hence the waiting time is not available, a uniform distribution is assumed for the simulation. Given the average scheduled headway of around 10 minutes and based on evidence presented in [27], this is considered as a reasonable assumption.

Figure 5 shows the boarding and arriving stairs figure of the 11th stop on the case route. The red line is plotted with the EZ-link dataset, in which the detailed boarding time of each passenger is included. The blue line is created following the assumption that in each interval, the passengers arrive uniformly. Because of the randomness in generating uniform distributions, various initial scenarios could be created as the input parameters for the following simulation process.

The initial scenarios are created from the EZ-link data of the case service route on 11, April, 2011, with 18179 trips in total.
**Simulation Process**

Since in the last step, initial scenarios for the simulation are created. Then, the simulation can be run according to the initial scenario. In this part, the process of how the buses run along the route is simulated under different initial scenarios for passengers. In order to identify the argument appropriately, without the randomness of driving velocity into consideration, it is assumed that all the buses can drive at the same velocity.

![Figure 6](image)

**Figure 6** Trajectory figures extracted from real data and simulation process

Figure 6(a) plots the trajectories of each bus running on the case route (11, April, 2011), while Figure 6(b) shows the trajectories of each bus in the simulation under a certain initial scenario with 10 minutes interval. As can be seen in Figure 6(b), the occupancy of each bus is basically the same with buses around it when there is no bus bunching happens, while the situation will occur in which one bus is full while the following one is empty. As in reality a certain level of the randomness is always prevalent, the bunching problem is inevitable if there is no specific control strategy. However, as mentioned above, bunching problems occur more frequently with increasing travel distance. In the simulation experiment discussed in the following, the impact of cutting the original service route into two segments is evaluated.

**Strategy of Cutting Route**

To make the route distance shorter, the most effective method is to cut the route into linked segments, which means to have new interchange stops in the original route. For the purpose of comparing the original operating strategy with cutting the service route into two linked segments (add one interchange stop on the route), the total at-stop waiting time for all the passengers on this route is chosen as the index to measure the service reliability. To this end, the waiting time for each passenger is defined as the time between the passenger’s arrival time at the bus stop (based on a uniform distribution in each interval) and the boarding time. The simulation is conducted with the parameters given in Table 1. Therefore, if one passenger cannot board on the first bus which arrives because of the capacity constraint, the waiting time will increase until he/she is able to board on the following bus.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Boarding time for each passenger</td>
<td>3s</td>
</tr>
<tr>
<td>Number of buses on route (segments)</td>
<td>120</td>
</tr>
<tr>
<td>Start time of simulation</td>
<td>4a.m.</td>
</tr>
<tr>
<td>End time of simulation</td>
<td>1a.m.(next day)</td>
</tr>
<tr>
<td>Capacity of bus</td>
<td>120</td>
</tr>
<tr>
<td>Desired velocity</td>
<td>5m/s</td>
</tr>
</tbody>
</table>
To test how the system performs after cutting the route into segments, the 29th stop of the case route is chosen as the interchange stop. The route becomes two services operating separately: the first segment is operated from the 1st stop to the 29th stop, with a total length of 12.4 km, while the second segment is operated from the 29th stop to the 71st stop, with a total length of 15.2 km.

Figure 7 Trajectory figures extracted from simulations

To make full comparison of the cutting strategy with the original route service, 1000 random initial scenarios are simulated for this study. Figure 7(a) shows trajectory simulated from one of the scenarios, where bus bunching occurs. Figure 7(b) shows the trajectory simulated after cutting the route at the 29th stop, located at 12.4 km from the starting stop. Compared with Figure 7(a), bus bunching problems are reduced as a result of shorter service distance and the occupancies of buses are more advantageous for passengers. It can be observed directly from the comparison that the level of service has been improved after cutting the route without considering the waiting time of the passengers.
As for the waiting time shown in Figure 8, with 1000 simulations for each situation, the average waiting time of 7.86 minutes compared to 8.61 minutes is substantially lower than the original service. This assessment includes the additional waiting time caused by the 2977 additional transfers for the passengers who board on the first segment and alight on the second segment. In fact, the level of service of the proposed situation is higher than before in all aspects mentioned above: headway reliability, on-board occupancy and average waiting time. Except for the potential cost of constructing interchange facilities, no additional operating costs are expected. Considering the departure intervals of these two situations are the same, no additional buses are needed if the system can be maintained appropriately. Detailed results of the simulations are shown in Table 2.

Table 2 Results of the simulation

<table>
<thead>
<tr>
<th></th>
<th>Average waiting time</th>
<th>Maximum standard deviation of headway (s)</th>
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<tbody>
<tr>
<td></td>
<td>Mean (s) Standard deviation (s)</td>
<td></td>
</tr>
<tr>
<td>After cutting</td>
<td>471.46 4.27</td>
<td>268.8753</td>
</tr>
<tr>
<td>Original route</td>
<td>516.56 7.56</td>
<td>416.1401</td>
</tr>
</tbody>
</table>

CONCLUSION AND FUTURE RESEARCH

In this paper, the study on bus service reliability is conducted based on fare card data to analyze the level of service of a typical route in Singapore. The EZ-link data needs to be processed in order to obtain bus-specific
information. The characteristics of a certain route were analyzed in terms of headway distribution and average travel velocity, from which it can be concluded that the unreliability increases for the chosen bus line quite linearly with increasing travel distance. Based on the analysis of the average velocity, it is also feasible to find how the traffic condition varies with time of day. For this selected route, the impact from evening peak is much more significant than the morning peak.

A simulation model based on different initial scenarios of passengers’ arrival time profiles is used in this study, to investigate the appropriateness of bus services with long travel distance and relatively frequent services. As a case study of bus network design optimization, the route of the service is reconstructed into two segments in the simulation, which is called the strategy of cutting route in this paper. The simulation has illustrated that level of service will be improved with short operating distance in terms of passengers’ average waiting time and the buses’ occupancy, despite that some passengers need to transfer causing additional waiting time.

The study presented in this paper is by no means complete, and the future research is needed in the following domains. First, more detailed simulations need to be developed to take more factors into consideration, such as variability of travel time between stop based on traffic condition for which historical data can be employed. Second, although bus bunching problems can be found in the simulation of the original service configuration and after cutting the bus line into two segments, there are still many factors in reality affecting bus service quality to be explored. They have the ability to expand or reduce reliability, such as the relevance of designated bus lanes, overlapping bus lines and precedence of buses at traffic lights. By enriching the detailed fare card data with information on traffic condition and organization of the transport infrastructure, more strategies like cutting routes should be developed apart from control strategies of buses.

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