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Abstract

Evaluating the reliability of a bus line can provide useful information on the service performance of the city's bus transit system and the need for improvements. This paper presents a reliability evaluation model of a bus line based on information entropy. The model integrates the weighted bus-stop index and the variation index of bus travel time. To better determine the weights of the bus stop, six multiple indices were established based on three characteristics: passenger flow, bus stop properties, and the environment. The proposed model was applied to typical bus lines in Fuzhou, China. The results show that most of the bus stop reliabilities at the peak period were smaller than those at the off-peak period. Besides, for either the peak or off-peak period, the reliability shows a slight upward trend following a gradual decline after the first stop reflecting the influence of passenger flow, environment, and location factors generally.

Key Words: Bus line; Reliability evaluation; Bus-stop weigh; Information entropy.

1 Introduction

With the increasing traffic congestion, the development of good bus transit systems has become an important strategy for solving traffic problems. For the urban bus transit systems, many studies have confirmed the complex network characteristics and randomness of the bus transit system (Wu et al. 2004; Lu and Shi 2007). Therefore, it is no longer adequate to consider partial or deterministic measures in evaluating system performance. In recent years, the concept of reliability has become a valuable tool in transportation engineering (Arhin et al. 2016; Fonzone et al. 2015; Wang et al. 2015). The reliability of bus travel time and road network needs to be introduced into the planning and management of the bus transit systems. Evaluating the reliability of the bus lines can provide the basis for improving bus transit system for both travelers and transport managers.

Many factors affect bus transit reliability, including traffic conditions, bus stop conditions, and time of day (Arhin et al. 2016). Researchers have developed different reliability models for different components of the bus transit system such as bus stop, bus line, and bus network. Wang et al. (2015) established an evaluation index system of bus travel time reliability to analyze the correlation between traffic conditions, road conditions, sampling interval, and fluctuation and delay indices. Arhin et al. (2016) suggested that minimize the total bus-stop time (TBST), which is defined as the sum of the dwell time and the time it takes a bus to availability enter the bus stop and re-enter the traffic stream, can be beneficial to improve the overall bus transit reliability.

From the passenger-service perspective, passenger perception of reliability is affected by several factors, including average lateness, excess waiting time, and adherence to bus schedule (Mkwanazi et al. 2015). Service irregularity increases passenger waiting time and decreases the attractiveness of public

transport (Fonzone et al. 2015). Sorratini et al. (2008) found that the variability of passenger demand distribution has the greatest impact on bus reliability. Bowman and Turnquist (1981) mainly studied passenger arrival behavior and developed a model that links reliability and level of service to the arrival distribution. Dai et al. (2008), Huo et al. (2014) proposed reliability models based on passenger waiting time distribution and bus headway. From the network-structure perspective, Chen et al. (2009) discussed the reliability evaluation of bus stops and lines using three indicators: one punctuality index for lines, two deviation index and evenness index for stops. These indices are used to evaluate the service reliability of stops, routes and network levels in Beijing.

The main measure used in most studies to evaluate reliability is bus arrival time from stop-level. Based on the literature review, the evaluation indices of bus arrival time can be divided into three categories: probability index, variation index, and a comprehensive index. The probability index reflects the reliability of bus arrival time by comparing actual and planned arrival times (Bates et al. 2001; Dai et al. 2008). This index mainly reflects the punctuality of bus operation, which is simple and intuitive and is easy to understand and accepted by the public. However, the application of this index requires establishing standards for the acceptable deviation from the planned time (deviation threshold) that may vary for different cities and even for different bus lines within the city. The variation index refers to the unreliability of bus arrival time by analyzing its standard deviation and coefficient of variation (Bates et al. 2001; Dai et al. 2008). The calculation of the variation index is simple and is superior to the probability index because not only data acquisition is simpler, but also it avoids the need for establishing a deviation threshold. The comprehensive index defines the reliability of bus operation time as the probability that actual arrival time exceeds the average arrival time equal to or less than 10% (Meyer 2002). This index,

which combines bus arrival time and statistical characteristics, can effectively evaluate the arrival state of buses. The variation index is considered more synthetic and objective than other indices. Therefore, this index was integrated into the proposed bus-line reliability model based on information-entropy.

Based on the preceding review, it is clear that previous studies have rarely considered bus reliability as a system, and often overlook the exploration of the importance of each station in the bus line. Passenger flow is usually used as the only factor that represents the importance of a bus stop. However, other factors such as bus-stop type, location, and connectivity also affect the importance of the bus stop in the bus line. The purpose of this paper is twofold: (1) to develop a weighted bus-stop index based not only on passenger flow but also on other characteristics of the bus stop; and, (2) to develop a bus-line reliability model using information entropy that integrates the weighted bus-stop index and the variation index of bus travel time.

The next sections present the basic information-entropy model and the proposed information entropy-based reliability model for bus lines. The application of the proposed model to Fuzhou city is then presented, followed by the conclusions.

2. Basic Information-Entropy Model

Typically, the disordered state of the system is described by the entropy, which originates from thermodynamics as a physical concept (Liu et al. 2016). Shannon (1948) introduced information entropy into information theory as a rough measure of the uncertainty of information. Entropy numerically describes the difference between disorder and order: the greater the entropy of a system, the greater the uncertainty and the disorder of the system. The advantage of using the information entropy model to evaluate system reliability is that the model is not affected by subjective factors, and reliability can be

evaluated using internal components and their relationships within the system.

According to the principle of information entropy, the performance of the system X is discrete and the system may have different states n . The probability of each state is described by a probability distribution function. Let the probability distributions of the possible states be $p = (p_1, p_2, \dots, p_N)$. Then, the distributions satisfy the following conditions:

$$0 \leq p_k \leq 1, k = 1, 2, \dots, N \quad (1)$$

$$\sum_{k=1}^N p_k = 1 \quad (2)$$

The information entropy of the system is expressed as:

$$H(x) = -a \sum_{k=1}^N p_k I_k \quad (3)$$

$$I_k = -\ln p_k \quad (4)$$

where I_k = information contained in state k and a = constant that is equal to or greater than 0 (in most cases, $a = 1$).

The information entropy of a continuous random variable can be derived from the discrete entropy.

For a continuous system, the information entropy of a system x is defined as:

$$H(x) = -\int_{r_1}^{r_2} p(x) \ln p(x) dx \quad (5)$$

Where r_1, r_2 = range of random variable x , $p(x)$ = probability distribution of a random variable x , and $\ln p(x)$ = self-information that the random variable x carries.

Based on Eq. (5), the range of I_k of Eq. (4) is 0 to ∞ and therefore the entropy function $H(x)$ is non-negative. From Eq. (5), obviously, the carried information will decrease with the increase in the

probability of a certain state. Note that $p(k)$ corresponds to the weight of each state and the system entropy is established using the weights of all states. The smaller the probability of occurrence of a state, the more information it carries and the more dispersed the situation of the system is. This leads to increased uncertainty and lower system reliability. When the probability of all random events is equal to 1, the entropy function is 0, the system is in a deterministic state, and the reliability is max. For the bus transit system, the operation is affected by numerous factors that are uncertain and therefore information entropy is a suitable method of evaluating system reliability.

3. Proposed Bus-Line Reliability Model

3.1 Model Formulation

Consider a bus line L with several stops that are assumed to be a discrete system. The bus arrives at each stop is equivalent to the random state of the system and the entropy can be used to describe the reliability of the bus line. The bus transit system is under normal operating conditions, that is, unreliability caused by traffic accidents, natural disasters, and weather conditions is not considered. Based on Eq. (5), the information contained in bus stop i and the entropy of the bus line are given, respectively, by

$$I_i = -\ln(R_{si}), i=1, 2, \dots, n \quad (6)$$

$$H_L = -\sum_{i=1}^n p(R_{si})\ln(R_{si}), i=1, 2, \dots, n \quad (7)$$

Where R_{si} = stop-level reliability index for stop i , n = number of bus stops, H_L = reliability of bus line L (entropy), $p(R_{si})$ = weight of bus stop i . The reliability of the bus line is considered as a weighted average of the reliabilities of bus stops along the bus line.

Since the entropy H_L falls in the range $[0, +\infty]$, it is converted so that it falls in the range $[0, 1]$

103 using the following mapping formula,

$$104 \quad f(x) = \frac{1}{1+x} \quad (8)$$

105 where $f(x)$ = revised reliability of bus line and $x = H_L$. The proposed information entropy-based
 106 reliability model for bus lines requires as input two main components: bus stop-level reliability index and
 107 bus-stop weight. The development of these components is presented next.

108 3.2 Bus-Stop Reliability Index

109 The deviation-type evaluation index is easy to calculate, and the calculation combines the average travel
 110 time, average speed and other evaluation indexes, and integrates the statistical characteristics. The data
 111 acquisition is relatively simple, avoiding the blindness of the threshold value, and is more applicable than
 112 the probabilistic index. And at the same time, considering that not all planned timetables exist in the
 113 operation of bus lines, this paper selects headways between two buses on the same line as the station
 114 reliability evaluation index.

115 Consider bus stop i along a bus line, where $i = 1, 2, \dots, n$. Buses arrive at the stop at times t_1 ,
 116 $t_2, \dots, t_m$, where m is the number of buses. The headway of bus j at bus stop i is $h_{ji} = t_{(j+1)i} -$
 117 t_{ji} , where $t_{(j+1)i}$ and t_{ji} are arrival times of buses $j+1$ and j , respectively at bus stop i . and $j =$
 118 $1, 2, \dots, m-1$. Then, the stop-level reliability index of bus stop i is expressed as:

$$119 \quad R_{si} = 100(1 - R_i) \quad (9)$$

$$120 \quad R_i = \frac{S_i}{h_i} \quad (10)$$

$$121 \quad S_i = \sqrt{\frac{\sum_{j=1}^{m-1} (h_{ji} - \bar{h}_i)^2}{(m-1)}} \quad (11)$$

$$\bar{h}_i = \sqrt{\frac{\sum_{j=1}^{m-1} (t_{(j+1)i} - t_{ji})^2}{(m-1)}} \quad (12)$$

where R_i = coefficient of variation of headway at bus stop i , S_i = standard deviation of headway at bus stop i (s), h_{ji} = headway of bus j at bus stop i (s), and $\bar{h}_i$ = average headway at bus stop i (s). The reliability index reflects the degree of uniformity of actual bus headways compared with the average headway and ranges from 0 to 100, where larger values indicate better reliability.

3.3 Bus-Stop Weight

As stated before, the importance of a bus stop along a bus line is reflected not only by the passenger flow but also by bus-stop attributes and environmental characteristics (Fig. 1). Therefore, three types of dynamic and static factors (passenger flow, bus stop, and environment) were selected for determining the weight of bus stop i , $p(R_{si})$. Six indices were identified within the preceding factors. Then, the index for each bus stop is calculated as the sum of the respective six indices, as follows:

$$l_i = \sum_{j=1}^6 l_{ij}, i = 1, 2, \dots, n, \text{ and } u = 1, 2, \dots, 6 \quad (13)$$

$$p(R_{si}) = \frac{l_i}{\sum_{i=1}^n l_i}, i = 1, 2, \dots, n \quad (14)$$

where l_i = weight index of bus stop i . The six indices include three indices related to passenger flow, one index related to the bus-stop attribute, and two indices are related to environmental characteristics. The values of two dynamic indices {(a), (b)} are calculated using formulas, while the rationale of guidelines for the four static indices {(c), (d), (e), (f)} are set primarily by consulting experts and bus companies, these experts are familiar with the Fuzhou bus network. The development of these indices is presented next.

(a) The intensity of Passenger Flow Index

This index is defined as the ratio of the number of passengers at each stop and the total passengers of the bus line during the study period. The index is given by

$$l_{i1} = \frac{c_i}{c_L}, i = 1, 2, \dots, n \quad (15)$$

where l_{i1} = intensity of passenger flow at bus stop i , c_i = the number of passengers at bus stop i during the study period, and c_L = the total number of passengers of the bus line during the study period.

(b) Floating of Passenger Flow Index

This index is equal to the ratio of the difference between the maximum and minimum values of passenger flows and the average passenger flow of the bus line during the study period. The index is expressed as:

$$l_{i2} = \frac{f_{hi} - f_{li}}{\bar{f}_i}, i = 1, 2, \dots, n \quad (16)$$

Where l_{i2} = floating index of passenger flow at bust stop i , f_{hi} and f_{li} = maximum and minimum passenger flows at bus stop i during the study period, and $\bar{f}_i$ = average passenger flow at bus stop i during the study period.

(c) Bus-Stop Connectivity Index

This index refers to the number of connecting (transfer) bus lines at the bus stop. Generally speaking, the larger the number of connecting lines, the more important the bus stop is. After determined by consulting experts and bus companies, when there are 20 bus lines at a bus stop, the value is 1. When there are 10 to 19 bus lines, the value is 0.5. When there are less than 10 bus lines, the value is 0.3. Guidelines for the bus-stop connectivity index, I_{i3} , are presented in Table 1. Similarly, the values of the

remaining three indexes are also determined by consultants and bus companies.

(d) Bus-Stop Type Index

This index refers to the geometric form of the bus stop: on-lane stop, harbor-shaped stop, terminal stop. For on-lane stops, the bus stops on the traveled lane since the curb at the bus stop are adjacent to the edge of the traveled lane. Therefore, bus arrivals and departures easily affect the operation of other vehicles on the road. On the other hand, harbor-shaped stops allow buses to stop away from the traveled lane and therefore their effects on the operation of road traffic are minimal. The terminal stop refers to the last stop of the bus line. The value of this index is determined according to the type of bus stop (on-lane stop, harbor-shaped stop, and terminal stop). Guidelines for the bus-stop type index, I_{i4} , are presented in Table 1.

(e) Land-Use Type Index

According to the land use, the functional zoning of the city is divided into four types: commercial area, residential area, cultural area, and industrial area. The value of this index is determined according to the type of land use of the bus stops. Generally, the stops lying in commercial areas are the most important. Guidelines for the land-use index, I_{i5} , are presented in Table 1.

(f) Bus-Transfer Type Index

This index refers to the connectivity level between the bus stop and other modes of transportation. The type of connectivity is generally divided into four modes: railway mode, bus mode, taxi mode, and bicycle mode (Jin et al. 2010). The more modes of connection, the greater the density of connection, and the more important the stop is. Guidelines for the bus-stop transfer type index, I_{i6} , are presented in Table 1.

4. Application to Fuzhou City

This section introduces the information entropy evaluation model of bus line reliability proposed in this paper to evaluate the reliability of Fuzhou bus lines.

4.1 Study transit lines and data collection

The proposed methodology was applied to evaluate the reliability of two bus lines in Fuzhou City, China: a downtown bus line (No. 8) and an intercity bus line (No. 95). These lines, shown in Fig. 2, were selected because line layout and bus-stop distribution along the line were typical of other bus lines in Fuzhou city. Bus line No. 8 included 28 bus stops and bus line No. 95 included 24 bus stops. The stop numbers and names of each bus line are shown in Table 2. The data collection cycle in this study covered two periods: peak period (7:30 a.m. to 8:30 a.m.) and off-peak period (9:30 a.m. to 10:30 a.m.), time lasts a week. The data collected at each stop included passenger flow, bus arrival time, number of transfer lines, type of transfer, type of bus stop, land use type.

Passenger flow, number of transfer lines, type of transfer, type of bus stop, and land use type are mainly collected through manual investigation. The bus arrival time can be obtained through the bus arrival and departure data obtained from the Fuzhou Public Transport Group. Part of the bus arrival and departure data of bus line No. 8 and bus line 95 are shown in Table 3. According to the bus arrival and departure data, the bus headway for each stop of the line during both peak and off-peak periods can be obtained.

4.2 Calculation of Bus-Line Reliability

The analysis requires the calculation of deviation rate, bus-stop weight, and bus-stop reliability. Use the measured data of bus arrival times to calculate the standard deviation of bus headway for each stop of the

bus line during both peak and off-peak periods. The trends of bus stop reliability index vary as shown in Fig. 3. To determine the bus-stop weight, the values of $l_1 \sim l_6$ are determined for each stop, based on the presented evaluation system, as follows:

(a) The results of the intensity of passenger flow, based on Eq. (15), are shown in Fig. 4. Some stops with large values are shown in Table 4.

(b) The results of the floating of passenger flow index, based on Eq. (16), are shown in Fig. 5. Some stops with large values are presented in Table 6.

(c) The bus-stop connectivity index was calculated by counting the number of connecting lines in each stop and evaluating them using the guidelines of Table 1. The results are shown in Table 5.

(d) The results of the bus-stop type, land-use type, and bus-transfer type indices are shown in Table 7. These results are based on the guidelines presented in Table 1.

The weight of each bus stop is calculated using Eqs. (13) and (14). The results are shown in Fig. 6.

The reliability of the bus line, represented by the information entropy, is calculated using Eqs. (6) ~ (8).

4.3 Discussion of Results

From the stop-level perspective, whether it is a downtown bus line or an intercity bus line, the reliability of stops is greater than 80% at off-peak period, while it falls mostly in the range of 60% to 80% during the peak period. Most stop reliabilities at the peak periods were lower than those at the off-peak periods. The results indicate that bus line reliability at the off-peak period was higher than that at the peak period for either bus No. 8 or bus No. 95. Besides, for either the peak or off-period, the reliability shows a slight upward trend after the gradual decline from the first stop to the end, which indicates that reliability has a cumulative effect. It means a vehicle not operating on time in the first half of the stops will cause

unpunctual arrival at the follow-up stops. The reason for the rise of the curve may be related to the subjective control behavior of the driver. To reach the required terminal arrival time, the driver may deliberately change the speed of the vehicle, so that it can meet the time requirements of the scheduled.

Fig. 3 shows that the mode of stop reliability of No. 8 bus falls in the range of 0.6-0.9 and the mode of stop reliability of No. 95 bus falls in the range of 0.7-0.9. Combined with the results of bus-line reliability, the operation of the intercity bus line (No. 95), which connects Jinshan district to the university town, is in good condition at the peak and off-peak periods. The overall reliability of the line is high. The actual situation shows that the roads that No. 95 bus passes through are in good conditions, because travel demands in the residential and educational areas are relatively lower. The line of bus No. 8 connects Software Park and Bai Huting which are located in the center of Fuzhou city commercial district and the old city town. The roads are crowded, the traffic environment is complex, and the passenger flow is high, especially that the Software Park has the obvious peak of the passenger flow. Thus, the reliability of the bus line is low, especially at the peak period. This is consistent with the reliability calculated using the proposed model.

4.4 Model Verification and Sensitivity

To verify the results of the reliability model, the model results were compared with actual conditions. An approximate measure of reliability that reflects the adherence of bus travel time to scheduled travel time was used. Data on scheduled travel time were collected from the Fuzhou Public Transport Group and were compared to actual bus travel time for bus No. 8 and bus No 95 for both peak and off-peak periods, as shown in Fig. 7. The mean-squared deviation (MSD) between actual and scheduled travel time between adjacent stations is calculated as:

$$MSD = \sqrt{\frac{1}{n} \sum (T_{actual} - T_{scheduled})^2} \quad (17)$$

Where T_{actual} = actual travel time between adjacent stations (s) and $T_{scheduled}$ = scheduled travel time between adjacent stations (s).

The results of the mean-squared deviation are shown in Table 8. As noted, the results of the reliability model are consistent with actual conditions. Specifically, the mean squared deviation (Actual-Scheduled) of the peak period of bus No.8 is 58.6 s, which is higher than the off-peak period (35.5 s). And the trend is the same for bus No. 95.

To examine the sensitivity of bus line reliability to small changes in the guidelines used for bus-stop indices, the values were slightly changed (decreased by 0.1). Using the new set of indices, the reliability of bus No. 8 changed to 79.5% and 86.4% at the peak and off-peak period, respectively (compared with 78.3% and 85.0% for the original indices set). The reliability of bus No. 95 is 82.3% and 87.9% at the peak and off-peak periods, respectively (compared with 81.7% and 86.5% for the original indices set). These results show that the model is not very sensitive to slight variations in the indices and approximate values of the indices as established in Table 1 would be acceptable.

5. Conclusions

Bus travel-time reliability is one of the most significant tools for evaluating the service performance of bus transit systems. This paper has presented a reliability evaluation method of bus line based on information entropy. The method first adopts the deviation rate of the bus headway index to evaluate the stop-level bus reliability. Then, information entropy was used to develop a bus line-level reliability index. The practical example shows that the performance results of the proposed model are in good agreement

with actual conditions, indicating that the model has certain rationality. Compared with other methods, the impact of the threshold value is much smaller and the computations are simpler and more practical. The proposed evaluation method offers a new idea for the reliability evaluation of bus lines. It is hoped that this method can help assess the reliability of current bus operations and provide the necessary basis for improving service performance of the city and intercity bus transit systems.

This study is to use the information entropy evaluation model of bus line reliability to evaluate the reliability of bus lines. Nowadays, many cities have greatly improved the reliability of bus lines by adopting bus priority measures such as setting up bus lanes, and with the in-depth application of new generation of information technologies such as mobile Internet and Internet of Things in urban public transportation operations, services, and management, comprehensively improve the level of urban public transportation intelligence, the public transport information service system can provide real-time information such as the time of arrival of public vehicles at the bus station, congestion status, etc., but the model in this paper can still be used to evaluate the reliability of bus lines. The future research will continue to improve the model in this paper and compare it with other models.

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References

Wu, J., Gao, Z., Sun, H., and Huang, H. 2004. Urban transit system as a scale-free network. Modern

- 285 Physics Letters B, 18(19n20): 1043–1049. doi:10.1142/S021798490400758X.
- 286 Lu, H., and Shi, Y. 2007. Complexity of public transport networks. *Tsinghua Science and Technology*,
287 12(2): 204–213. doi:10.1016/s1007-0214(07)70029-9.
- 288 Arhin, S., Noel, E., Anderson, M.F., Williams, L., Ribisso, A., and Stinson, R. 2016. Optimization of
289 transit total bus stop time models. *Journal of Traffic and Transportation Engineering (English Edition)*,
290 3(2): 146–153. doi:10.1016/j.jtte.2015.07.001.
- 291 Fonzone, A., Schmöcker, J.D., and Liu, R. 2015. A model of bus bunching under reliability-based
292 passenger arrival patterns. *Transportation Research Part C: Emerging Technologies*, 59: 164-182.
293 doi:10.1016/j.trc.2015.05.020.
- 294 Wang, D., Tang, Y., Chen, Q., Gao, Y., and Jin, S. 2015. Influence factors of interval travel time
295 reliability of public transit station based on gps data. *Journal of Southeast University of C.E. &*
296 *Architecture*, 45(2): 404-412, doi:10.3969/j.issn.1001-0505.2015.02.036.
- 297 Mkwanzazi, M.S., Mbohwa, C., and Nemarumane, T. 2015. Passenger perceptions on reliability of an
298 inter-campus bus system. 2015 IEEE International Conference on Industrial Engineering and
299 Engineering Management (IEEM), Singapore, Singapore, 6-9 Dec. 2015. pp. 1026-1030,
300 doi:10.1109/ieem.2015.7385804.
- 301 Sorratini, J.A., Liu, R., and Sinhan, S. 2008. Assessing bus transport reliability using micro-simulation.
302 *Transportation Planning and Technology*, 31(3): 303-324. doi:10.1080/03081060802086512.
- 303 Bowman, L.A., and Turnquist, M.A. 1981. Service frequency, schedule reliability and passenger wait
304 times at transit stops. *Transportation Research Part A: Policy and Practice*, 15(6): 465–471.
305 doi:10.1016/0191-2607(81)90114-x.

- 306 Dai, S., Zhu, C., and Chen, Y. 2008. Research on time reliability of urban public transit system. Journal
307 of Wuhan University of Technology (Transportation Science & Engineering), 32(5): 869-871.
308 doi:10.3963/j.issn.2095-3844.2008.05.025.
- 309 Huo, Y., Li, W., and Chen, Q. 2014. Study on estimation method of time distribution for public transit
310 passengers. Journal of Transportation Engineering and Information, 12(1): 41-47,
311 doi:10.3969/j.issn.1672-4747.2014.01.007.
- 312 Chen, X., Yu, L., Zhang, Y., and Guo J. 2009. Analyzing urban bus service reliability at the stop, route,
313 and network levels. Transportation Research Part A, 43(8): 722-734, doi:10.1016/j.tra.2009.07.006.
- 314 Bates, J., Polak, J., Jones, P., and Cook, A. 2001. The valuation of reliability for personal travel.
315 Transportation Research Part E, 37(2): 191-229, doi:10.1016/S1366-5545(00)00011-9.
- 316 Meyer, M.D. 2002. Measuring system performance: Key to establishing operations as a core agency
317 mission. Transportation Research Record: Journal of the Transportation Research Board, 1817: 155-
318 162, doi:10.3141/1817-20.
- 319 Liu, Q., Gao, N., Zheng, L., and Wu, P. 2016. Public traffic line selection model based on information
320 entropy and genetic algorithm. Journal of Transportation Engineering and Information, 13(1): 87-94,
321 doi:10.3969/j.issn.1672-4747.2016.01.015.
- 322 Shannon, C.E. 1948. A mathematical theory of communication. The Bell System Technical Journal, 27(3):
323 379-422.
- 324 Jin, L., Peng, J., Liu, K., and Peng, F. 2010. Study on the theory and method of urban subway station
325 classification. Journal of Underground Space and Engineering, 6(A01): 1339-1342,
326 doi:10.3969/j.issn.1673-0836.2010.z1.004.

327 **Figure Legends**

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332 (b) Bus No. 95

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334 (a) Bus No. 8

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- 10 Table 8 Mean-squared deviation of actual and scheduled travel time between adjacent stops

12 Table 1 Guidelines for indices values for determining the weight of bus stop

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Characteristic	Index Value
(a) Bus-Stop Connectivity Index	
Number of Connecting Lines	I_3
0-9	0.3
10-19	0.5
≥ 20	1.0
(b) Bus-Stop Type Index	
Stop Layout	I_4
On-lane stop	0.3
Harbor-shaped stop	0.5
Terminal stop	1.0
(c) Land-Use Type Index	
Land Use Type	I_5
Commercial	1.0
Residential	0.7
Cultural	0.5
Industrial	0.3
(d) Bus-Transfer Type Index	
Number of Transfer Modes	I_6
1	0.3
2	0.5
3	0.7
4	1.0

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Table 2 Stop names and numbers of bus lines No. 8 and 95

Stop Number	Stop Name	Stop Number	Stop Name
(a) Bus Line No. 8			
1	Baihu Ting	15	Union Hospital
2	Yingbin Road	16	Daoshan Junction
3	Trigeminal Village	17	South Street
4	Trigeminal Street	18	Gu Lou
5	Zhongfu Temple	19	Health Department
6	Huawei Station	20	Ping Shan
7	Long Fu Market	21	Sanjiao Jing
8	Guangming Bridge	22	Zuohai Park
9	Lian Pan	23	Tian Feng
10	Changle Road	24	Tong Pan
11	Xiangtou Shan	25	Military Region Kindergarten
12	South Park	26	Military Region
13	Bus station	27	Gate of Software Park
14	Zhuangyuan Jing	28	Software Park
(b) Bus Line NO. 95			
1	Freeway Maintenance Section	13	Flag stop(2)
2	Zhongmei Village	14	East Gate of Fuzhou University
3	Bus Parking Lot of Univ. Town	15	Southeast TV station
4	Meiqi Village	16	Fuzhou No.1 Middle School
5	Qingzhou Village	17	Ju Yuanzhou
6	College of Trad. Chinese Medicine	18	Rongxin Community
7	Medical University	19	Hong Wan Road
8	Jiangxia College	20	Autumn Garden
9	Fuzhou Univ. student apartment	21	Winter Garden
10	North Gate of Fuzhou University	22	Lu Bin Road
11	Flag stop (1)	23	Lu Bin Road East
12	Boshihou Shopping plaza	24	Jinshan Bus Terminal

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18 Table 3 Part of the bus arrival and departure data of bus line No. 8 and bus line 95

(a) Bus Line No. 8				
Plate Number	Running Direction	Stop Name	Arrival or Departure	Business Hours
AYE516	up direction	Baihu Ting	Arrival	6:59:00
AYE516	up direction	Yingbin Road	Arrival	7:03:16
.....				
AYE516	up direction	Gate of Software Park	Arrival	8:31:33
AYE516	up direction	Software Park	Arrival	8:32:50
(b) Bus Line No. 95				
Plate Number	Running Direction	Stop Name	Arrival or Departure	Business Hours
AYD667	up direction	Freeway Maintenance Section	Arrival	9:08:00
AYD667	up direction	Zhongmei Village	Arrival	9:09:22
.....				
AYD667	up direction	Lu Bin Road East	Arrival	9:39:32
AYD667	up direction	Jinshan Bus Terminal	Arrival	9:42:11

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21 Table 4 Bus stops with large intensity of passenger flow for bus lines No. 8 and 95

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Period		The intensity of Passenger Flow						
(c) Bus Line No. 8								
Stop Number	8	9	12	13	15	16	26	28
Peak	0.034	0.061	0.052	0.044	0.069	0.035	0.091	0.125
Off-Peak	0.055	0.055	0.045	0.090	0.062	0.070	0.027	0.015
(d) Bus Line No. 95								
Stop Number	5	12	17	18	21	22	23	24
Peak	0.085	0.024	0.065	0.032	0.043	0.105	0.078	0.227
Off-Peak	0.069	0.045	0.069	0.061	0.045	0.053	0.016	0.224

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Table 5 Value of bus stop connectivity index for bus lines No. 8 and 95

Number of Connecting Lines	Stop Number		Index I_3
	Bus Line No. 8	Bus Line No. 95	
0-9	3, 4, 6, 7, 14, 19, 22, 23, 24, 25, 26, 27, 28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 19, 20, 21, 22, 23	0.3
10-19	2, 5, 8, 9, 10, 11, 12, 13, 15, 16, 18, 20, 21	12, 13, 14, 15, 16, 17, 18	0.5
≥ 20	1, 17	24	1.0

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Table 6 Bus stops with large floating of passenger flow index on bus lines No. 8 and 95

(a) Bus Line No. 8									
Stop Number	1	9	3	6	15	18	26	28	
Index I_3	1.47	1.84	1.57	1.44	1.59	1.47	1.78	2.32	
(b) Bus Line No. 95									
Stop Number	2	6	7	9t	11	12	22	23	
Index I_3	2.80	2.67	2.72	2.47	3.14	2.23	2.78	2.28	

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Table 7 Value of bus-stop type, land-use type, and bus-transfer type indices for bus lines
No. 8 and 95

Index Elements	Stop Number		Index Value
	Bus Line No. 8	Bus Line No. 95	
(a) Bus-Stop Layout Index, I_4			
On-lane stop	3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15,	2, 3, 4, 5, 8, 11, 12, 13, 14,	0.3
	16, 17, 19, 20, 22, 23, 24, 26, 27	17, 18, 19, 20, 21, 22, 23	
Harbor-shaped stop	2, 7, 18, 21, 25	6, 7, 9, 10, 15, 16	0.5
Terminal stop	1, 28	1, 24	1.0
(b) Land-Use Type Index, I_5			
Commercial	1, 2, 6, 7, 13, 14, 15, 16, 17, 18, 19, 22	12, 13, 24	1.0
Residential	3, 4, 5, 8, 9, 10, 11, 12, 20, 21, 23, 24	17, 18, 19, 20, 21, 22, 23	0.7
Cultural	25, 26, 27, 28	3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 16	0.5
Industrial	n.a. ^a	1, 2	0.3
(c) Bus-Transfer Type Index, I_6			
1	n.a. ^a	1, 2, 3, 4, 5	0.3
2	2, 3, 5, 6, 7, 9, 10, 12, 13, 14, 16, 18,	6, 7, 8, 9, 10, 11, 13, 15, 16,	0.5
	19, 21, 23, 24, 26, 27	17, 18, 20, 21, 22, 23	
3	4, 8, 11, 12, 15, 22, 25, 28	12, 14, 24	0.7
4	1, 17, 20	19	1.0

^a Not applicable

34 Table 8 Mean-squared deviation of actual and scheduled travel time between adjacent stops

Bus Line	Peak Periods		Off-Peak Periods	
	MSD (s)	Model	MSD (s)	Model
	(Actual-Scheduled)	Reliability (%)	(Actual-Scheduled)	Reliability (%)
No. 8	58.6	78.3	35.5	85.0
No. 95	35.4	81.7	22.8	86.5

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Fig.1 Indices for determining weight of bus stop

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Fig. 2 Location of bus lines used in the application

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(a) Bus No. 8

(b) Bus No. 95

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Fig. 3 Variation of headway reliability index along bus line for peak and off-peak periods

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(a) Bus No. 8

(b) Bus No. 95

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Fig. 4 Intensity of passenger flow for peak and off-peak periods

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Fig. 5 Floating index of passenger flow

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Fig. 6 Weights of bus stops

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(a) Bus No. 8 (off-peak)

(b) Bus No. 8 (peak)

(c) Bus No. 95 (off-peak)

(d) Bus No. 95 (peak)

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Fig. 7 Comparison of actual and scheduled travel time between adjacent bus stops