

Method to Calculate Dynamic Accessibility of Urban Bus Rapid Transit System

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Abstract. Bus rapid transit (BRT) is an important transit mode in the urban transportation system, especially in improving the urban transit's operating efficiency. The accessibility of BRT is an important factor to measure its service level, however, most existing methods of calculating the accessibility can hardly reflect its real-time changes due to the lack of consideration for the time-varied vehicle capacity or the passenger's walking distance. Therefore, a new enhanced two-step floating catchment technique (E2SFCA) is proposed to calculate the dynamic accessibility instead of the traditional two-step floating catchment technique (2SFCA) by adding a distance-decay function. Two districts in Guangzhou, i.e. TianHe and HuangPu are presented as real-life examples to validate the effectiveness of E2SFCA. Based on the results, some conclusions and suggestions are provided to improve the service of BRT. The related results also confirm that E2SFCA has a significant advantage to the planning and operation of BRT.

Introduction

Traffic jams are very common in big cities nowadays, as the fast growth of urban population and private cars. To alleviate the traffic pressure, the bus rapid transit (BRT) system has been developed in many big cities. Various calculation methods of transit accessibility have been proposed (Chen et al.2008); Chen (2015) used the GIS spatial analysis the transit accessibility. Luo (2003) put forward two step floating catchment technique(2SFCA)to research the accessibility of medical care space. By modifying the 2SFCA, Langford (2012) measured the transit accessibility of Merthyr.

Compared with the design of ordinary bus lines and stops, the design of BRT focuses on the network integrity and real-time vehicle information. Thus, the dynamic accessibility measure is more suitable for BRT. The walking distance and transit coverage are two important factors for the dynamic accessibility calculation of BRT. O'Sullivan (1996) found that the transit demand was diminished by 70% with the walking distance increasing from 200 to 400m. Zhao (2003) observed that the optimal walking distance should not more than 550m. Hess (2012) suggested that the optimal walking distance was 400m.

To our best knowledge, few existing researches consider the dynamic accessibility. Moreover, 2SFCA method ignores the distance attenuation factor. Therefore, the results may not reflect the actual case. On the basic of the traditional 2SFCA method, this paper proposed an enhanced two-step floating catchment technique (E2SFCA) to calculate the accessibility of BRT by considering a distance-decay function.

BRT Dynamic Accessibility

Accessibility is usually defined as "the degree of convenience that people can reach some certain services from their origination" (Lu et al.2009). For public transportation system, an accurate accessibility measurement is an important factor in evaluating the service level of transit, and it is also provide guidance to the construction and improvement of the transit.

This paper defines the concept of the transit dynamic accessibility as “a real-time measurement of the difficulty that people can reach the transit service in a relatively stable transit operation environment”, and it is affected by the number of buses in service and the transit demand in real time. Comparing with static accessibility, the dynamic calculating method highlights the instantaneity and flexibility of the measurement. Moreover, the indicator of dynamic accessibility is also accessibility influenced by some other factors, such as geographical location, passenger flow, vehicle capacity and traffic density.

Modification of E2SFCA Based on BRT

Introduction about 2SFCA. 2SFCA (Luo et al.2003) is a static binary method. It is based on the assumption that all the service points within a scope have the same attraction.

Luo (2009) proposed an enhanced 2SFCA (E2SFCA) method by adding a distance-decay factor. This modification indicates that the transit accessibility changes versus service distance. E2SFCA is a dynamic method, which improves the effect of walking distance on the transit demand, and it reflects the real case better.

Calculation of the Attenuation Coefficient. It is obvious that the passengers also less to be attracted by distant stops in the transit service area. Thus, E2SFCA has improved 2SFCA by considering a distance-decay weighting coefficient W_{kj} . By this, the ratio of transit supply and demand R_j and accessibility metric A_k , are formulated as Eq. (1)-(2), respectively:

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \leq d_{\max})} P_k \times W_{kj}} \quad (1)$$

$$A_k = \sum_{j \in (d_{kj} \leq d_{\max})} R_j \times W_{kj} \quad (2)$$

where:

S_j : service quantity provided by stop j

P_k : transit demand assembled at point k in the service area of stop j

d_{kj} : distance from point k to stop j

Three formulations of the distance-decay weighting coefficient W_{kj} , are given as follows:

Linear decay

$$W_{kj} = \frac{(d_{\max} - d_{kj})}{d_{\max} (d_{kj} \leq d_{\max})} \quad (3)$$

$$W_{kj} = 0 (d_{kj} > d_{\max})$$

Gauss decay

$$W_{kj} = \text{Exp}(-d_{kj}^2 / d_{pass}^2) \quad (4)$$

$$d_{pass} = 200$$

Butterworth filter

$$W_{kj} = \sqrt{\frac{1}{1 + e(d_{kj} / d_{pass})^n}} \quad (5)$$

($e = 1, d_{pass} = 250, n = 6$)

According to Zhao's (2003) study, the bus occupancy decreases sharply when walking distance exceeds 91meters, and it is nearly to be zero when the walking distance is above 580meters. The change of the bus occupancy versus walking distance is similar to the Butterworth curve, thus Butterworth filter is used to calculate distance decay factor.

Modification of E2SFCA Based on the Characteristics of BRT. As shown in Fig.1, E2SFCA needs to consider the relationships between bus stop and public transit service.

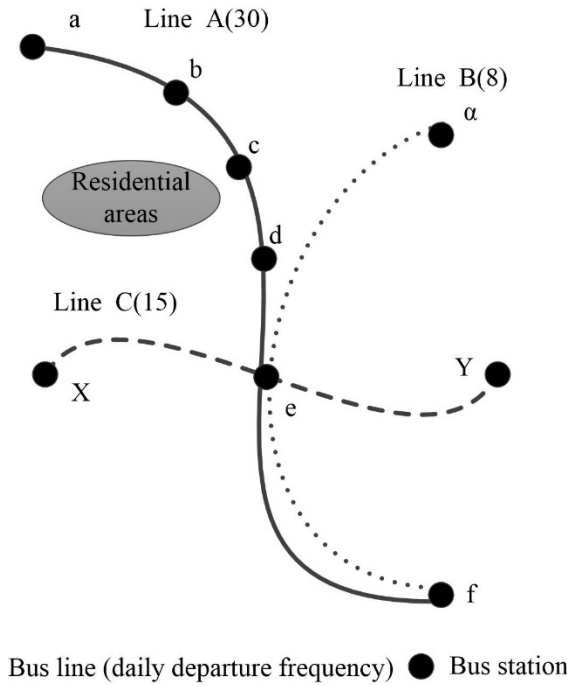


Fig.1 The BRT lines

Fig.1 describes a typical situation, where there are three bus routes, nine stops and a single population centroid (transit demand). All the bus stops are within the service distance range. Since there exist both boarding and alighting demands at each stop, the transit supply provided by buses at different stops are different. If this factor is set to be a constant, the transit accessibility will be misestimated.

Moreover, the stops near to passengers are likely to be chosen as boarding stops. It is worth noticing that when calculating the accessibility metric A_k , for each demand point k , the distance-decay weighting W_{kj} , needs to be multiplied by each ratio of transit supply and demand R_j for each stop j . By this, the main steps of the modified E2SFCA based on the characteristic of BRT are given as follows.

Step1: Calculating the transit supply at stop j by recording the number of boarding and alighting passengers, and the number of buses of vehicle type i , which are represented respectively by S_j^{up}, S_j^{down} , and N_i . The maximum vehicle capacity of type i is represented by p_i . The calculation of S_j and R_j are given as follows:

$$S_j^s = \sum_{i \in I} \left(N_i \times p_i - \sum_{m=1}^{j-1} (S_m^{up} - S_m^{down}) \right) \quad (6)$$

$$R_j^s = \frac{S_j^s}{\sum_{k \in (d_{kj} \leq d_{\max})} P_k \times W_{kj}} (s \in S_j) \quad (7)$$

Step2: Calculating the accessibility of demand k based on $d_{kj(s)}^{\min}$ (the shortest distance from the transit demand point k and the occupied stop j):

$$A_k = \sum_s R_j^s \times w_{kj} (\forall s: d_{kj(s)}^{\min}) \quad (8)$$

A Case Study: Transit System Accessibility TianHe and HuangPu Districts in Guangzhou

Introduction. A real-life example based on TianHe district and HuangPu district in Guangzhou is presented to analyze the BRT stop accessibility and the surrounding communities through two districts. The BRT stops as shown in Fig.2.

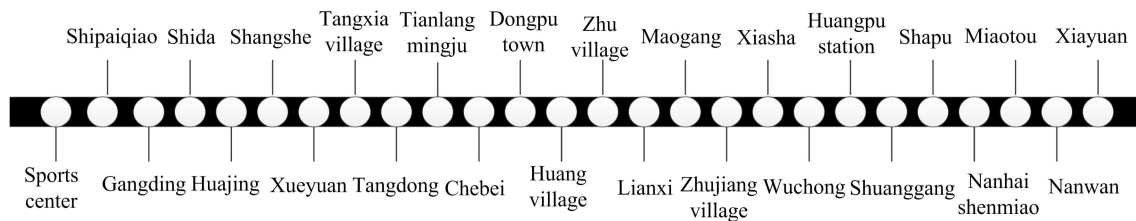


Fig.2 BRT stops

Accessibility Calculation

(1) Basic data

The information of the BRT stop mainly includes: latitude and longitude, recording time, the number of passengers boarding and alighting, and the number of vehicles. The information of the community mainly includes the geographic location, the information of BRT stops within the community's distance scope, the walking distance to the BRT stop and the attenuation coefficient. The information of each type of the bus is given in Table 1.

Table 1 Information of each type of the bus

bus type	seating	standing area(square meter)	carrying capacity(person)
29seats	29	15.3	75
33seats	33	14	75

(2) Accessibility results

Fig.3 is the flow chart of calculating the dynamic accessibility of the BRT station and the community:

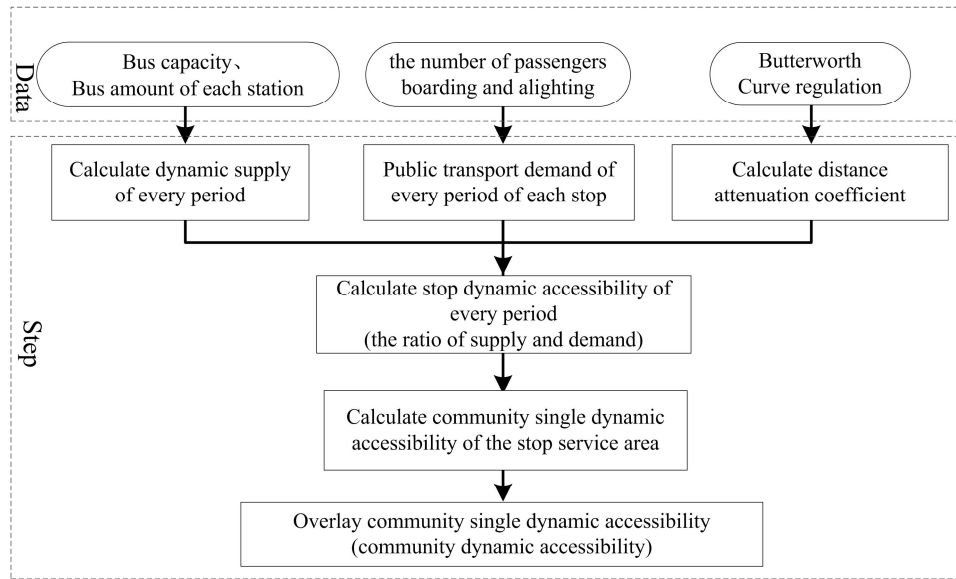


Fig.3 Dynamic accessibility calculation steps of BRT stops and districts

According to the dynamic accessibility calculation steps in Fig.3, the results during the period of 8:30-9:00 a.m. on a weekday are showed in Table 2 and Table 3.

Table 2 BRT stops dynamic accessibility

stop	time	card amount	passenger capacity	accessibility
Xiayuan	8:30-9:00	124	2 175	17.540 322 58
Nanwan	8:30-9:00	13	2 054	157.961 538 5
Miaotou	8:30-9:00	25	1 975	78.987 586 21
Nanhaishenmiao	8:30-9:00	69	1 743	25.262 547 3
Shapu	8:30-9:00	22	1 268	57.648 544 56
Shuangang	8:30-9:00	74	1 523	20.584 753 59
Huangpu station	8:30-9:00	25	939	37.577 524 32
Shida	8:30-9:00	97	1 795	18.503 217 63
Gangding	8:30-9:00	487	3 556	7.302 211 003
Shipaiqiao	8:30-9:00	9	4 263	73.678 792 4
Sports center	8:30-9:00	54	5 884	108.967 430 6

Table 3 Districts dynamic accessibility

community name	adjacent stop	walking distance	distance decay factor	stop accessibility	signal accessibility	accessibility y
Sports west	Sports center	500	0.124 034 735	51.355 569 37	6.369 874 438	6.369 874 43
Yunan	Tangdong	503	0.121 861 689	1.286 073 096	0.156 723 04	0.156 723 04
Fuli	Tianlangming ju	324	0.417 450 8 393	7.122 300 342	2.973 209 976	2.973 209 97
Xihua garden	Tianlangming ju	444	0.175 735 393	7.122 300 342	1.251 640 25	1.549 575 22
	Chebei	486	0.134 872 929	2.209 005 006	0.297 934 975	
Jujing garden	Tangxiacun	431	0.191 545 232	3.030 470 522	0.580 472 179	1.396 475 19
	Tangdong	267	0.634 491 943	1.286 073 096	0.816 003 017	
Xiangxin garden	Shuanggang	309	0.468 014 794	11.652 682 99	5.453 628 03	5.453 628 03
Shapu village	Shapu	420	0.206 358 578	34.905 040 17	7.202 954 455	7.202 954 45
Bochuan	Nanhaishenmia	207	0.869 650 08 2	16.363 255 2	14.230 306 19	14.230 306 1

(3) The design and analysis of accessibility map

For analyzing the changes of the results, accessibility maps are accomplished by ArcGIS. As shown in Fig.4 and Fig.5, circular classification symbol and histogram are used to represent stop accessibility and community accessibility.



Fig.4 BRT stops dynamic accessibility GIS map

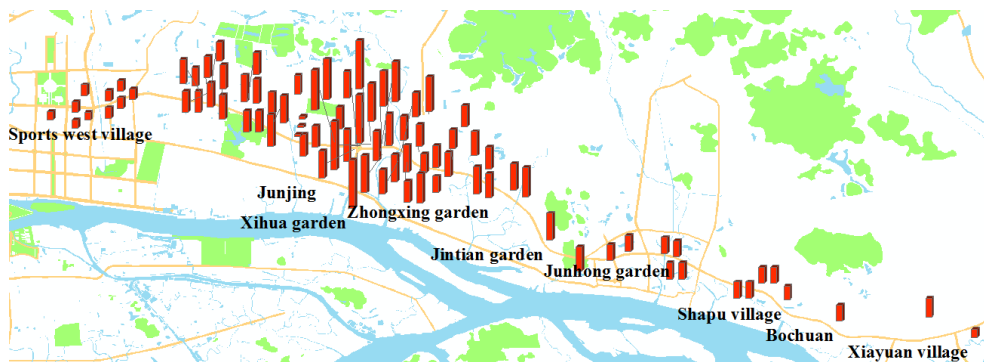


Fig.5 Districts dynamic accessibility GIS map

The results of the stop accessibility show that the accessibility of station on both ends is low, while the accessibility in the middle part is high. The different results can be attributed to the different stop distribution, geographical location, and population density of the stations. On the right side of the bus line are industrial parks, which belong to sparsely populated region and the population type there is also single; while on the left side of the bus line are commercial districts, where the transit network is complex and the transit service is also improved, thus the BRT dynamic accessibilities there are at a higher level. The middle part of the bus line is a residential area, where the population density is larger. Moreover, this area belongs to suburban areas, where the economic and the relative infrastructure are not well developed. It makes the BRT dynamic accessibility there quite low.

The results of the community accessibility show that the accessibility in the central district is higher than villages at the endpoints. The main reason is that a large number of migrant workers reside in rural-urban continuum. To meet the people's travel demands, BRT stops are densely distributed, thus the community dynamic accessibility is high. While the villages regions at the endpoints are industrial and commercial districts, causing that the population distribution is unbalanced. The villages are distributed in pairs of spots, thus the distance attenuation coefficient is larger and the accessibilities are lower. Based on the above analysis, the example validates that BRT can alleviate the pressure of the residents, and E2SFCA is effectiveness.

In addition, since the accessibilities of stops and communities are reversible, demand and supply are not balance in some areas. The transit demand from the communities in the middle of the bus line cannot be satisfied at peak period, while there exists oversupply on the endpoints of the line.

Optimization and Analysis. Based on the assumption that there are enough vehicles, the dynamic accessibility information is used to guide the operation of BRT by adjusting the departure time and the headway in real-time.

In reality, the BRT service includes two types, BRT short-line service and BRT express services. It is more reasonable to combine these two types together to do the optimization rather than handling them separately. For example, the optimal solutions of Line B1 and some related suggestions are as follows:

(1) Increasing the BRT express service and BRT short-line service

Considering the dynamic accessibility of each BRT stop, the operations of increasing the BRT express service and BRT short-line service to serve the low accessibility stops and adjusting the change with the change of demands.

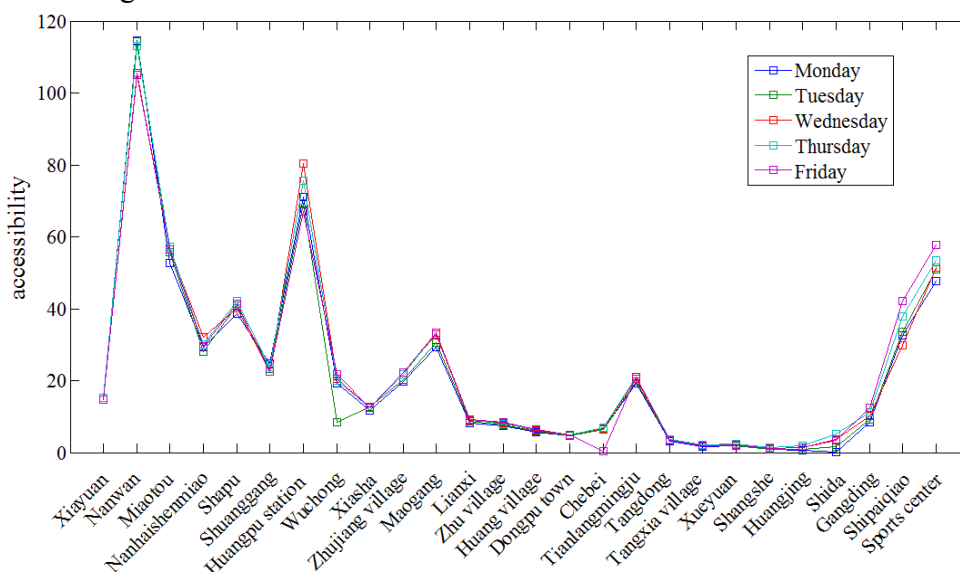


Fig.6 B1 stop dynamic accessibility during morning rush

From Fig.6, B1 express is designed according to the transit supply and demand at each stop, and is formulated as : Xia Yuan - Shuanggang - Xiasha - LianXi – Dongpu town - Chebei -

Tangdong-Tangxia village - Xueyuan - Shangshe - Huajing - Gangding - Sports center; the operating hours are 7:00-9:00.

(2)Adjustments of BRT express stops and BRT short-line service stops

The vehicle schedule, line length and stop spacing for existing express and short routes should be adjusted considering the dynamic accessibility.

① B1 express service

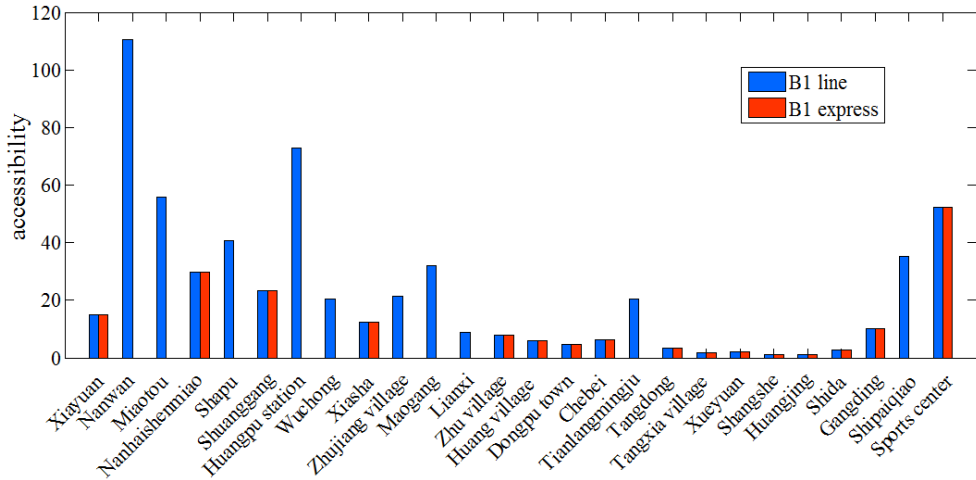


Fig.7 Comparison of accessibility between B1 line and B1 express during weekly morning rush

As shown in Fig.7, comparing with the stop accessibilities of morning peak, B1 express stops should be adjusted by removing stops with higher accessibility, such as Nanhaishenmiao , Shuanggang、 Sports center, and adding lower accessibility stop like Lianxi. Therefore, the new B1 express is: Xiayuan - Xiasha - LianXi – Zhu village – Huang village –Dongpu town - Chebei- Tangdong – Tangxia village- Xueyuan - Shangshe - Huajing- Shida-Gangding.

② B1 short-line service

B1 short route passes the residential area of TianHe district, and the line chart is shown in Fig.8:

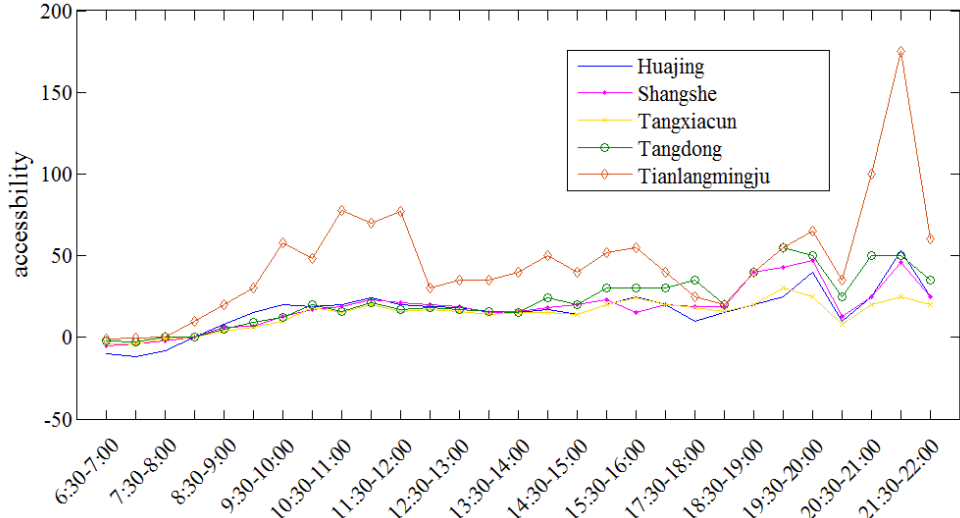


Fig.8 B1 stop dynamic accessibility all the time

Taking the Tianlangmingju stop as an example, the accessibility of this stop is lower in morning peak、 evening peak and during20:00 - 22:00. Thus, B1 short route only needs to stop at this stop during these three periods.

(3)Reducing the headway and adjusting the departure time

The operation of BRT express and BRT short trip are based on the real-time vehicle capacity. In order to allocate resources reasonably, adjusting headway and departure time based on the stop dynamic accessibility. For instance, as shown in Fig.9, the operating time for B1 express is from 7:00 to 22:00.

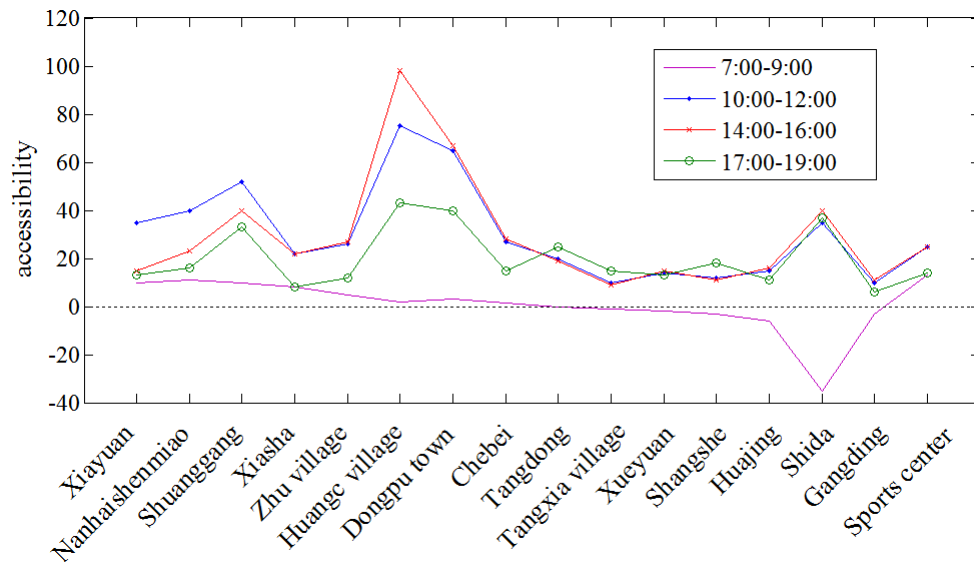


Fig.9 Dynamic accessibility of B1 fast stops all the time

Because the stops accessibilities are lower during peak time, the headway during these periods should be shortened. In addition, since a stop's accessibility is higher during 10:00-12:00 and 14:00-16:00, it is suitable to increase the headway during these periods.

Conclusions

This paper puts forward an E2SFCA method to calculate the dynamic accessibility of BRT by considering the impact of the walking distance on the transit demand. Two districts in Guangzhou, e.t. TianHe and HuangPu are presented as real-life examples to validate the feasibility of the method. The related results are calculated, and then some visualized maps based on GIS follow. In a certain range of allowable error, the results show that E2SFCA can calculate the BRT dynamic accessibility accurately and reflects the real case better. The results are of great significance to optimization and construction of BRT system.

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