

CCM-Based Accessibility Evaluation of the Public Bus Network in Beijing City, China

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Abstract: The surface public bus has a great advantage in mitigating traffic congestion in Beijing city in a short-term period and accessibility analysis of public bus network is one of the most important topics for urban sustainable development. On the basis of actuality analysis of such indexes as line length, network density, repetition coefficient of public bus network in Beijing, the paper improved the Critical Cluster Model (CCM) which is one of the spatial optimization models applying to the assessment of evacuation risk and introduced a new concept the maximum bus line capacity demand for the bus stop. It evaluated the accessibility of Beijing public bus network with the reformative CCM and GIS technology. The results revealed the accessibility characteristics and the existing problems, which will help to the further improvement program.

Key Words: *Accessibility Evaluation, Public Bus Network, GIS (Geographic Information System), CCM (Critical Cluster Model)*

1. INTRODUCTION

With the rapid economy growth, urbanization and motorization, traffic problem has more and more severe impact in urban sustainable development of China. The importance of public transport services in a successful transportation system is widely recognized (May and Roberts, 1995; Shapiro, 2004; Glaeser *et al.* 2006). As one of the important modes, surface public bus plays a key role in improving traffic congestion in Beijing city during a short-term period (Xie *et al.* 2006). One of the importantly interrelated issues to be addressed in providing public transportation is accessibility to this travel mode. The “accessibility” of urban public bus may be defined as the description of traffic degree of ease for individuals to

reach the destinations from a given origin by means of public bus mode which denotes the proximity of different areas in the same city achieving by public bus lines (Geurs and Wee, 2004). Moreover, accessibility also encompasses the operational functioning of a system for regional travel. Therefore accessibility analysis can be regarded as integrated criteria for evaluating whether the surface public transit system can complete the transportation task with good quality and efficiency.

The Critical Cluster Model (CCM) is one of the spatial optimization models applying to the assessment of evacuation risk for an area or a city. The Bulk Lane Demand (BLD) refers to the ratio of population to exit capacity which is an evacuation difficulty index (Church and Cova, 1997). CCM uses such an index to identify neighborhoods facing transportation difficulties during an evacuation process. Moreover, the accessibility of public bus network describes the degree of ease for individuals to reach the destinations by means of public bus mode which is adversative to the evacuation difficulty index BLD in CCM. Based on this context, the accessibility can be reflected indirectly by BLD in CCM. Therefore, if CCM is introduced into the evaluation of public bus network and make appropriate adjustments, a new accessibility evaluation system will be constructed.

The paper had digitized Beijing public bus network inside the 5th ring road with the support of GIS technology according to Beijing Urban Map and the information on the web of Beijing Public Bus and Capital Public Bus, and analyzed the characteristics of different indexes of all lines in the Beijing public bus network up until August 2007(Wang and Li, 2007; Li *et al.* 2008). On the above basis, the paper seeks to apply the reformative CCM to evaluate the accessibility of public bus network of Beijing city with the support of GIS technology. The result analysis will help to find out the main problems of Beijing surface public bus and put forward the improvement countermeasure and further optimized project for line layout.

2. PUBLIC BUS NETWORK IN BEIJING CITY

To mitigate the increasingly severe traffic problem and its social and economic impacts, Beijing government implemented a series of systematic reforms on public bus in such aspects as operation management, bus line layout and so on. By year 2007, the development of Beijing public bus has achieved obvious improvement. Figure 1 shows that the number of operating vehicles and operating line length both increases more than 3 times in ten years. By the end of 2007, there are totally 18567 operating vehicles (including Buses and Trolley Buses), and about 4,031,690,000 passengers carried a year. There are totally 554 bus lines and 1389 bus stops inside the 5th ring road of Beijing public bus network until August 2007 when the Beijing Public Transport Company had completed five sets of bus line adjustments at the first stage.

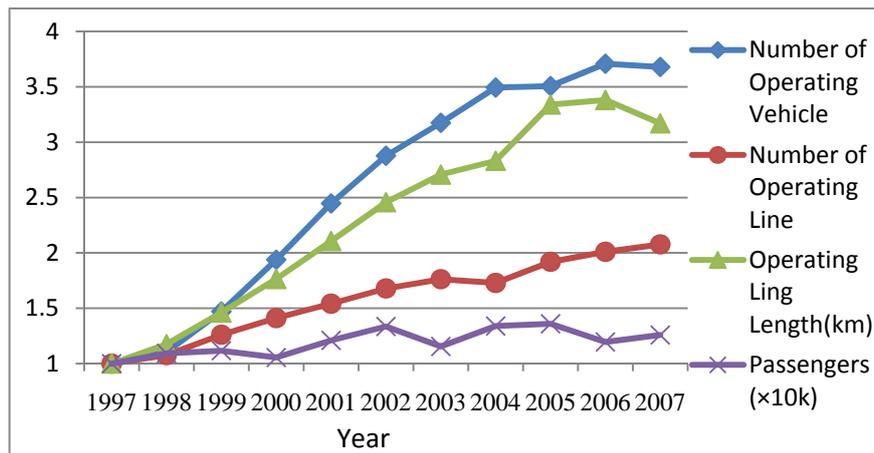


Figure 1 Changes of Beijing Public Bus Network

2.1 Line Structure and Line Length

There are six types lines such as inner city line, near suburb line, far suburb line, yuntong line, special line and night line in the Beijing public bus network. The statistical results in Table 1 show that the public bus lines are mainly made up of the near suburb line and the far suburb line, and the average length of 554 bus lines in Beijing is 25.6km. The total length and average length of the inner city line, near suburb line and far suburb line all increase gradually.

Table 1 Structure and line length of public bus line

Line type	Lines	Proportion	Total length (km)	Average length (km)
Inner city line	92	16.6%	1250	13.6
Near suburb line	209	37.7%	3557	17.0
Far suburb line	214	38.6%	8215	38.4
Yuntong line	20	3.6%	679	34.0
Night line	12	2.2%	240	20.0
Special line	7	1.3%	218	31.1
Total	554	100%	14159	25.6

2.2 Network Density

The average network density of Beijing public bus network is 1.58 km/km^2 , and network density is degressive from the central districts (Xicheng, Dongcheng, Xuanwu and Chongwen districts) to the peripheral districts (Haidian, Chaoyang, Shijingshan and Fengtai districts) as shown in Table 2. According to the theoretical analysis, the suitable public bus network density is about 2.5 km/km^2 , and the network density must be increased gradually to 3 - 4 km/km^2 in the urban central area and decreased contrarily to 2 - 2.5 km/km^2 in the suburban areas (Wang *et al.*2002).

Obviously, both the total network density and the network density in every district are largely

under the above level.

Table 2 Network density and repetition coefficient of different districts

Districts	Line network density (km/km ²)	Line repetition coefficient
Xicheng	2.72	8.40
Dongcheng	2.21	7.27
Xuanwu	2.29	11.90
Chongwen	2.10	8.55
Haidian	1.43	9.18
Chaoyang	1.72	8.94
Shijingshan	1.14	4.80
Fengtai	1.27	7.66
Total	1.58	8.17

2.3 Repetition Coefficient

According to *Code for Transport Planning on Urban Road* (China, 1995), repetition coefficient refers to the ratio of the total length of public bus lines to the length of line network that can reflect the intensive degree of public bus lines in the urban main roads. Generally, the repetition coefficient on the main artery should be less than 8 at the most and less than 5 for the best.

From Table 2 we can see that the line repetition coefficients in districts except Xuanwu and Haidian district were all close to the limited value 8, therefore it could be assumed that the public bus network was becoming reasonable.

3. CCM AND ITS APPLICATION IN ACCESSIBILITY EVALUATION

3.1 The Implement of CCM

In the CCM, the evacuating risk in a known hazard area can be understood as the demand of capacity of road exit depended on the people needing evacuation in the known hazard zone that is BLD. As an evacuation difficulty index, BLD can be used to identify small neighborhoods about a given node that have potentially risky combinations of high population and low exit road capacity. BLD is simply defined in formula (1), where P is the population involved and C is a measure of the capacity of the exit choice set (Cova and Church, 2000). In the CCM, the higher the BLD, the higher the evacuation difficulties, that is there are more difficulties in leaving a known hazard area.

$$BLD = \frac{P}{C} \quad (1)$$

In the CCM, urban road is abstracted into network and nodes. Nodes represent the road

intersections and the arcs between the nodes represent the roads. By analyzing the structure of road network, the whole hazard area can be delimited into many different small zones which centered on individual nodes. Each individual node in the road network represents a separate optimization problem under this model. Accordingly, the calculation of the whole hazard area diverts to the risk estimation of each node in the area. In that case, the areas that may face the most transportation difficulties during an evacuation will be identified.

In the CCM, for a given root node and specified cluster size (the maximum of node count, which is the approach to limiting evacuation cluster size) in nodes, there exists the critical cluster of nodes in a network that contains the root node and maximizes the BLD value. Figure 2 is part of the road network, which shows an example of how a critical cluster will come into being for a given root node. To simplify this example, we suppose that each node has a population of 1 and each arc has one lane in each direction. The maximum of node count for the critical cluster must be less than or equal to five nodes for this example. Node A is the root node, and the directions of evacuation exits are shown as red arrows. The nodes involved in cluster are labeled inside the red real lines. To find out the critical cluster of the node A, we should add the nodes of cluster of node A gradually till five nodes, and calculate the BLD value according to the different cluster.

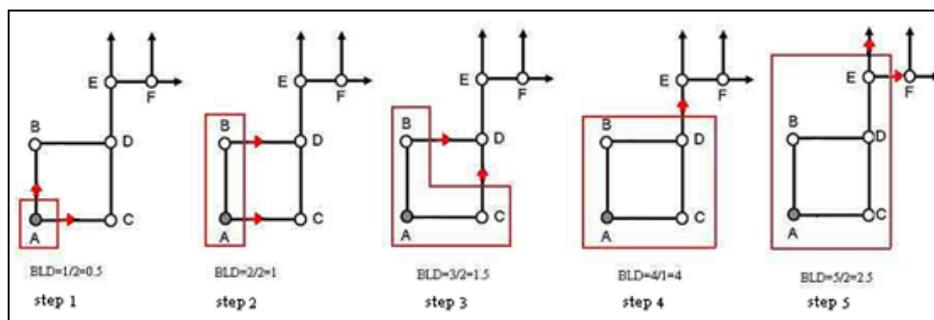


Figure 2 The forming of the critical cluster for a given root node

At step 1, when the cluster includes node A only, there exists two evacuation exit roads in the direction of B and C respectively, and the population is 1, according to the formula (1), the BLD is equal to 0.5; At step 2, when the cluster includes node A and B, there exists two exit roads in the direction of C and D, and the population adds to 2, here the BLD is 1; Like the process of Figure 2, the BLD value can be calculated till the cluster includes five nodes. Once the node count exceeds the maximum five, the calculation finished. By comparing the relationship between cluster size and the BLD value in Figure 3, it is known that the BLD gets its maximal value when the cluster includes four nodes, so the critical cluster for node A occurs at a cluster size of four nodes.

On the basis of the above example, we can evaluate the evacuation risk of the transportation network on the scale of entire urban areas by virtue of CCM.

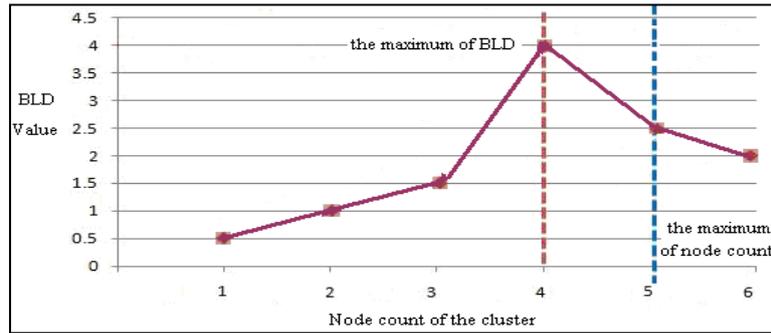


Figure 3 The relationship between cluster size and the BLD value

3.2 The Improvement to CCM

In CCM the population data and road exits attach themselves to the calculation of BLD as the unique attribute of the nodes, whereas there may be many public bus lines passing by the same road section in the public bus network. In other words, the C in formula (1) which described the capacity of the exit choice set changed as the increasing of public bus lines in the direction of the exit. The more the public bus lines in the same road, the more the road exit capacity. As a result, it is quite necessary to consider the different public bus line in the same road section when calculating the BLD value of the public bus network. It is the key to the reformative CCM.

The maximum bus line capacity demand for the bus stop is a new concept in this research, which shows the maximum bus line capacity demand determinate by the population nearby the bus stop. Here the BLD value which denotes the maximum bus line capacity demand for the bus stop should be calculated by the formula (2). Road section repetition coefficient, which can reflect the distribution of public bus lines in the same road, is introduced into the formula.

$$BLD = \frac{\sum_{i=1}^n P_i}{\sum_{j=1}^m L_j} \quad (N \leq 10) \quad (2)$$

Where, P is the total population centralized on a bus stop, N is the node count in the critical cluster with the bus stop as the root node, m is the exit road count of the critical cluster, and

L_j is the road section repetition coefficient in the direction of the exit road j, $\sum_{j=1}^m L_j$ is the bus

line capacity for all exit roads (from 1 to m). As for the choosing of N, there is no theoretical or empirical certain value and it depends on the network size and actual condition. Richard and Thomas selected six nodes as the limiting size in their example. Considering that there are more than 1,300 bus stops in Beijing public bus network, and by using the method of trial and error, the maximum of node count N for the cluster must be less than or equal to ten nodes for

this evaluation. Likewise, the higher the BLD value shows that the public bus line transport capacity of the bus stop can't meet the travelling demand. In that case, the accessibility of the stop is worse, and it is not convenient for the passengers to travel by bus. Evaluating the accessibility of a public bus network is just to take every stop as the root node, and identify the critical cluster for each node, at last calculate the maximum bus line capacity demand for each bus stop according to the reformative CCM.

4. ACCESSIBILITY EVALUATION OF PUBLIC BUS NETWORK

4.1 Data Processing

The population data was from the population density map of Beijing city, which was the production of spatializing the census statistical data of all streets in 2004 on the basis of the contemporaneous Beijing TM remote sensing image (Zhuo et al. 2005). The most involved step was to transform the population density data to the nodes data of public bus network of Beijing with the support of GIS technology. One approach to this process is depicted in Figure 4 as follows.

In the process as Figure 4, the generation of Thiessen polygon for each node and further subarea to the whole public bus network is the key of population data processing (Flowerdew and Green, 1992). Figure 5 is the population distribution map of Beijing public bus stops. By applying the zonal statistic command in ArcGIS, the population data for each bus stop can be obtained.

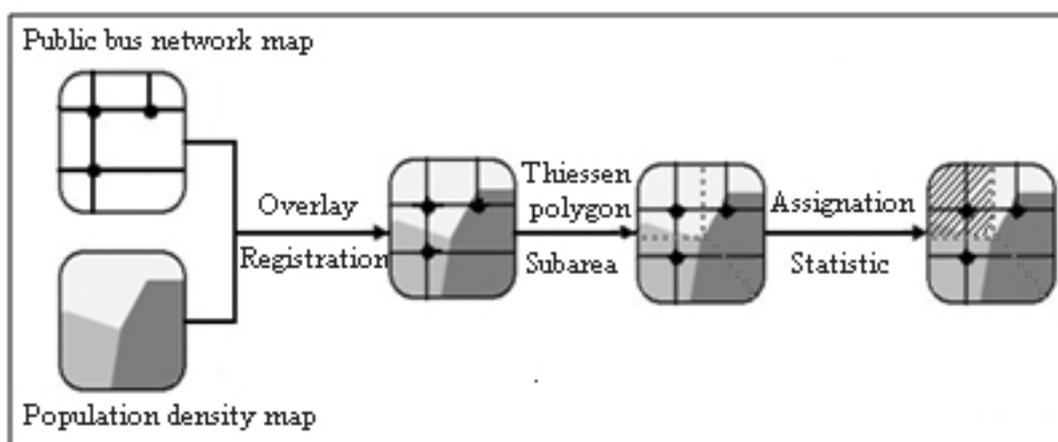


Figure 4 The process of spatial assignment of population data

The repetition coefficients between any two adjacent bus stops were calculated with the support of GIS and a spatial distribution map of the repetition coefficient was created. In Figure 6, there are five ranks in total. The thickness of the arc segment represents the rank of the repetition coefficient of public bus lines. The thicker sections denote that there are more different bus lines passing by the road sections. Moreover, the repetition coefficients of each bus stop can be obtained according to the corresponding relation between the bus line and the bus stop.

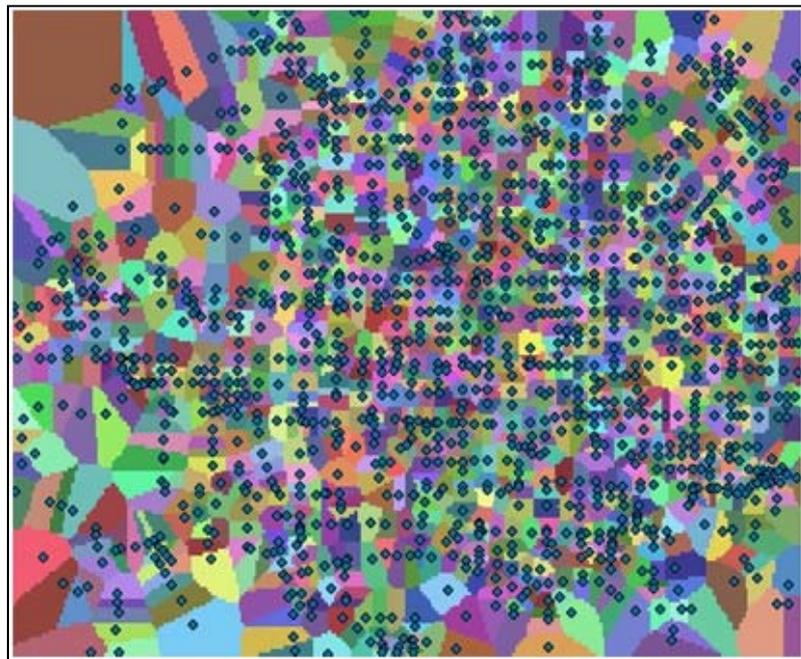


Figure 5 The population distribution map of the bus stops

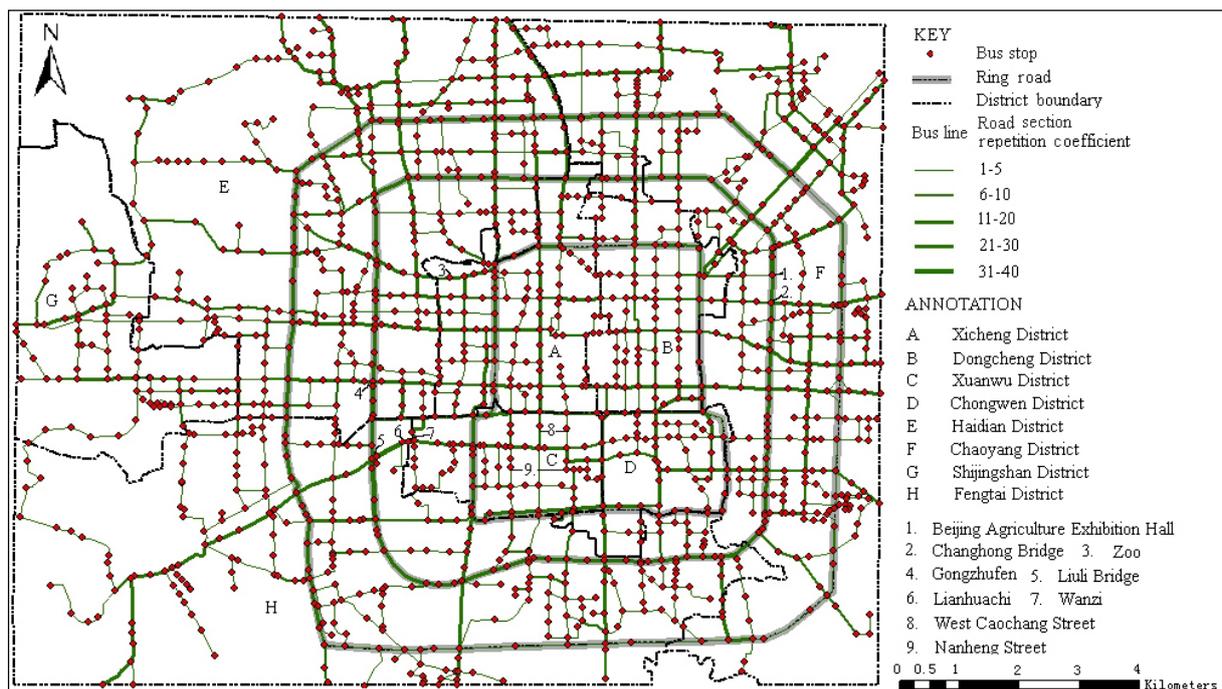


Figure 6 Road section repetition coefficients distributing of the public bus network of Beijing city

By applying the reformative CCM, the maximum bus line capacity demand of each bus stop can be calculated. To reflect the accessibility status of the road section in the public bus network, it is necessary to transform the maximum bus line capacity demand of the bus stops into the road sections. According to the corresponding relationship between bus stops and road sections in the public bus network, the transform can perform in terms of formula (3).

$$BLD_{AB} = \frac{BLD_A + BLD_B}{2} \quad (3)$$

4.2 Accessibility Evaluation of Beijing Public Bus Network

Figure 7 is the accessibility thematic map of the public bus network in Beijing by using reformative CCM and GIS technology. According to the statistical analysis and spatial distribution of the result, on the basis of former evaluation of the public bus network of Beijing(Wang and Li, 2007) and the real-time traffic information map issued by Beijing Traffic Management Bureau, BLD values are categorized to five grades to depict the road sections accessibility, the BLD value from 0 to 100 denotes the best accessibility; the BLD value in ranges of 100-200, 200-300 and 300-400 respectively denote a better accessibility, an ecumenical accessibility and a worse accessibility; when the BLD value exceeds 400, the accessibility of road sections will be the worst.

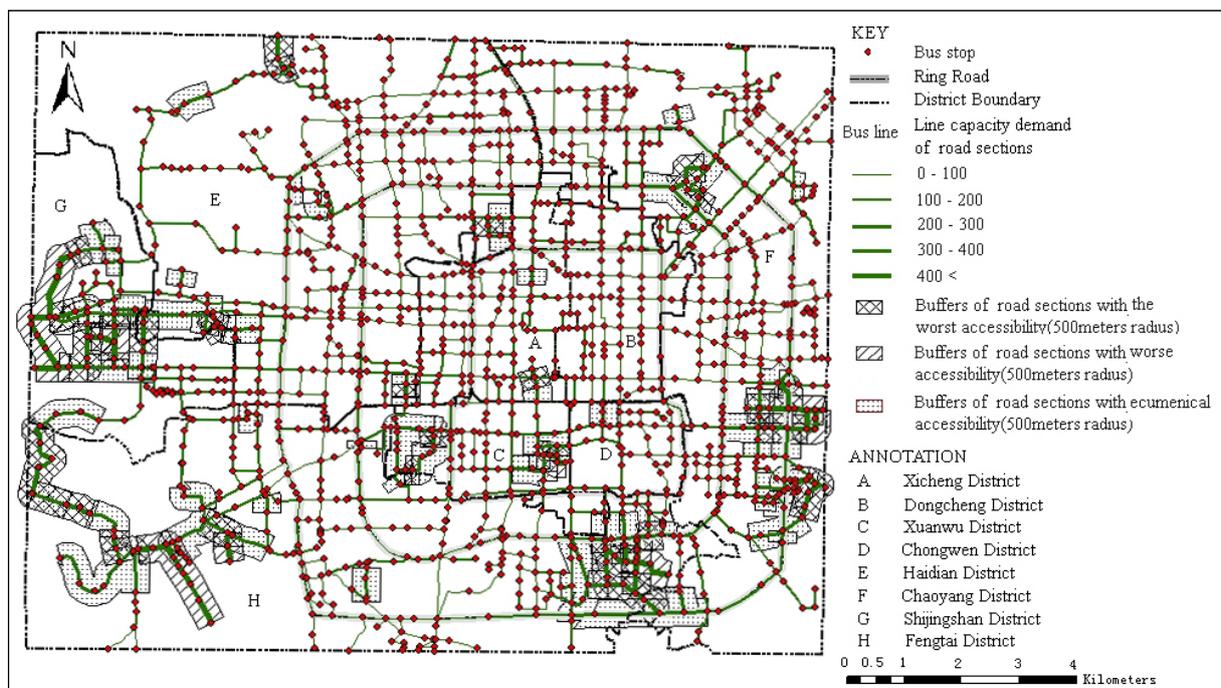


Figure 7 Accessibility thematic map of the public bus network of Beijing city

By analyzing the BLD value of all the road sections and the spatial distribution of the accessibility of Beijing public bus in Figure 7, the accessibility characteristic of Beijing public bus may be concluded as follows:

(1) The accessibility of Beijing public bus network in most roads sections is satisfying.

The average BLD value of Beijing public bus network is 135.8, and 70.0% road sections whose BLD value is less than the average value. In particular, there are 83.2% road sections whose BLD value is below 200, which show that the persons who live nearby such road

sections have the best accessibility or a better accessibility.

(2) The accessibility difference of dimensional distribution is obvious. The accessibility in the north central districts (Xicheng and Dongcheng districts) is better than the southwest districts (Shijingshan and Fengtai districts). The road sections with the worst accessibility and worse accessibility mainly distribute in the peripheral districts.

Table 3 shows that the average BLD value of the eight districts and the proportion of road sections with the worst accessibility and worse accessibility. The accessibility of Dongcheng district is the best and Xuanwu district is the worst of the four central districts. The accessibility of Shijingshan district is the worst and the average BLD value is up to 261.2, which shows that the persons who live in Shijingshan districts haven't a good accessibility in daily travel. In Chaoyang district there are the most road sections with the worst accessibility and worse accessibility, Fengtai district and Shijingshan district are in the next place. Chongwen district has no road sections with the worst accessibility and worse accessibility.

Table 3 Average BLD and the proportion of road sections of different BLD

Districts	Average BLD	Proportion of road sections with the worst accessibility	Proportion of road sections with worse accessibility	Population density(Permanent Population)(person/km ² , 2007)
Xicheng	107.4	1.1%	4.4%	21031
Dongcheng	105.6	2.1%	1.5%	21784
Xuanwu	136.3	9.5%	5.9%	29244
Chongwen	115.3	0.0%	0.0%	18099
Haidian	107.3	17.9%	11.8%	6533
Chaoyang	132.2	25.3%	35.3%	6594
Shijingshan	261.2	19.0%	14.7%	6475
Fengtai	169.3	25.3%	26.5%	5536

(3) The accessibility of the road sections with a high repetition coefficient is correspondingly good.

Table 4 shows that the average BLD decreased gradually along with the increasing of the road section repetition coefficient. The road sections with a repetition coefficient from 1 to 5, have the largest average BLD, and the average BLD value of road sections with a repetition coefficient more than 5, are all less than 100.

Table 4 Proportion of road sections and average BLD within different area of repetition coefficient

Road section repetition coefficient	Proportion of road sections	Average BLD
1 - 5	48.4%	199.0
6 - 10	19.6%	99.0
11 - 20	21.8%	69.2

21 - 30	9.3%	49.5
31 - 40	0.8%	41.3

By comparing the dimensional distribution of road section repetition coefficient in Figure 6, it is obvious that the road sections along the 3rd ring road with high repetition coefficient almost have the best accessibility.

Although the accessibility of most road sections is satisfactory, there still exist some problems. For example:

(1) In terms of overall condition of the central four districts, the public bus network in Xuanwu district is most in need of further improvement. Xuanwu district has the largest population density 29244 person/km², and the network density 2.29km/km² is largely less than the theoretical standard 3-4km/km². Moreover, the BLD value is the largest in the four central districts, although the repetition coefficient in Xuanwu district is largest.

As for the peripheral districts, the public bus network of Shijiangshan district needs to be improved most. Because Shijiangshan district not only has the worst accessibility but also some road sections with bad accessibility.

(2) Although the road sections with the worst accessibility and worse accessibility accounted for only 9.0%, people living nearby by such road sections will have a poor convenience when traveling by bus.

It is found that the repetition coefficient of the road sections with bad accessibility is all no more than 4. Table 5 shows the repetition coefficient structure of the road sections with the worst and worse accessibility. The road sections with the worst accessibility and worse accessibility which passed by only one bus line accounted for respectively 63.2% and 33.8%. The areas labeled in simple hatching and crosshatch in Figure 7 are the buffers of the road sections with the worst accessibility and worse accessibility with 500m radius respectively generated in ArcGIS. In these places people who want to travel by bus can choose only less than four public bus lines. The insufficiency of the public bus line is the main reason why the accessibility is lower in these road sections. Moreover, many blind areas exist such as West Caochang Street and Nanheng Street labeled in Figure 6.

Table 5 Repetition coefficient structure of the road sections with the worst and worse accessibility

Road section repetition coefficient	Proportion of road sections with the worst accessibility	Proportion of road sections with worse accessibility
1	63.2%	33.8%
2	29.5%	35.3%
3	7.4%	20.6%
4	0.0%	10.3%

From the point of supply and demand, the method to improve the accessibility condition of these road sections is to add or adjust the public bus line layout in these sections after reinvestigating the demand in the interrelated region. And the improvement need to stress in such road sections as those with the worst and worse accessibility in Chaoyang district and Fengtai district, and the road sections in Shijingshan district where the whole accessibility is the worst.

(3) The road sections with the best accessibility almost have high repetition coefficient. The average repetition coefficient of the road sections with the BLD value between 0 and 100 is 12. Just shown in Table 6, the proportion of road sections with repetition coefficient less than 5 is only 25.5%, in particular, the proportion for that less than 8 is 40.0%.

Although the lower BLD of the road sections denotes that the better accessibility, sometimes the real condition is not so optimistic. If there is high repetition coefficient, mass public buses may pull in synchronously at the same stop which will bring traffic jam and passengers' lag, in result accessibility descends. Especially the road segment with high repetition coefficient which lies in the ring artery and some entryways, which can directly impact the whole traffic condition once the road segment happen to emergency. For example, just as shown in Figure 4, some road sections near the Beijing Agriculture Exhibition Hall, Changhong Bridge, Zoo, and Gongzhufen, the road section repetition coefficients are more than 30. In particular, the repetition coefficients of road sections near Liuli Bridge, Lianhuachi, and Wanzi are up to 40.

Therefore, a further readjustment of public bus lines should be done. Furthersome step to improve the accessibility of these road sections is to reduce the road sections repetition coefficient, and take some operation and management means at the same time, such as enlarge the bus capacity, decrease the leaving frequency, especially in the rush hours.

Table 6 Proportion of road sections with different repetition coefficient

BLD	Proportion of road sections with repetition coefficient 0 - 5	Proportion of road sections with repetition coefficient 6 - 10	Proportion of road sections with repetition coefficient 11 - 20	Proportion of road sections with repetition coefficient more than 20
0 -100	25.5%	21.2%	35.4%	17.9%

5. CONCLUSION

The surface public bus has a great advantage when dealing with the change of urban transport demands. The paper has applied the reformative CCM and the GIS technology to evaluate the public bus network. The results accords with the liner appraisal and the application of CCM in accessibility assessment of public bus network in Beijing tests the flexibility of this method. The result helps in finding the existing problems in the public bus network and further complements the adjustment and optimization of the public bus network, to ensure the role of public buses.

The main accessibility characteristic of Beijing public bus may be concluded as follows: (1) The accessibility of Beijing public bus network in most roads sections is satisfying; (2) The accessibility difference of dimensional distribution is obvious; (3) The accessibility of the road sections with a high repetition coefficient is correspondingly good. Although the accessibility of most road sections is satisfactory, there still exist some problems. For example: In terms of overall condition of all districts, the public bus network accessibility of Xuwu and Shijiangshan districts needs to be improved most; The road sections with the worst accessibility and worse accessibility, and the road sections with the best accessibility all needs to readjust in different way.

Road section repetition coefficient and population are all important factors which impact the accessibility in CCM. In the paper the population data is from census, so it is not the real data people traveling, moreover, some floating population should be taken into consideration because Beijing is the capital of China and there are many floating population. And as the road section repetition coefficient increase to some degree, it may lead to accessibility descending, therefore a proper correction coefficient needs to introduce into the reformative CCM. Because of the speciality of public bus, the factors such as roads selection and intersection capacity, human behavior also need to be further discussion.

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