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Research Article

Research on the Impact Scope of Bus Stations Based on the Application of Bus Lanes

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Designation of bus lane means implementing the priority of urban bus system by monopolizing portion of the road resources, which has greater attraction for passengers and can impel the shift of bus passenger flow, thus impacting bus stations. With the aim of mastering the scope and extent of the impact accurately, the article firstly modified the bus station network and the bus transfer network. Furthermore, this paper proposed an algorithm for detecting communities in the improved bus transfer network to mine the transfer relations between any bus routes, and then, on the basis of the improved bus station network, designed a referable bus travel time and put forward an impact model to calculate the absolute impact and relative impact of bus lanes. Finally, the validity of the method was verified according to the actual investigation data. The results show the feasibility and effectiveness of the proposed approach that can obtain the impact of bus lanes on the stations. The research in this paper will be beneficial to the strategy of bus scheduling and also has guiding significance for the evaluation of existing bus lanes or further applications.

1. Introduction

In recent years, the number of motor vehicles owned increased sharply in many cities, which has a negative impact on public transportation. As a result, public transportation vehicles cannot run smoothly and the reliability of transit can hardly be guaranteed. For the lack of road resources and high costs of transport infrastructure, making use of the existing road sections to designate bus lanes has become one of the effective ways to implement public transportation priority. The data have revealed that after the application of bus lanes, compared with the previous mixed traffic, the speed of buses has been greatly increased, parts of them even twice as before [1]. Obviously, the travel condition of buses can be improved and the reliability of the public transport can also be guaranteed through the setup of bus lanes.

Generally speaking, when travelling by urban public transportation, especially commuting, the length of travel time is a prerequisite for passengers to select bus routes. However, the reliability of bus trips has fallen sharply with the incensement of car ownership in recent years; the uncertainty caused by the crowded mixed traffic environment may even make it more difficult for passengers to determine the actual arrival time. In this case, the reference value of travel time is relatively low. The greatest advantage that bus lane brings to public transportation is to guarantee the reliability of bus trips among some bus stations. In 1994, Abdel-Aty et al. [2] illustrated in a survey about route selection in Los Angeles that fifty-four percent of interviewees regard the reliability of travel time as the most or the second most important factor when they select their primary commute routes. One year later, Abdel-Aty et al. found in a further survey [3] that when the change of travel time is beyond the endurance of passengers, they would rather select a longer but more reliable route. Liu et al. [4] established a mathematical model to study the impact of travel time reliability on passengers' routes selection based on the travel data; they demonstrated that passengers prefer paying more attention to the lowering of variability during trips compared to shortening the travel time. Actually, we also learnt from a filed survey that some passengers are inclined to select bus lane for commuting because of its high reliability, even though that may not shorten their travel time [5]. In addition, according to a traffic survey in Shanghai [6], about seventy-eight percent of interviewees, especially commuters, take the reliability of travel time very seriously; they reckon that the reliability of travel time matters more than the length of travel time. It can be seen that the higher reliability and shorter travel time brought by bus lane will certainly attract some passengers, especially commuters, which can promote the changes in bus trips distribution and have an impact on bus stations. For the transit planners and schedulers, it is a long-term impact, even permanent. Thus, it is very important to understand how many bus stations are impacted and how much the impact is. In this way, we are able to carry out the planning work among the bus stations. On one hand, we can avoid road congestion caused by the shift of passenger flow; on the other hand, we can maximize the utility of bus lanes and improve the passenger transport efficiency of public transit system.

All the time, literatures on the impact of bus lane have been quite substantial. Kiesling and Ridgway (2006) used the cities like San Francisco as examples to discuss what benefits could be derived after the implementation of bus-only lanes [7]. Patankar et al. (2007) developed a microsimulation traffic model to research the impact of BRT dedicated lanes over existing mixed lanes on traffic and commuter mobility [8]; they concluded that the average bus speed is increased and travel time, delay time, and stop time had also significantly decreased. Sakamoto et al. (2007) had identified the effectiveness of the bus priority lane in Shizuoka City, Japan, as a countermeasure for traffic congestion, queue-length and jam-length measurements showed signs of easing of traffic congestion, and travel times of general vehicles were improved [9]. Arasan and Vedagiri (2010) studied the impact of provision of reserved bus lanes on urban roads based on a developed microsimulation [10]. Another research performed by Surprenant-Legault and El-Geneidy evaluated the impact of adding a reserved bus lane on the running times and on-time performance of bus routes; the result showed that reserved lanes had a substantial effect on both service reliability and on-time performance [11]. Tse et al. (2014) studied the safety implications in roads with the setup of bus lanes [12]. Truong et al. (2015) investigated the operational effects of bus lane combinations to establish whether multiple bus lane sections create a multiplier effect in which a series of continuous bus lane sections creates more benefits than several single-lane sections; the results confirm that there is a multiplier effect, so bus travel time benefits and general traffic travel time disbenefits are proportional to the number of links with a bus lane [13]. Bus lanes with intermittent priority (BLIP) were studied by Chiabaut and Barcet (2018); they have demonstrated the strategy of a real-field in Lyon, France, and evaluated the impacts on bus systems performance to show that BLIP can be a promising strategy [14]. The literatures above are mainly divided into two categories: one is the impact on transit operations; the other is the impact on traffic flow. However, less attention has been paid to the bus stations. Actually, the impact on stations can be reflected in the changes of passenger flow in and among corresponding bus stations.

To this end, the paper mainly aims at exploring the impact of bus lane on bus stations. Here, it should be noted that current research suggests the transit network is a typical complex network [15]. Bus stations and relations among them can be studied through the structure of networks. Therefore, it is reasonable to be studied from the perspective of network based on the research content of article. In addition, community structure [16] is an important characteristic of complex network. Nodes in community are tightly connected and connections between communities are sparse. Elements in networks can be clustered by using a rational method of detecting communities. Inspired by the above literatures and ideas, this paper proposes an algorithm to explore the transfer relations through bus transfer network; thereupon we are able to get some sets of bus stations that may be impacted by bus lanes and finally develop an impact model to figure out the accurate impact scope of bus lanes on the stations.

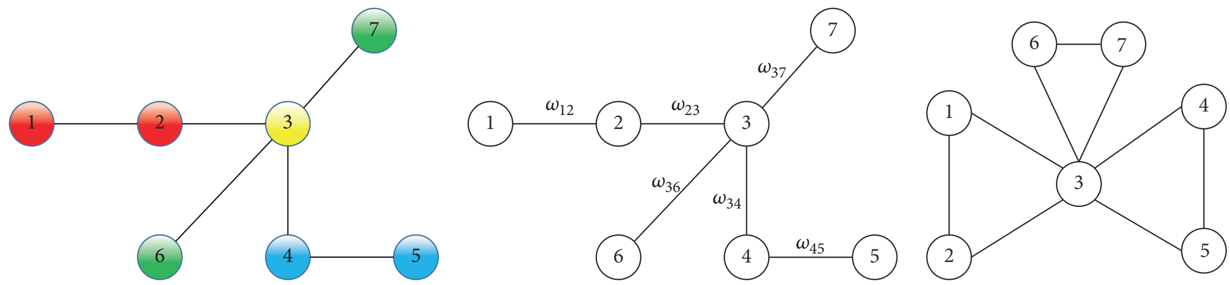
2. Public Transit Networks and Topology

2.1. Methodology. To analyze the properties of public transit networks which are composed of stations and routes, one should start with a proper definition of network topology. Traditionally, the space-L and space-P representation models are widely used [15]. In the space-L network, nodes represent bus, tramway, or underground stations, and an edge connects any two nodes if these two stations are adjacent in at least one common route. Nodes in space-P network have the same meaning with previous topology; however, an edge between two nodes means that there is a direct bus, tramway, or underground route that links them. From the purpose of this paper, on the one hand we need to learn the transfer times between different routes; on the other hand we need to calculate the travel time among stations. Therefore, space-P and space-L are both used for reference.

Each of the networks has its own characteristics. Bus station network not only retains the topology of original network, but also reflects the space and logic relation among stations; based on the bus transfer networks we can learn the transfer relations between different routes. These two networks are shown in Figure 1, in which numbers indicate the stations.

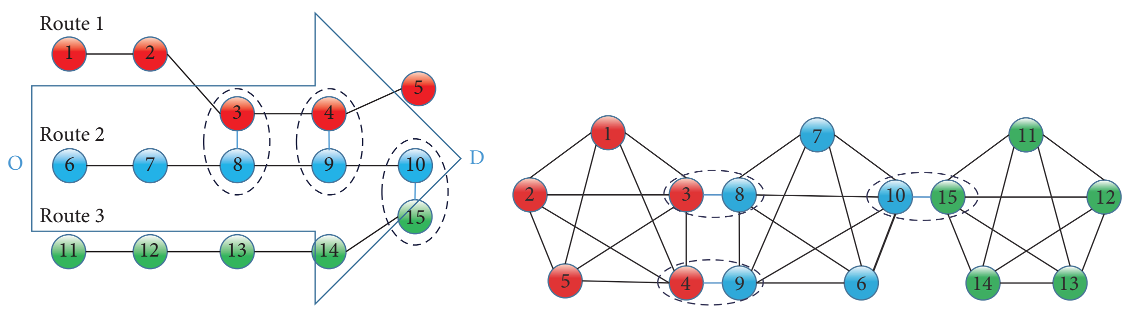
2.2. Network Improvement. In general, sometimes there are no routes between two stations. However, the two stations are so close that people can travel between the two only by walking. As shown in Figure 2, if passengers want to get station 8 or station 10, they may get to station 3 through bus route 1 or get to station 15 through bus route 3 and then walk to station 8 or 10; these traffic routes are rational. However, if the bus station network is built in accordance with the original space-L topology, passengers have to select route 2 to reach destination, which may take a long time.

Considering the above analysis, we set the walking distance equal to 500 meters, with reference to literature [17]. That is to say, any two stations belonging to different bus routes should be linked in the improved bus station network, if the distance between the two is no more than 500 meters. On this basis, the bus transfer network must be adjusted



(a) Original network (b) Bus station network (c) Bus transfer network

FIGURE 1: (a) An original network is composed of three bus routes. The three routes are displayed in red for route 1, blue for route 2, and green for route 3. Station 3, colored in yellow, is a common station shared by three routes. (b) The corresponding bus station network. The variables floating on the edges are, respectively, RBTT between any two stations which will be explained in the following sections. (c) The corresponding bus transfer network.



(a) Bus station network considering walking (b) Bus transfer network considering walking

FIGURE 2: Sketch of bus networks considering walking.

accordingly, as shown in Figure 2(b). It is tantamount to set three new routes between stations 3 and 8, 4 and 9, and 10 and 15; each has only two stations. Obviously, because of these links, passengers can have a new transfer scheme.

Besides, for each route r in Figure 1(b), we set weight coefficients ω_{ij} $\{i, j \in r\}$ to indicate the referable bus travel time (RBTT) between stations i and j during peak hours. This paper holds that the RBTT is related to the Peak bus travel time (PBTT) and the corresponding transit reliability (TR). The PBTT t_{ij} $\{i, j \in r\}$ between any two bus stations i and j denotes the bus travel time in the road section from stations i to j, when the road section has the greatest saturation but not jam. The data of PBTT can be obtained through field survey, Traffic Management Bureau, or traffic flow theory [18]. R_{ij} is the TR of bus travel time from stations i to j; the acquisition method is to observe the number of days d when the bus running time t is equal to or less than t_{ij} within the total working days D of last month and then figure out the results following

$$R_{ij} = \frac{d}{D}\left\{t \le t_{ij}\right\}. \tag{1}$$

All historical data in (1) can also be obtained by field survey or Traffic Management Bureau. It is clear that $R_{ij} \in (0, 1]$.

This paper needs to analyze the impact degree of bus lanes through travel time. There are two reasons to use PBTT as the reference of bus travel time. (1) In the vast majority of urban expressways and arterial roads, the bus travel time is generally approaching or even exceeding PBTT during peak hours. (2) Bus lanes monopolize portion of the road resources to ensure bus priority; thus some of the vehicles are squeezed out to use other road sections, especially around the road sections that include bus lanes. As a result, the saturation of these road sections must be increased. In addition, the purpose of introducing TR is to analyze the probability that the road condition can meet the passengers' demand with recent historical data. The higher the value of TR, the more stable the traffic condition; otherwise passengers are more likely to select other routes. For the bus passengers, it is difficult to estimate the actual travel time; however, judging by historical experience it is feasible. Given the above, we can obtain RBTT as shown in

$$\omega_{ij} = \frac{t_{ij}}{R_{ij}}. \tag{2}$$

For example, if t_{ij} is 30 minutes. We can obtain the RBTT with different TR in 30 workdays according to (2); the results are shown in Figure 3.

As shown in Figure 3, from the view of passengers, RBTT is able to reflect the possible bus travel time in the corresponding road sections. It can be seen that if the TR is lower than 80%, it indicates the road sections being in congested state for at least two days in weekdays and being

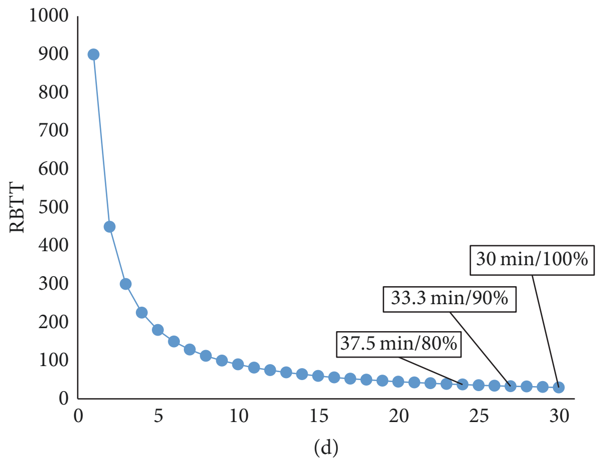


Figure 3: Result of RBTT with different TR in 30 workdays.

unable to meet passengers' requirements. The smaller the TR value than 80%, the more likely the commuters to abandon these road sections. This is in line with the reality.

Then, we can obtain the PBTT T_r of route r as shown in

$$T_r = \sum_{i,j\in r} t_{ij}. \tag{3}$$

A bus route r is composed of several relatively independent road sections. The corresponding time offsets will be accumulated in each section when buses pass by and the influence on reliability will be increasing. Therefore, the TR of bus route should be determined by the number of road sections between origin station and arrival station [19]. Assuming that a single bus route r is composed of n stations and $n-1$ road sections, thus the TR R_r of route r can be obtained as

$$R_r = \sum_{i=1}^{n-1} \sum_{j=2}^{n} a_j R_{ij}. \tag{4}$$

a_j is the reliability coefficient from origin station o to arrival station j as

$$a_j = \frac{j-1}{n(n-1)/2}. \tag{5}$$

In conclusion, we can obtain the RBTT W_r of route r as

$$W_r = \frac{T_r}{R_r}. \tag{6}$$

3. Network Analysis and Algorithm

This section will analyze the characteristics of passengers and bus stations which are impacted by bus lanes.

3.1. Network Analysis. There is usually more than one bus route between any two places in cities. As shown in Figure 4, five routes in different road sections can meet the travel demand between OD pair.

Routes 1, 2, and 4 connect with route 3, respectively, as the diagram displays; these are S_1-S_3-S_6, S_3-S_6, and S_7-S_6. Distance between routes 2 and 3 and routes 5 and 3 are nearly the same; however, route 5 has no connection with other routes. Routes 3 and 4 have common bus station S_5. The five routes have the same trip conditions before the setup of bus lanes. Passengers can select the nearest bus stations for trips. This article assumes that the bus lane set is in the road that contains route 3; therefore, route 3 will be the most attractive bus route between OD pair, obviously. Due to the attraction of bus lane, passengers tend to select the routes which are running in bus lanes to replace original routes partially or totally to better meet their travel demands. Generally, they can reach the stations in bus lane by walking or transferring through other bus routes and then continue their trips along the bus lane. However, it should be noted that changes in bus trips are not as flexible as changes in car trips. Not only are bus trips related to the locations of stations, but also they are restricted by the transfer relations between different bus routes. Moreover, bus lanes are usually available during peak hours. For example, most of the valid time of bus lanes in Beijing, Shanghai, and other cities is 7:00 to 9:00 and 17:00 to 20:00. It is clear that the more time the passengers spend to arrive at route 3, the weaker their willingness to select bus lanes.

Further analysis on Figure 4 is as follows.

(1) Passengers near stations S_5 and S_6 are able to select route 3, for they have the best transfer conditions. Passengers near stations S_1, S_3, and S_7 have to transfer one time to reach route 3, which has certain transfer conditions. Routes 2 and 3 have the same distance to route 5, but the passengers who took route 5 before can hardly transfer to route 3 due to transfer restrictions at station S9.

We know that bus transfer is a necessary step for passengers to change routes. However, the time of bus transfer can only passively depend on the arrival time of the previous bus route and departure time of the next one. The reliability of bus transfer is also close to the reliability of the bus running time of the two routes; thus bus transfer has a great uncertainty. The more the times of transfer, the greater the loss of bus travel time.

In addition, we can see from Figure 5 that if passengers only need to transfer one time to reach bus lanes it must happen on bus lanes. Bus lane can guarantee the reliability of travel time, so the bus transfer time will be also guaranteed when passengers transfer from the previous route. Based on this, the acceptability of bus passengers to transfer to bus lanes must be high; moreover, the commuting distance is not very long generally. Based on the characteristics of commuting in peak hours [20] and field research [5], we can see that the times of bus transfer are generally once at most in daily commuting. In view of the above analysis, we will no longer consider the passengers who need to transfer at least two times to reach the stations in bus lane.

(2) The stations S_1, S_3, S_5, S_6, and S_7 are all located in the impact scope of bus lanes, which have a certain probability to transfer. The probability depends on the improvement of travel time after the selection of routes in bus lanes.

In conclusion, we can sum up the characteristics of passengers who are impacted: (1) they reach the bus lanes

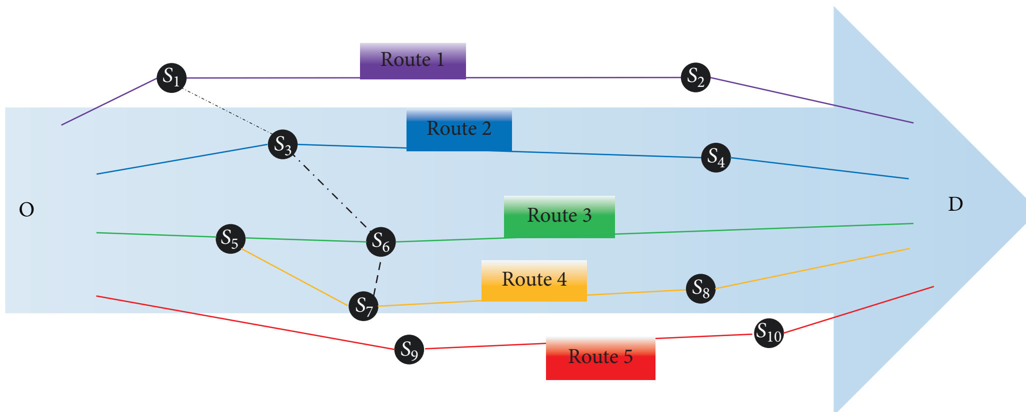


Figure 4: Sketch of impact on stations.

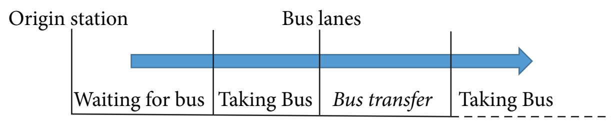


Figure 5: Sketch of transfer to bus lanes.

with high convenience; (2) travel time can be acceptable after the selection. Attraction of bus lane is also determined by the two conditions above.

We can divide the acceptable time described in condition (2) above into two types: one type is the travel time being less than before when passengers select routes that include bus lanes. In this case, we call it absolute impact (Abi) on the corresponding bus stations E_a, as follows:

$$E_a = T - A \cdot T_0 \quad \text{if } E_a > 0, \tag{7}$$

where T, T_0 are, respectively, the shortest bus travel time before and after the application of bus lane between OD pairs and A is the transfer factor.

The other type is the travel time being no less than before when passengers select routes that include bus lanes, but it can be accepted by passengers. In this case, we call it relative impact (Rei) on the corresponding bus stations E_r, as follows:

$$E_r = -E_a = A \cdot T_0 - T \quad \text{if } 0 \le E_r \le \eta \cdot T. \tag{8}$$

η is the endurance coefficient, which indicates the increase proportion coefficient of bus travel time that passengers can endure. It can also be obtained by field research. For example, the average travel time in research area is 45 minutes, the survey data revealed that most of the passengers can accept the new and more reliable trip which is no more than 60 minutes; then we can consider setting $\eta = 1/3$. We can believe that there will be a very high transfer probability of passengers under the absolute impact, while they may have a certain probability to transfer under the relative impact [3]. In this way, the traffic managers can get a more accurate determination of the impact.

We define transfer factor $A = 1+\ln(1+h)$ and h is transfer times [21]; it can be seen that the more the transfer times are, the greater A is. By substitution into (7)-(8), we can obtain (9)-(10) as follows:

$$E_a = T - [1 + \ln(1+h)] \cdot T_0 \quad \text{if } E_a > 0 \tag{9}$$

$$E_r = [1 + \ln(1+h)] \cdot T_0 - T \quad \text{if } 0 \le E_r \le \eta \cdot T. \tag{10}$$

Bus travel time consists of three parts, which are bus waiting time, bus running time, and bus transfer time. This paper assumes that the departure interval of buses is τ in peak hours; that is to say, waiting time in one bus route is τ. Therefore, the more the routes one can use, the shorter the the bus waiting time. Then by substitution into (9)-(10), we can obtain (11)-(12) as follows:

$$\begin{aligned} E_a = {} & \left(\frac{\tau}{n_0} + W_l\right) - [1 + \ln(1+h)] \\ & \cdot \left[\frac{\tau}{n_1} + \left(\frac{\tau}{n_2} + t'\right) \cdot h + t\right] \quad \text{if } E_a > 0 \end{aligned} \tag{11}$$

$$\begin{aligned} E_r = {} & [1 + \ln(1+h)] \cdot \left[\frac{\tau}{n_1} + \left(\frac{\tau}{n_2} + t'\right) \cdot h + t\right] \\ & - \left(\frac{\tau}{n_0} + W_l\right) \quad \text{if } 0 \le E_r \le \eta \cdot T, \end{aligned} \tag{12}$$

where τ can be obtained through transit planning, such as 2 or 5 minutes. W_l is the RBTT of route l. n_0 and n_1 are, respectively, the number of bus routes available at the origin stations in the trips with or without bus lanes. n_2 is the number of bus routes available at the transfer station; transfer times $h = 0$ or 1. t is the bus running time in the trips with bus lanes; t' represents the average transfer time.

Hence, the impact of bus lanes E can be obtained as follows:

$$E = \begin{cases} E_a & \text{if } E_a > 0 \\ -E_r & \text{if } 0 \le E_r \le \eta \cdot T \\ 0 & \text{else.} \end{cases} \tag{13}$$

E is expressed through bus travel time; the larger E is, the greater the impact is and vice versa. Thus, in this paper, a positive value indicates the absolute impact and a nonpositive value indicates relative impact.

Calculation procedure is described as follows.

(1) Obtain the improved bus transfer network N_P based on the method in Section 2.2 and then detect community structure in N_P to get transfer relations between any two bus stations. The set of stations θ is composed of stations that have zero or one time transfer relations with the stations in bus lanes.

(2) Obtain the improved bus station network N_L based on the method proposed in Section 2.2 and calculate the RBTT among stations.

(3) Designate the OD pairs and based on the Dijkstra or Floyd algorithm calculate the travel time of the shortest path P_{st} and the second-shortest path P_{ss} between the stations in θ and the destination. If bus lanes are not included in path P_{st} or P_{ss}, then set E of the station equal to zero and reselect others.

(4) If the bus lanes are included in path P_{st}, we can calculate the shortest bus travel time T_{st} based on (11). After this, we will change the corresponding weights in N_L to the bus travel time that existed before the application of bus lanes and recalculate the new shortest bus travel time T'_{st} and finally obtain the absolute impact E_a by $T'_{\mathrm{st}} - T_{\mathrm{st}} = E_a$.

(5) If the bus lanes are included in path P_{ss}, then we can calculate the relative impact E_r through the second-shortest bus travel time T_{ss} in P_{ss} and the shortest bus travel time T_{st}; that is, $T_{\mathrm{ss}} - T_{\mathrm{st}} = E_r$.

(6) Change back the weights of bus lanes that are modified in Step (4). Calculate and repeat until all stations in θ obtain an impact value E. The values are marked on the corresponding stations in N_L, according to (13). Finally, the accurate scope can be divided into two sets of stations; these are absolute impact (Abi) set θ_a and relative impact (Rei) set θ_r.

3.2. Overlapping Community Detection. According to the calculation procedure in Section 3.1, we first need to explore the transfer relations between bus routes. Three bus routes 1-2-3, 3-4-5, and 3-6-7 are shown in Figure 1(c), respectively. The three routes are three complete subgraphs. Obviously, passengers do not need to transfer when they travel inside a single complete subgraphs. Node 3 is an overlapping node in Figure 1(c); from that we can see that if there are two or more complete subgraphs having at least one overlapping node, passengers need to transfer at most once among the stations which belong to these complete subgraphs. For example, if node 3 is the overlapping node in both 1-2-3 and 3-6-7, passengers need to transfer once if they travel to node 1 or 2 from node 6.

It can be seen that the transfer relations can be explored based on bus transfer networks, so we need an appropriate algorithm to cluster the stations in the bus transfer network. Community can also be referred to as cluster or module, which refers to a set of objects with similar functions or same feature. Thus, community structure detection is a reasonable method for network-mining and element-clustering in complex networks. There are many algorithms to detect communities, according to whether a node belongs to multiple communities, which can be classified into two categories: one is to detect nonoverlapping communities, such as Spectral Bisection [22], Hierarchical Clustering [23], and GN algorithm [24]; the other is to detect overlapping communities based on Clique Percolation [25], Local Expansion and Optimization [26], or Fuzzy Community [27].

On the basis of the analysis above and the characteristics of bus transfer networks, it can be seen that the algorithm for detecting the overlapping community structure is reasonable. Therefore, based on Clique Percolation and Hierarchical Clustering algorithm, taking Figure 2(b), for example, we proposed the algorithm as follows.

Step 1. Obtain the improved bus transfer network N_P based on the method in Section 2.2; then get the adjacency matrix GP of N_P.

Step 2. Find out all complete subgraphs in N_P as follows:

(1) Select node i ($i = 1, 2, 3, \ldots, N$) as the initial node arbitrarily, where N is the total number of nodes. If node i has no neighbors, set $i = i + 1$ and restart the search.

(2) If node i has a neighbor node j ($j = 1, 2, 3, \ldots, N$; $j \neq i$), then we set i and j together to form a new complete subgraph G_1 which has two nodes. Continue to search new neighbors of node i; if there exist new neighbors that can form a new complete subgraph with G_1, then add them into G_1; otherwise start a new search, by analogy until no node can be added in. The process is shown in Figure 6.

(3) Set $i = i+1$ and continue to search new node, till $i > N$.

Step 3. Based on the Hierarchical Clustering algorithm, each of the complete subgraphs in Step 2 is considered as a new node (community). Then link any two nodes with an edge if the corresponding complete subgraphs have at least one common node. New graph will be formed in this way and repeat operation until all nodes agglomerate into one community. Process is shown in Figure 7. Six complete subgraphs are composed of fifteen nodes, that is, nodes 1 to 5, 6 to 10, and 11 to 15, besides nodes 3 and 8, nodes 10 and 15, and node 4 and 9, respectively. The six complete subgraphs are six communities, which are named "0-transfer-network." That is to say, passengers do not need to transfer when they travel within the six "0-transfer-network" communities, respectively. Similarly, the "1-transfer-network" is composed of two "0-transfer-networks," which represents at least one time to transfer when passengers travel within the "1-transfer network." Finally, the entire network agglomerates into one community as a "2-transfer network." That is to say, the transfer times are at most two when travelling in the whole network. In addition, we need to improve the "0-transfer-network" in the above process. As shown in Figure 7, the complete subgraph which contains only two nodes is processed as one edge. In this way, the three original bus routes have a reasonable transfer relation; otherwise, they would only be three separate routes.

Step 4. Confirm the result of community detection. As everyone knows, there are hundreds of bus routes in cities. This paper detects communities in bus transfer network based on agglomerative algorithm; moreover, we can intuitively

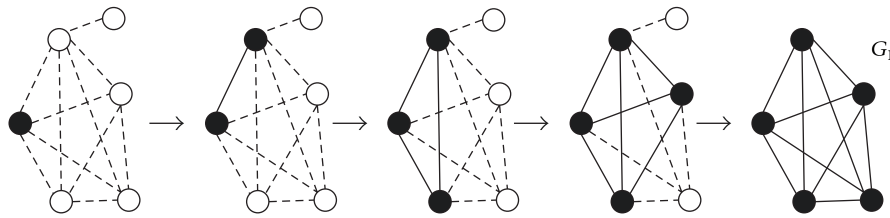


FIGURE 6: Search process of complete subgraph.

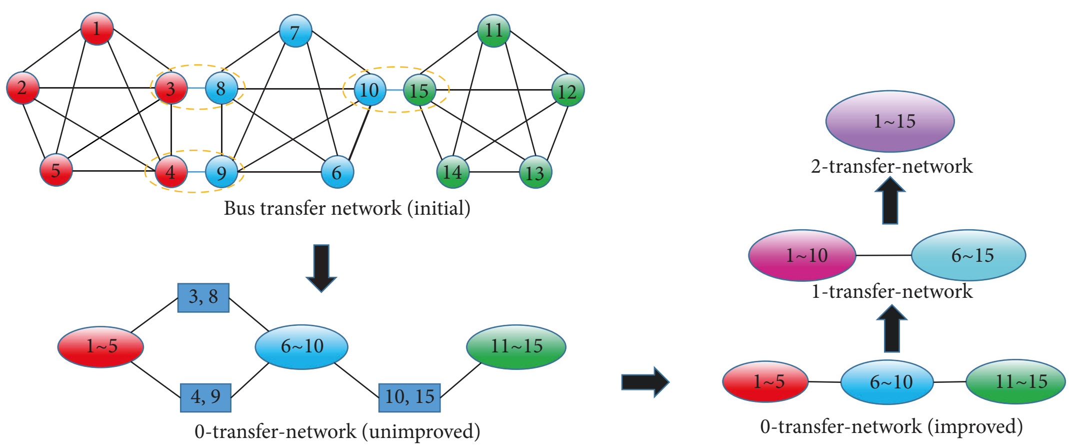


FIGURE 7: Community detection of bus transfer network.

observe transfer relations between any bus routes through tree structure based by modularity Q.

To obtain the best partition of network we should select a level or threshold to cut the tree. It can not only evaluate the quality of detection, but also observe the relations between routes. Newman-Girvan modularity [28] is proposed to evaluate the statistical significance of a given community partition. It is expected that better community partitions will have larger Q-value and vice versa. In reality, the Q-value is often between 0.3 and 0.7. The Newman-Girvan modularity is defined as

$$Q = \frac{1}{2M}\sum_{i,j}\left(a_{ij} - \frac{k_i k_j}{2M}\right)\delta\left(\sigma_i, \sigma_j\right), \tag{14}$$

where M is the number of edges in network and a_{ij} is element of adjacency matrix of network. k_i and k_j are the degree of nodes i and node j, respectively. δ is equal to one if node i and node j are both in the same community and zero otherwise.

Based on the Newman-Girvan modularity, a huge number of algorithms have been proposed at previous years. However, it can only find out the coarse community structure and cannot detect overlapping communities. Thus, Shen et al. [29] proposed new modularity as shown in

$$Q_c = \frac{1}{2M}\sum_{c\in P}\sum_{uv}\delta_{cu}\delta_{cv}\left(a_{uv} - \frac{k_u k_v}{2M}\right), \tag{15}$$

where P is universal set of communities. One node may belong to at least two communities in some networks; therefore we need to improve function δ in (15) and obtain (16) as follows:

$$Q_c = \frac{1}{2M}\sum_{c\in P}\sum_{uv}\alpha_{cu}\alpha_{cv}\left(GP_{uv} - \frac{k_u k_v}{2M}\right), \tag{16}$$

where

$$\alpha_{cu} = \frac{n_{cu}}{\sum_{c\in P} n_{cu}}, \qquad \alpha_{cv} = \frac{n_{cv}}{\sum_{c\in P} n_{cv}}. \tag{17}$$

n_{cu} and n_{cv} are the edges of node u and node v in community c, respectively. α needs to be satisfied as follows:

$$\sum_{\forall c\in P}\alpha_{cu} = 1, \quad 0 \le \alpha_{cu} \le 1, \ \forall c \in P, \ u \in V. \tag{18}$$

The physical significance of α is to determine the membership degree based on the link proportion inside and outside a community. Using (16), we calculate the value of modularity in Figure 7 as 0.3984, which shows that the modularity is obvious.

In summary, we can figure out the number of transfer times when passengers travel among the "N-transfer-network" and obtain the relations among any bus routes.

4. Application

In order to meet a huge amount of commuting demand between Tong-Zhou District and downtown Beijing, the Jing-Tong expressway has set bus lanes, which are about 8.6

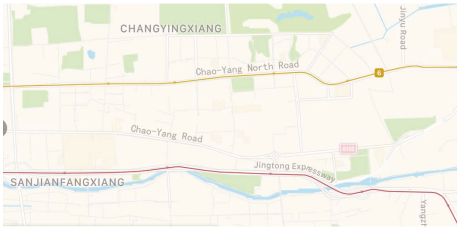


Figure 8: Five square kilometers of Jing-Tong expressway.

kilometers long. During morning peak, the commuters go into town from east side of Jing-Tong expressway. The road network is shown in Figure 8; commuting trips in Tong-Zhou District are mainly accomplished through Chao-Yang North Road, Chao-Yang Road, Jing-Tong expressway, Jian-Guo Road, and so on.

We take the above description, for example, to study the impact of bus lane and verify the results by field investigation.

(1) Determine Bus Transfer Relations in the Research Area. There are 218 bus stations and 35 bus routes of the road network in Figure 9 (data sources: http://beijing.gongjiao.com). We can obtain thirty-five "0-transfer-networks", nineteen "1-transfer-networks," and one "2-transfer network."

(2) Obtain the Set of Stations θ. There are many bus routes running in the bus lanes of Jing-Tong expressway, such as No. 626, No. 668, and No. 322. Refer to the results in step (1); it is concluded that the bus routes such as No. 615, No. 316, and No. 666 need at most one transfer to reach Jing-Tong expressway. This paper takes the OD pair from Tong-Zhou District to Guo-Mao CBD as the research object. In this way, we can get the set of stations θ that may be impacted by bus lanes.

(3) Calculate the Impact Value (E_a and E_r). There are no intermediate bus stations in bus lanes of Jing-Tong expressway; thus the bus stations to enter Jing-Tong expressway are transfer stations in morning peak. We can calculate the results based on the connection between the transfer stations and the stations in θ. In this way, the accurate impact scope of bus lanes θ_a and θ_r is obtained.

(4) Field Research and Results Validation. Take the stations in θ_a and θ_r as center, respectively. Field investigations are carried out in the residential areas which are in the coverage of stations. We collect the information of the residents' routes selections through questionnaire, to investigate whether there exist commuters who change their routes after the application of bus lanes and to verify the transfer proportion under different impact degrees, and then analyze the main impact factors. In this paper, we refer to literatures [17, 30] and set the coverage of bus station as a circular region with radius of 500 meters.

According to θ_a and θ_r, we selected three residential areas for investigation, that is, Liu-Zhuang, Tong-Dian, and Alpha, respectively, as shown in Figure 9(a). Bus stations in Liu-Zhuang and Alpha mainly belonged to the "1-transfer-network," and those in Tong-Dian mainly belonged to the "0-transfer-network." Tong-Dian is the nearest residential area to enter Jing-Tong expressway; Liu-Zhuang and Alpha each have the same distance to the entrance of Jing-Tong expressway; however, the number of bus routes is more in Liu-Zhuang than in Alpha.

We have taken statistics on the shift of passengers during the six months to fully understand the impact of bus lane. 585 questionnaires have been obtained in this survey; the valid number is 563, and the effective rate is 96.24%.

The shift proportion under the absolute influence (Abi) is shown in Figure 9(b). Obviously, from the second month, the transfer proportion is gradually stable, and the maximum shift proportion of Liu-Zhuang is 72%, Tong-Dian is 68%, and Alpha is 54%. Liu-Zhuang and Alpha are relatively far apart from the entrance of Jing-Tong expressway; however, the number of bus routes in Liu-Zhuang is more than Alpha and the travel time can be shorter by at least 20 minutes when commuters select the routes with bus lanes; thus Liu-Zhuang is more significantly impacted. Tong-Dian is the nearest residential area to the entrance of Jing-Tong expressway, so the shift proportion is the highest theoretically. However, the origin station named Ba-Li-Qiao in Tong-Dian is much crowded in morning peak; it is difficult for some commuters to get into the buses and this leads the shift proportion to be lower than Liu-Zhuang. This illustrates the necessity of enhancing public transportation service level. During survey, we also learn that the number of routes in Alpha is small, but some commuters can reach Jing-Tong expressway by bike with the development of bike-sharing in recent years. It illustrates that with more traffic resources that can be used in "1-transfer-network," the shift proportion will be higher.

The shift proportion under the relative impact (Rei) is shown in Figure 9(c). We noticed that, in the first three or four months, the shift proportion gradually increased and then began to stabilize. The reason is that the relative impact value E_r is gradually decreasing. Why? Because part of the road space is exclusive for bus lanes and some of the vehicles are squeezed out to use other road sections during peak hours. As a result, the travel environment of buses in other road sections gets worse and some commuters have to select the routes which include bus lanes. The assumption can be confirmed through the changes in vehicle volume, as shown in Table 1.

In conclusion, after the application of bus lanes, bus stations must be impacted by the shift of passenger flow in bus network. The shift proportion under absolute impact is obviously larger than that under relative impact. However, the shift proportion under relative impact will be changed along with the service level of corresponding road sections.

5. Conclusion

In this paper, a quantitative analysis approach is designed for detecting the accurate impact of bus lane on the stations in transit network. It is not only reasonable, but easy to execute and it has the following advantages.

(1) Through finding the overlapping communities of bus transfer network, we can indicate the possible impact scope

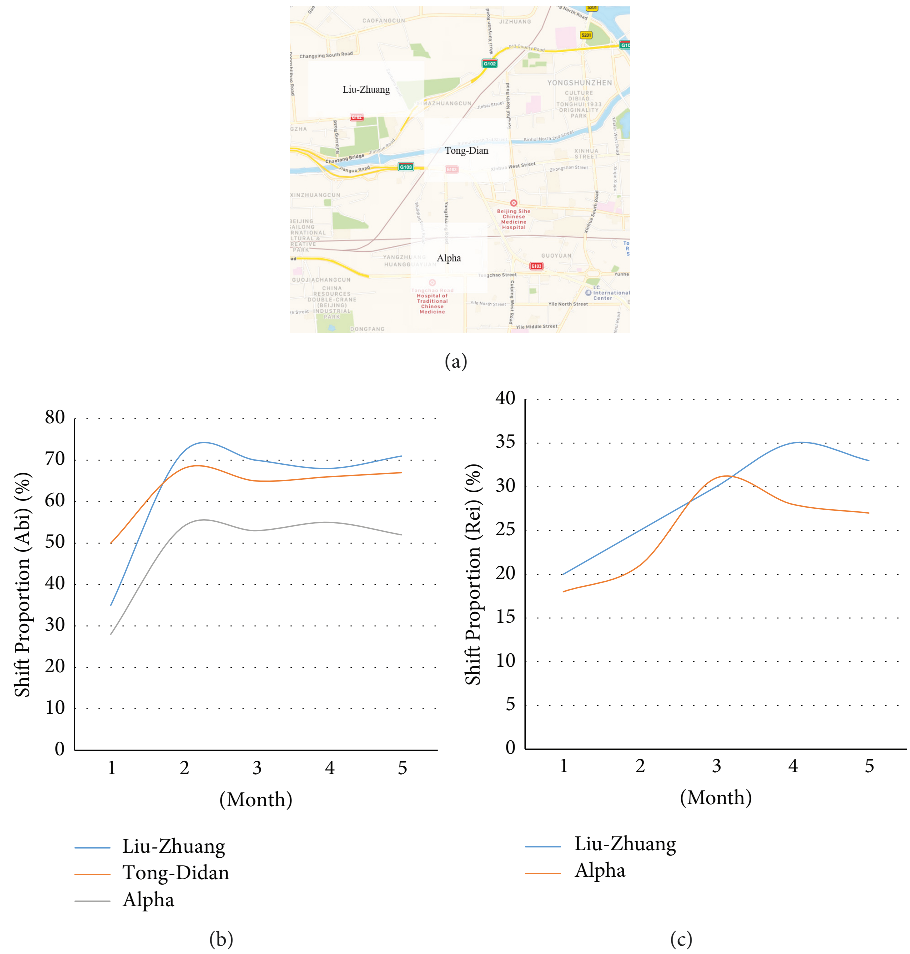


FIGURE 9: Research area and transition probability.

TABLE 1: Changes in vehicle volume after bus lane set in Jing-Tong expressway [5].

Time period	Vehicle volume Before (pcu/h)	After (pcu/h)	Change rate (%)
Morning peak	6488	4242	−34.6
Evening peak	5071	3233	−36.3

after the bus lanes are applied in any road section. In this way, we can try to avoid the expensive public transport investigation.

(2) The analysis shows that the interactions among bus routes are the basis of the impact of bus lanes. On the other hand, improving the level of Public Transport Services and the conditions of the transfer stations in bus lanes are effective measures to deepen the impact.

(3) The impact of bus lane on the stations can be divided into absolute impact and relative impact. Service level of the surrounding road sections may decline after the application of bus lanes and the relative impact could be changed on some stations. This situation can serve as a reference for traffic planners.

(4) From the point of view of networks, based on the status of widely applying bus lanes in many cities, the approach in this paper can also be used to study the impact of multiple bus lanes.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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