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Influence of Guangzhou Metro Line 6 on Transit Accessibility in Xunfengzhou District, Guangzhou

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ABSTRACT

The great changes of transit accessibility have taken place in Xunfengzhou district after the operating of Guangzhou metro line 6. Apply the travel time to measure the accessibility from the Xunfengzhou district to Gongyuanqian station before and after the metro line 6 operated. Analyze the changes of public transit accessibility and its reasons after metro line 6 operated by comparison. Completely explore the influence of subway operating on public transit system. Then infer the departure time in morning commute in Xunfengzhou district and portray the departure time isochrones map based on the isochrones measure to provide the guidance for the residents in Xunfengzhou district. The results show that the transit accessibility improved a great extent in Xunfengzhou district due to the operating of metro line 6. The subway operating is beneficial to improve the accessibility of public transit system.

Keywords: accessibility, isochrones, departure time, Xunfengzhou, travel time

INTRODUCTION

With the continuous expansion of city and the rapid increase of population, the conventional public transport system cannot meet the travel needs of urban residents in Guangzhou. The emergence of urban rail transit system supplement the deficiency of the conventional public transport system, and bear the transportation task of about half of the bus passengers. Now, there are metro line 1, metro line 2, metro line 3, metro line 4, metro line 5, metro line 6 etc. in Guangzhou. Among them, metro line 6 came into service on 2013.12.28. The origin station of metro line 6 is Xunfenggang station, which located in Xunfengzhou district. The destination is Changban, which located in Tianhe district. Metro line 6 can transfer with metro line 1, metro line 2 and metro line 5. The changes of the public transit system have taken place in Xunfengzhou district.

At present, the research is abundant for the impacts of new rail transit system on residents' travels. Richard etc. found that the Manchester subway system could enhance the residents' travel speed and frequency effectively (1). Haper found that the subway system could affect residents' travel mode significantly (2). Golias indicated that the metro system attracted at least 53% of the bus travelers (3). O'Sullivan etc. calculated the travel time of residents from origin station to CBD according to the data of multi-modal transit network, and then portrayed the isochrones map of travel time (4). Yu Wei etc. analyzed the accessibility changes of public transit network before and after the subway operated in Nanjing based on the complex network analysis (5). Huang Xiao-yan etc. comprehensively discussed the influence of the subway system on the public transport accessibility (6).

Accessibility is widely considered difficult to define but a critical understanding of transport issues (7). In the early time, the accessibility has been defined as 'the ease with which any land-use activity can be reached from a particular location, using a particular transport system' (8) (9). Later, a more concise definition of accessibility as 'the ease with which activities at one place may be reached from another via a particular travel model' (10).

A widely variety of accessibility measures has been developed over the past decades (11). Accessibility measures contain the spatial-temporal constraints model (12), the isochrones measure (13), the spatial separation measure (14), the utility model (15), the competition model (16), the network model (17), and the time-of-day-based analysis tool of transit accessibility (18). They also contain the Public Transit and Walking Accessibility Index (PTWAI) (19), and other GIS-based accessibility measures (20), etc. The isochrones measure is widely used in the analysis of the public transportation accessibility among them.

The isochrones used to refer to a line joining a set of points at equal travel time from a specified location (21). The isochrones map shows the travel times by public transport from the city center and can be used to assist the urban transport planning (22). Forer and Kivell's had been plotted the housemakers casts isochrones based on the space-time approach (23). O'Sullivan etc. proposed an approach to generate the public transportation isochrones automatically based on GIS (21). HU Ji-hua, etc. utilized the bus GPS data to portray the isochrones map in Tianhe, Guangzhou, selected the covered space of unit time isochrones as the metric of accessibility to calculate the time-space accessibility (24).

Although the isochrones measures have been used to analyze the accessibility in previous studies, there is relatively little research on accessibility that using the isochrones (lines of equal departure time) to help the resident's morning commute and to optimize public transit directly. There is no research analyze the accessibility changes in Xunfengzhou district after the metro line 6 operated.

In light of the related researches, this paper proposed the time backward inference method of resident's travel time and departure time for morning commute. The isochrones measure were used to portray the isochrones map (lines of equal departure time) of resident's morning commute via public transit from Xunfengzhou district to city center, Gongyuanqian station. Analyzed the accessibility changes in Xunfengzhou district before and after the operating of the metro line 6 in order to provide guidance for residents' working-trip (9:00 am) and for public transit optimization.

STUDY AREA AND DATA SOURCES

Study Area

Xunfengzhou district is a region which surrounded by Pearl River, it is about 9 square kilometers and located in the west of Guangzhou, that is a junction of Guangzhou and Foshan. Xunfengzhou district consists of three parts; they are Jincaozhou, Jinshazhou and Haibei area. Before the metro line 6 operated, the public transportation all centralized at the Jinshazhou Bridge, which connect Xunfengzhou district with the city center.

In order to achieve the connection and extension from Guangzhou city center to latitudinal direction and relieve the traffic pressure in Xunfengzhou district, Guangzhou metro line 6 operated on December 28, 2013. There are three stations in Xunfengzhou district, namely Xunfenggang station, Hengsha station and Shabei station. Passengers can take metro line 6 then transfer to metro line 5, metro line 2 or metro line 1 to the city center. Gongyuanqian station served as the city center in this study. Figure1 shows the Xunfengzhou district map.

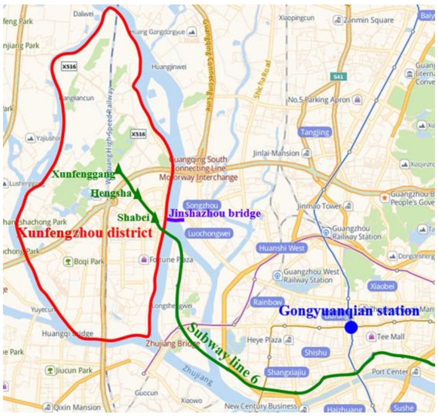

Figure1. *Xunfengzhou District Map.*

In order to cooperate with the metro line 6, part of the bus lines have been made some adjustments. The adjustment results as shown in Table 1.

Table1. *Bus Line Changes after Guangzhou Metro Line 6 Operated*

Changed lines	Newly added bus stop
Guang 12 bus (Xunfengzhou-- city center)	Huangli stop, Xunfeng stop, Hengsha stop
Guang 790 bus (Xunfengzhou bus line)	Huangli stop, Xunfeng stop, Hengsha stop
Guang 974 bus (Xunfengzhou bus line)	Xunfeng stop, Hengsha stop
Guang 276 bus (Xunfengzhou-- city center)	Xunfeng stop, Hengsha stop
Guang 283 bus (Xunfengzhou-- city center)	Huangli stop, Xunfeng stop, Hengsha stop
Guang 55 shuttle bus (Xunfengzhou-- city center)	Xunfeng stop, Hengsha stop
Guang peak express 30 bus (Xunfengzhou-- city center)	Xunfeng stop, Hengsha stop
Guang 789 bus (loop line; Xunfengzhou bus line)	Shabei stop (bus terminal)

DATA

The required data included the bus reporting data, the line and station data on the October 15, 2013, and those data with the subway schedule, the IC card data on July 8, 2014. The bus reporting data and IC card data are from the bureau of transportation management of city government, and the subway schedule data are from the subway company's web site, and the line and station data of bus and subway are from the internet map and field investigation. All the data structure as shown below.

Table2. *Ic Card Data Structure*

Fields	Description
Logcardid	IC card no.
Thtime	Swipe time
Lineno	Bus line no.
Busno	Bus no.
Linename	Bus line name

Table3. *Bus Reporting Data Structure*

Fields	Description
Buscode	Bus no.
Routecode	Bus line no.
Busstop	Bus stop name
Adtime	Arrival/departure time at bus stop
Adflag	Arrival/departure flag

Table4. *Line and Stop Data Structure*

Fields	Description
Line	Bus line no.
Stop	Bus stop name
Time	Departure time
Direction	Driving direction

Table5. *First-Run Vehicle Schedules*

Fields	Description
Line	Bus line no.
Stop	Bus stop name
Longitude	Bus stop longitude
Latitude	Bus stop latitude

The emphasis of the data processing is building the relationship of connection and transference between the different lines. Figure2 shows the public transit paths diagram. The yellow area in the figure represents Xunfengzhou district, the subway travel path (blue lines) represents the route which from the origin to the destination along the subway lines. The bus travel path (red lines) represents the route which from the origin to the destination along the bus lines. The Gongyuanqian station located in the one of the prosperous places of Guangzhou, and it is the important transfer station of metro line 1 and metro line 2, so it was selected as the destination station of this study.

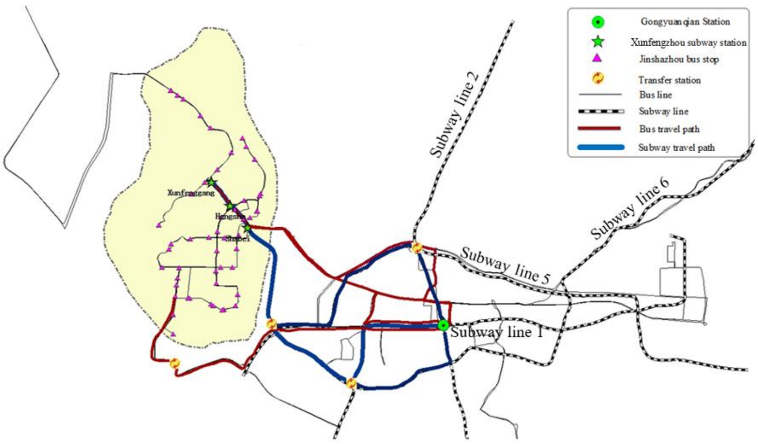

Figure2. *Public transit paths diagram.*

METHOLOGY

Departure time for morning commute refers to the time that residents must leave home for go to work on time. In order to obtain the departure time of residents, this paper use the time backward inference method which backward step by step based on the arrival time at stations, the complete travel time and the walking time. The isochrones of departure time in this paper refer to the lines of the positions with equal departure time in a study area, where residents will go to a same place (urban center, for example) to work on time (9 o'clock in the morning, for example).

In order to obtain the isochrones map with equal departure time in the study area, the first step is to calculate the vehicle departure time from the origin station (bus stop or subway station) in the area to the destination station (bus stop or subway station). Then, to calculate the walking time from home to the nearest origin station. Then subtract the walking time from the vehicle departure time to obtain the residents' departure time from home. Finally, the positions of equal departure time will be connected and the isochrones map is obtained.

The whole process contains seven steps, ①data acquisition and processing, ②walking time calculation, ③calculation of waiting and transfer time, ④calculation of vehicle travel time, ⑤whole travel time calculation. ⑥departure time calculation and⑦the isochrones generation. The flow chart as shown in Figure3.

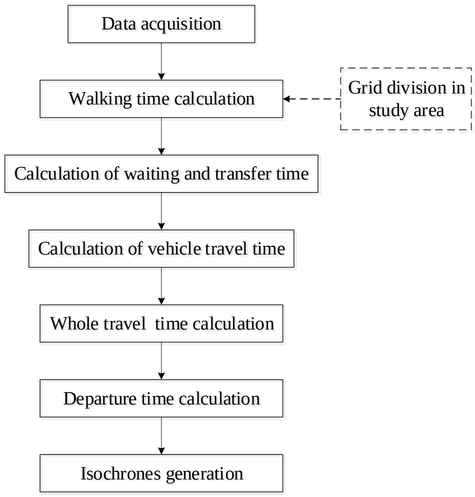

Figure3. *Flow chart.*

① Data acquisition and processing. The required data include bus-reporting data, IC card data, bus stop and subway station data in the study area, bus line data, subway lines and schedule data. To prepare these data and to establish the connective relationship between bus and subway for subsequent calculations.

② Walking time calculation. To divide the study area into regular grid according to the fixed distance (50 meters), then acquire the walking time from the center of each grid to all the bus stops in Xunfengzhou by Baidu API. Finally, choose the shortest walking time of each grid as the walking time of this grid.

③ Calculation of the waiting and transfer time. According to the previous studies, this paper choose half of the departure interval as the waiting and transfer time.

④ Calculation of vehicle travel time. The step contains two stages: route query, query of vehicles arrival time.

In the first stage, taken the bus stop (or subway station) in the study area as the origin station, and the station in the city center as the destination station. If there are both bus and subway in the area, the query results will be classified into four types: bus-only route, subway-only route, bus-subway transfer route and subway-bus transfer route, bus-bus transfer route may also exist in bus-only route, so does subway-subway transfer.

In the second stage, vehicle's arrival time query is to find all vehicles that can arrive at the destination station before working time (9:00 am), among them those arrival times at the destination are closest to the working time are selected. Then the vehicles' arrival time at origin station and their departure time are made clear.

A. For the subway-only route, calculate the arrival time at origin station according to the following formulas:

$$T_d = t_d + [\frac{T - t_d}{I}] \times I \tag{1}$$

$$T_{tr} = T_d - \Delta_t - I_{tr} \tag{2}$$

$$T_o = T_{tr} - \Delta_t - I_{tr} \tag{3}$$

$$T_{vt} = T_d - T_o \tag{4}$$

Where T is working time (9:00 am in general). T_d is the arrival time at the destination station. T_{tr} is the arrival time at the transfer station. T_o is the arrival time at the origin station. I_{tr} is the transfer time or berthing time. t_d is the arrival time at the destination station of the first train. I is the departure interval. and Δ_t is the travel time, T_{vt} is the vehicle travel time.

B. For the bus-only route, if there is no transfer happened, query the bus reporting data to obtain the arrival time at each origin station. If there exists transfer, the method is similar with the type A.

C. For the bus-subway route, firstly determine the arrival time at transfer station of the latest train according to the type A, then determine the arrival time at origin station of the latest bus according to the type B.

D. For the subway-bus route, firstly determine the arrival time at transfer station of the latest bus according to the type B, then determine the arrival time at origin station of the latest train according to the type A.

⑤ Whole travel time calculation. That is the sum of walking time and vehicle traveling time.

⑥ Departure time calculation. Using the reporting time of latest vehicle at destination station (before 9:00) minus the whole travel time to obtain the latest departure time.

⑦Isochrones generation. Finally generate the isochrones by connecting the positions with equal departure time and exhibit on the Arc map.

RESULTS

This research calculated the whole travel time and departure time from Xunfengzhou district to Gongyuanqian station before and after the subway operated based on the method and data above. The assumption of working time is 9:00 in the morning.

First, to calculate the complete travel time of every grid cell. The study area is divided into 9537 grid cells, the size of each cell is 50 meter multiplied by 50 meter, and each cell has two complete travel times and departure times, that subway operating before and after respectively. Figure4 is the statistical results of the data by subtracting the complete travel time of a grid cell before subway operating from that after subway operating of same cell. It can be observed that after the metro line 6 operated, the maximum decrease of complete travel time is 3300seconds (55 minutes), and the minimum one is -700 seconds (that is, an increase of 12 minutes). In general, there is an average decrease of 18 minutes.

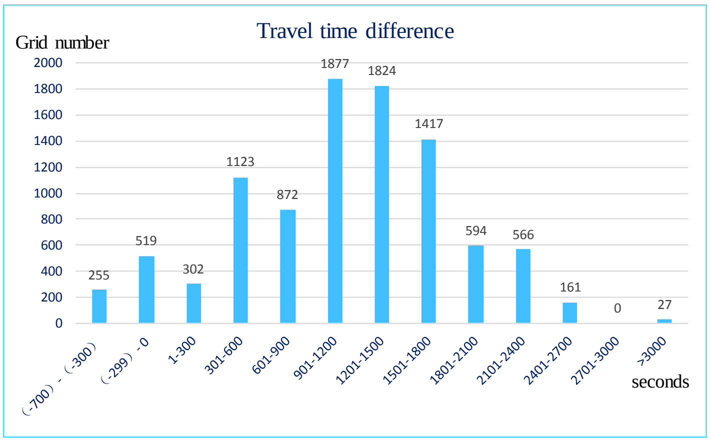

Figure4. *Travel Time Difference*

Figure5 shows the general characteristics of travel time changes. As can be seen from it, the complete travel time of 92 percent grid cells is reduced, of which 48 percent is reduced more than 20 minutes, and that of 14 percent reduced more than 30 minutes. The results show that the most regions' accessibility are improved to a certain extent after the operating of metro line 6, some regions are improved obviously.

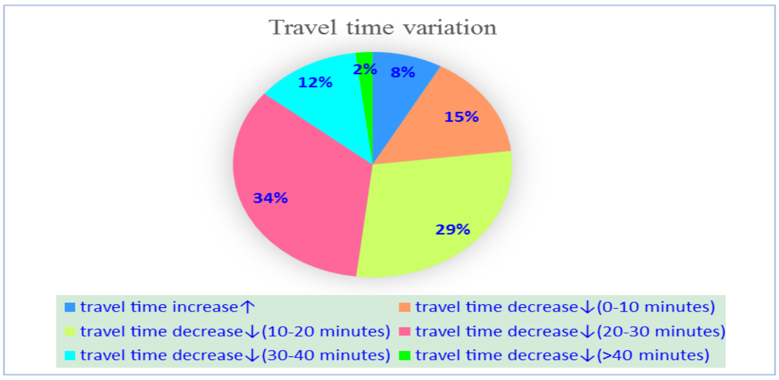

Figure5. *Travel time variation.*

Then the travel time of each grid has been shown on the arc map to show the accessibility variation intuitively. For the convenience of analysis, Xunfengzhou district has been divided into 4 zones, they respectively are Jincaozhou (zone 1), Jinshazhou (zone 2), Xunfeng Mountain (zone 3) and Haibei area (zone 4). As shown in the follow figures. Figure6 shows the travel time before (left) and after (right) the metro line 6 operated. Figure7 shows the corresponding isochrones map.

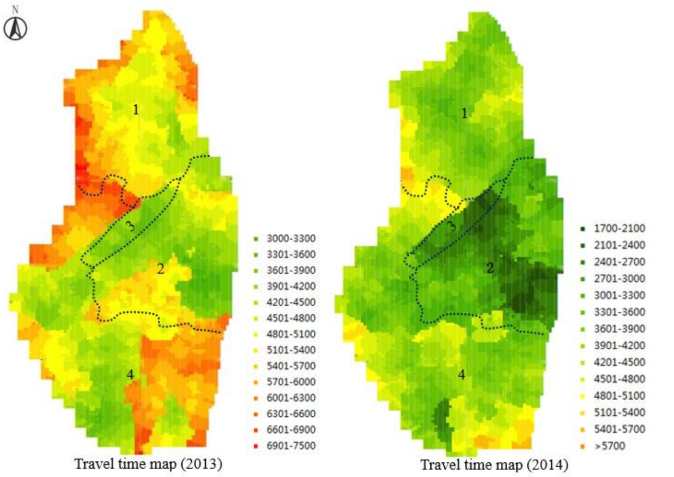

Figure6. *Travel Time Map*

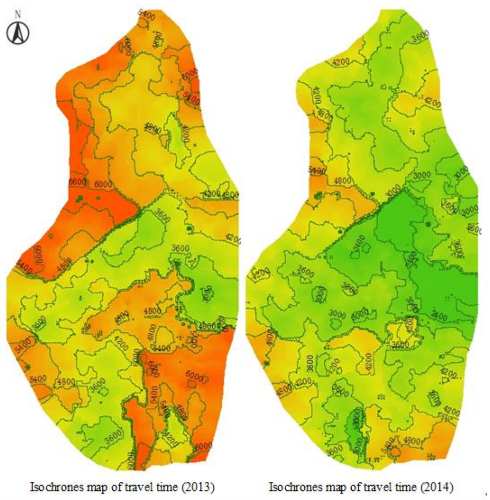

Figure7. *Isochrones map of travel time*

The travel time before the metro line 6 operated as can be seen on the left of Figure6. Overall, the travel accessibility of zone 2, zone 3 and about half of zone 4 are higher than other areas. The transit accessibility of the rest part is relatively lower. In zone 1, the travel time of most grids are between 3600s and 4800s, the travel time of rest grids are between 5100s and 7500s. In zone 2, the travel time of grids are between 3000s and 6300s. In zone 3, the travel time of grids are between 3000s and 4500s. In zone 4, the travel time of the northwest grids are between 5400s and 6900s. The travel time of the southeast grids are 4200s and 7500s. The travel time of the rest grids are between 3500s and 5000s. The corresponding isochrones map as can be seen on the left of Figure7.

The travel time after the metro line 6 operated as shown on the right of Figure6. Overall, the accessibility of zone 2 and zone 3 are higher. These regions are the subway stations surroundings area. In zone 1, the travel time of grids are between 3000s and 5000s. In zone 2, the travel time of most grids are between 1700s and 3600s, the travel time of few grids are between 4200s and 4600s. In zone 3, the travel time of most grids are between 1700s and 3000s, the travel time of few grids are about 4800s. In zone 4, the travel time of the upper left and lower right corner grids are between 4500s and 5400s, the travel time of the rest grids are between 2400s and 4000s. Similarly, the corresponding isochrones map as can be seen on the right of Figure7.

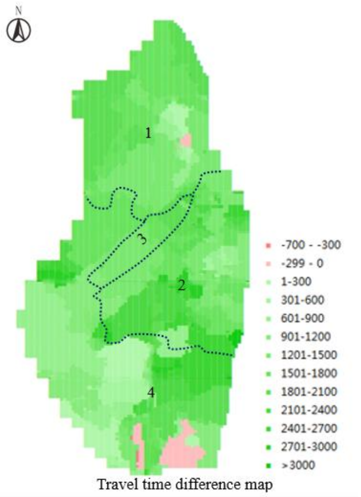

Figure8. *Difference Value Chart of Travel Time*

Figure8 shows the travel time difference. In addition, it also shows the improvement of accessibility after the metro line 6 operated. As can be seen from the Figure8, the accessibility of most regions improved, especially the regions which near the subway stations. Overall, the accessibility of zone 2, zone 3 and the most parts of zone 1 are greatly improved. Furthermore, the accessibility of the northeast part regions of zone 4 are also greatly improved. In zone 1, the travel time of most grids reduce between 600 seconds (10 minutes) and 2400 seconds (40 minutes), the travel time of red grids increase about 5 minutes. The result shows the accessibility decreased. From here to destination, the travel route is Guang 231 bus transfer metro line 2, so the operating of metro line 6 has little influence on accessibility here. Therefore, the reason may be that the data are not accurate. In zone 2, the travel time of grids reduce 800 seconds (13 minutes) and 3200 seconds (53 minutes). In zone 3, the travel time of grids reduce between 900 seconds (15 minute) and 1800 seconds (30 minutes). In zone 4, the travel time of most grids reduce between 300 seconds (5 minutes) and 3000 seconds (50 minutes), the travel time of the red grids increase about 5 minutes or 10 minutes. For the red grids of zone 4, the accessibility also decreased. From here to destination, the travel route is Guang 205 bus transfer metro line 1 before the metro line 6 operated. After that, the travel routes are Guang 205 bus transfer metro line 1 or Guang 789 transfer metro line 6 then transfer metro line 2. The travel time of two routes nearly, so the travel time increased (accessibility decreased) is normal based on the reporting data.

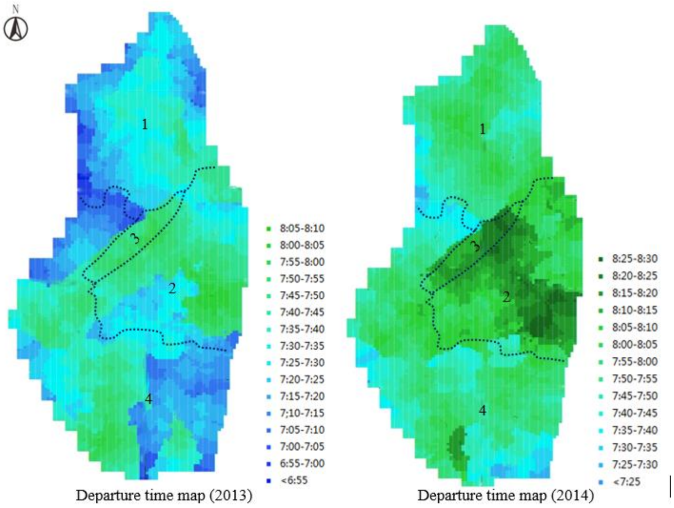

Figure9. *Departure Time Map*

Figure9 shows the latest departure time before (left) and after (right) the metro line 6 operated to provide the guidance for resident's working-trip. The blue the deeper, the earlier the departure time; the green the deeper, the later the departure time. The departure time and travel time closely related. The two type maps are similar. That is the travel time longer, the departure time earlier, the travel time shorter, the departure time later. The specific departure time as can be seen from the Figure9.

Figure10 shows the isochrones map of departure time before (left) and after (right) the metro line 6 operated.

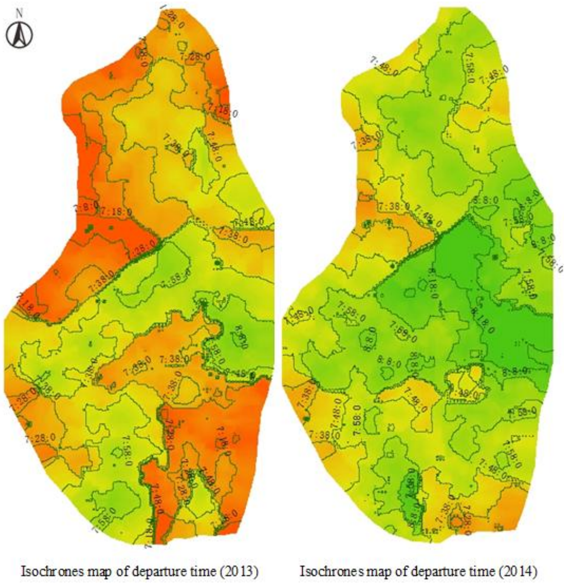

Figure10. *Isochrones map of departure time*

CONCLUSION

In this paper, a time backward inference method of residents' departure time for morning commute was proposed, and the improvement by the subway on the accessibility of Xunfengzhou district was evaluated. Based on the bus reporting data and subway timetable, the departure times of all locations in the study area from home to office were calculated using the proposed method under the constraints that residents must go to work on time.

The method was implemented from Xunfengzhou district to Gongyuanqian station. The common maps and isochrones maps were portrayed before and after the metro line 6 operated. On the result maps, the travel time and departure time for morning commute of all places in the district can be found, so it can provide specific guidance for resident's working-trip. Additionally, it can be found that the accessibility of most parts of Xunfengzhou district is obviously improved, but the accessibility of a few parts is not improved or even decreased, the reason may be that the data are inaccuracy. Besides, this research only use morning-peak data one day and there may be a deviation. Overall, these findings demonstrate that the accessibility greatly improved after the metro line 6 operated, meanwhile the approach can provide a useful guidance to help passengers for their morning commute and planners for improving district accessibility.

Further research includes applying the method to more work times and more destinations to evaluate the accessibility at different districts based on more data sources.

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