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RESEARCH PAPER

A Calculation Method and Its Application of Bus Isochrones

HU Jihua[1,2,*], CHENG Zhifeng[1,2], ZHONG Guangpeng[1,2], HUANG Ze[1,2]

1 Research Center of Intelligent Transportation System, School of Engineering, Sun Yat-sen University, Guangzhou 510275, China
2 Guangdong Provincial Key Laboratory of Intelligent Transportation System, Guangzhou 510006, China

Abstract: Bus isochrones indicate the maximum scale of bus system can extend during one time interval. A calculation method of isochrones is proposed in this paper and it can be applied to the analysis of public transport accessibility. The travel process by bus is analyzed and divided into five parts: walking to the bus stop from departure, waiting for buses, boarding buses, transfer and walking to the destination. Specific calculation methods of time cost are proposed for each part, respectively. Then, the isochrones are by the grid method and the inverse distance weighting method. The bus GPS data of Guangzhou, China is used to draw the isochrones maps and to demonstrate the Tee mall. Furthermore, the space-time accessibility is measured in the covering area of a unit time isochrones and the accessibility differences of different directions are then analyzed through profiles.

Key Words: urban traffic; bus; isochrones; spatiotemporal process; travel time; space-time accessibility

1 Introduction

Isochrones are a kind of contour with unit travel times, which is used to refer to a curve joining a set of points with equal travel time from a specific location. Bus isochrones are curves that are formed by the points with the same travel time by bus, and they clearly indicate the maximum distance that travelers can reach by the bus network within the given time duration. Thus, they are widely used to evaluate the level of bus service, urban space–time accessibility by bus, etc. Existing researches on the isochrones and transportation mainly focus on travel planning and space–time accessibility[1], and urban development[2,3], and so on. Bhat *et al*.[4] introduced travel time into the cumulative-opportunity model, in which the maximal time thresholds of different activities varied accordingly to their types. However, the maximal time thresholds were estimated values; they had no field data support. To overcome the defects of setting the threshold arbitrarily, Bertolini *et al*.[5] attempted to improve the rationality of isochrones by adding the traffic status (including congestion, slow, and smooth, etc.) factors during computation. However, they did not fully analyze the spatiotemporal process of the individual's travel, and the time costs of accessing the transport system (for instance, that of walking to a bus stop) were ignored. O'Sullivan *et al*.[6] proposed an automatic generation method of isochrones of public transportation using a geographic information system (GIS), which is based on a multi-travel-mode traffic network, including bus, metro, and light rail. This method could generate isochrones of public transportation with certain precision, but the time-varying characteristics of the bus network were neglected.

Isochrones are a kind of presentation of spatiotemporal constraints defined in time geography. Hägerstrand identified three types of spatiotemporal constraints to depict the restrictions of individuals' behavior, which are capability constraints (limitations to the number of activities a person can accommodate within a given time frame), coupling constraints (the need to be in particular places at particular times), and authority constraints (the times of operation of given activities, or of components of transport infrastructure/service)[7–9]. He designed two basic tools (space–time path and space–time prism) to describe those three types of spatiotemporal constraints and individual activities. Only in a specific time and space constraint can be

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*Corresponding author. E-mail: hujihua@mail.sysu.edu.cn

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significant for an individual's activities[10], so the individual's activities have limited scope in space and time. The bus is one of the most important travel modes in many cities, and its service quality has a significant influence on the maximum area that an individual can access. Space-time prisms determine the locations that can be accessed by given fixed space-time constraints, and bus isochrones can be seen as the projection of the space-time prism of an individual's activities by bus on a two-dimensional geographic plane, and their covered area indicates the variances of accessibility. Therefore, bus isochrones can be a tool for evaluating urban space-time accessibility.

As the rapid development of intelligent transportation systems (ITS) takes place, most buses in China have been equipped with GPS devices, and they can collect bus GPS data (including position data and status data) in seconds, so data limitations of previous researches disappear. Based on the GPS data, this research proposes a calculation method for bus isochrones. Guangzhou, a big city in China, is the study area.

The remaining sections of the paper are organized as follows: In the next section, the travel process by bus is analyzed and divided into five parts. In section 3, a specific calculation method is given for each part and the total travel time is calculated. Using a grid method and the Inverse Distance Weighting method, the isochrones are obtained. In section 4, a case study of Tee Mall, a shopping mall in Guangzhou, is demonstrated using bus GPS data, and isochrones are applied to the accessibility measurement. The paper concludes with a mention of further application of the accessibility measures and possible future works in the final section.

2 Individual's travel by bus

An individual's travel by bus is a process whereby that individual moves to the destination from the departure point, mainly traveling by bus, and whose position changes continuously over time until the travel is completed, so the individual's travel by bus is a kind of spatiotemporal process. The process includes five parts—walking to the bus stop from the departure point, waiting for the bus, travel in the bus, transfer, and walking to the destination; among them, transfer is another process of waiting for the bus. The total travel time is a sum of the travel time of each sub-process; it is defined as:

$$T=\sum_{i}^{n}t_{r_i}+\sum_{j}^{m}t_{t_j}+\sum_{k}^{p}t_{w_k} \tag{1}$$

where t_r is the walking time from the departure point to the bus stop or from the bus stop to the destination, and t_j is the running time between two stops, and t_w is the waiting time for buses or the transfer time. And n is the number of times walking is involved, m is the number of times of travel in the bus, and p is the waiting or transfer times.

3 Isochrones calculation

According to the spatiotemporal process discussed previously, the input of isochrones calculation for the bus network includes the departure point, travel mode, and traffic conditions; the output is a smooth curve reflecting a spatial area that can be accessed by a particular trip in a given time duration. As Eq. (1) shows, except for the time spent in the bus, which can be calculated by GPS data, the isochrones calculation includes four parts—the calculation of walking time, that of waiting time for the bus, and that of the bus transfer time, and the generation of isochrones.

3.1 Walking time calculation

Walking time is the time taken when the individual walks from the departure point to the nearby bus stop or from a bus stop to the destination. Before his trip, an individual always makes a choice of the bus stop and the route. If an individual is not familiar with the bus network, he will not be able to find the optimal route, but he will choose the nearest bus stop to travel from/to. Accordingly, the nearest stop from the destination will be chosen and the bus route will be selected between these two stops. During the above process, fewer stops and transfers are the criteria for the bus line selection. Otherwise, the individual would be able to predict the total walking time and the bus travel and he will choose the right stop and bus line, and find the optimal path.

Limited in time and experience, most individuals are not familiar with entire bus network of a city, and they will prefer to choose the nearest stop to avoid unnecessary walking; so, we calculate the walking time from a departure point to its nearest stop. Fig. 1 depicts an example for finding the route between the departure point and the nearest stop. The entrance of the road network is denoted as A, and O is the location of the departure of a trip, and S is the location of the nearest bus stop. In Fig. 1, A is found firstly, then the shortest path between A and S is searched, therefore a walking time t_r:

$$t_r=(D_n+D_s)/v \tag{2}$$

where D_n is the distance between O and A, and D_s is the length of shortest path between A and S, v is the walking speed.

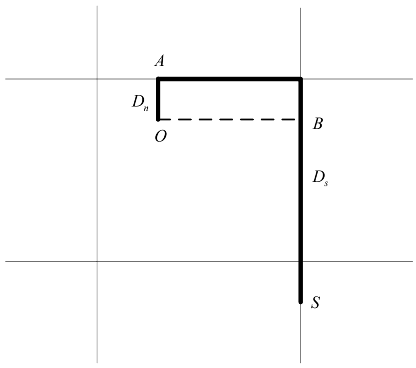

Fig. 1 Route between departure point and the nearest stop