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Transit accessibility measures incorporating the temporal dimension

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ABSTRACT

Transit accessibility should take transit timetable into account and be time-dependent. The reason is that the maximum passenger carrying capacity of a transit station is determined by the scheduled timetable. In addition, passengers always choose departure time according to their own need, which varies with time. Based on the traditional two-step floating catchment area (2SFCA) and gravity method, this paper proposes two new methods to evaluate transit accessibility. The proposed methods are implemented to evaluate the bus accessibility of Xiamen City, China. According to the local bus timetable, a typical workday is divided into three periods. Within each time period, bus travel supply-to-demand ratios by station are calculated and then aggregated into the traffic analysis zone (TAZ). The empirical findings show that fluctuations in travel demand and the passenger carrying capacity of bus stations in different time periods make the bus accessibility significantly differ throughout the city. They also show that bus accessibility based on the extended 2SFCA model are equivalent to that based on the extended gravity model, when the total demand is relatively lower than the total passenger carrying capacity of a bus station.

1. Introduction

Given that they always have finite resources and cannot afford car dependence in the long run, cities and regions shall have a competitive rather than a declined transit system. Compared to other transportation systems, the urban transit system could be distinct, most notably; it has a fixed timetable of operation and involves the "last mile" issue (Lott, 2013). The majority of transit services are performed by vehicles or trains traveling along fixed routes according to some scheduled timetables (Vuchic, 2006). Therefore, timetables are indispensable in the evaluation of the transit service quality. In other words, "a public transit performance measure that integrates trip coverage with spatial and temporal coverage could provide a more powerful and practical description of transit quality of service" (Mamun, Lownes, Osleeb, & Bertolaccini, 2013, p.144). However, few studies have assessed transit by combining temporal with the spatial indicators. Transit accessibility is mostly calculated based on methods such as the two-step floating catchment area (2SFCA) method and the gravity method, which overlook transit timetables.

In practice, accessibility is generally measured based on spatial elements. So are transit services. Transit-accessibility improvements can enhance the mobility of people. But the existing transit system evaluation overlooks the temporal components. The transit timetable influences the spatial mobility. Moreover, the transit timetable plays significant roles in enabling efficient public transport, providing alternative transport options, and potentially reducing reliance on the car. Thus, understanding transit accessibility accounting for the timetable can help transit planners improve trip distribution along the time axis and enhance connections between the transit system and urban development. In addition, with better transit accessibility measures, decision-makers and planners could optimize resource allocation across time and across space.

In light of the above, this article improves the traditional 2SFCA and gravity methods by adding temporal variables when calculating bus accessibility. The improved methods are implemented to evaluate the bus accessibility of Xiamen City, China. Based on such empirical studies, we show that if the temporal dimension of accessibility is not taken into account, the decision of transit service provision can be problematic.

The remainder of this paper is organized as follows. The next section (Section 2) reviews relevant literature. Section 3 details the extended accessibility measurement model. Section 4 presents empirical studies based on the models described in Section 3. Section 5 concludes.

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2. Literatures review

2.1. Accessibility without considering transportation modes

Hansen (1959) proposed the concept of accessibility and defined it as the level or opportunity of accessing a given place. Many scholars share the idea that accessibility refers to the convenience from a given location to the other or the ease of accessing some activities (Geurs & Van Wee, 2004; Goodall, 1987; Kwan, Murray, O'Kelly, & Tiefelsdorf, 2003; Shen, 1998a, 1998b).

In the transport field, many scholars have defined or measured accessibility differently (Jenelius, Petersen, & Mattsson, 2006; Kim & Kwan, 2003; Sandlin & Anderson, 2004). The commonly used methods can be summarized into the following: the mathematical programming method, discrete choice model, gravity method, and floating catchment area method.

2.1.1. The mathematical programming method

The mathematical programming methods require a detailed definition of the parameters as well as the decision variables. Also, it needs a large number of assumptions that may limit the practical capability. However, the mathematical programming method is widely used to evaluate the accessibility of transport infrastructure (Aksu & Ozdamar, 2014).

2.1.2. The discrete choice model

Unlike the mathematical programming method, which evaluates accessibility based on a subarea or an aggregation of subareas, the discrete choice model (DCM) is used to analyze the accessibility from the perspective of individual trip makers. DCM is connected to random utility maximization (RUM) which reflects the total gain of trip makers. The accessibility of a facility is formulated as the utility of each trip maker. The utility is functioned by some indicators such as capacity usage ratio, service kilometers, travel distance and length (Gulhan, Ceylan, Özuysal, & Ceylan, 2013; Lotfi & Koohsari, 2009). Although the DCM-based accessibility could reflect the ease to access a facility or service, its formulation has to be based on a great deal of questionnaire data, including the socio-economic characteristics of the trip maker as well as the feature data from the studied facility (or service). Data collection of DCM is thus an extremely complicated and costly process. As a result, it is still rarely used in the accessibility measurement.

2.1.3. The gravity model

The gravity model and the floating catchment area (FCA) method are the two most popular methods for accessibility measurement. The gravity method is used to assess the accessibility with different distance decay functions, which make them easy to use if the decay value (such as distance and cost) and the decay parameter were provided (Rodrigue, Comtois, & Slack, 2009). One limitation of the gravity method is that it only takes the "supply side" but not the "demand side" into account. It can be improved when the demand is considered (e.g., see: Khan, 1992; Kwan, 1998; Luo & Qi, 2009; Wang, 2003; Wang & Luo, 2005; Wang & Tang, 2013).

2.1.4. The floating catchment area (FCA) method

The FCA method provides another way to measure accessibility (Peng, 1997; Shen, 1998a, 1998b; Wang & Minor, 2002). They were once popular among scholars. However, the searching distance threshold is an inherent drawback of this method. That is, the actual supply–demand radius might exceed the predetermined threshold value, which decreases this method's popularity. This gave rise to the two-step FCA method (2SFCA) (Radke & Mu, 2000). Since around 2000, the 2SFCA method has been widely applied (e.g., Luo & Qi, 2009; Luo & Wang, 2003; Mamun et al., 2013; Wang & Luo, 2005). Most notably, the 2SFCA method could be adapted to reflect evaluation objectives or environment for accessibility measures (Bissonnette, Wilson, Bell, & Shah, 2012). It mainly consists of two steps. The first step is to determine the supply-to-demand ratio of each supply point in the catchment area. The second step is to calculate the accessibility of the demand point. However, despite that there have been abundant applications of the 2SFCA and gravity methods, people still rarely simultaneously consider the spatial with temporal dimensions of accessibility.

2.2. Transit accessibility without considering temporal dimension

Transit accessibility has been a key indicator of the coordination between transit services and riders' demand. Generally, transit accessibility is deemed as index values to assess the degree of ease in reaching the transit service or transit facility (Moniruzzaman & Páez, 2012). It is often defined with environmental inputs (Rastogi & Rao, 2003).

Transit accessibility can be measured in two manners: "to transit", when the evaluated subject is the transit facility, such as station, transit route and "by transit", when the evaluated subject is the transit user. The "to transit" measure is concerned with factors influencing the accessibility to the transit service or transit facility. Related factors include: the distance to the transit station, the length and width of the walking connector, the behavior of passenger influenced by the walking time, and the level of service of the transit facility (Delmelle & Casas, 2012; Foth, Manaugh, & El-Geneidy, 2013; Moniruzzaman & Páez, 2012). The "by transit" measure focuses on the convenience degree of accessing the transit service from a specific facility. Meanwhile, the service characteristics of the transit system are treated as a key factor which affects the "by transit" measure. The service characteristics commonly include the travel time (or distance), transfer number, fare cost and headway (Tilahun & Fan, 2014; Tribby & Zandbergen, 2012). An important factor related to the "by transit" measure is the "availability" of transit service among different groups of passengers. The "availability" has become a key indicator of the level of service of the transit system (Karner & Niemeier, 2013; Welch & Mishra, 2013).

However, the existing literature of "by transit" measure is still insufficient in terms of considering the temporal dimension. At the same time, in cases where the temporal factor is considered, the calculation of accessibility becomes very complex. Estimating the time-varying travel demand across the study area is technically difficult. Such calculation requires not only detailed information about social and demographic sectors of the study area but also good knowledge of the timetable and complicated algorithms for calculating travel cost matrixes for all demand points. This largely explains why many researchers ignore the temporal dimension when calculating transit accessibility.

2.3. Transit accessibility with temporal dimension

Most of the current methods for transit accessibility measures take the service capacity as well as the population within a buffer area into account (Welch & Mishra, 2013). Recent research has recognized the significance of incorporating the temporal dimension into transit accessibility measures. Farber, Morang, and Widener (2013) point out that the spatial accessibility of transit service depends on the time of departure. They demonstrate how timetable-dependent transit service could be factored into measures of accessibility after investigating variations in accessibility across the day. Lei, Chen, and Goulias (2012) and Owen and Levinson (2014) finish the similar work. Lei et al. (2012) extend