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Transit accessibility for commuters considering the demand elasticities of distance and transfer

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ABSTRACT

In this paper, a "by transit accessibility (BTA)" measure to evaluate the impacts of travel distance and transfer tolerance on the convenience of commuting by transit on a regional scale is proposed. Considering the spatiotemporal factors for commuting efficiency evaluation, the timetable-dependent passenger carrying capacity of the transit station and the time-varying passenger demand at originating sites have been formulated into the BTA model. Moreover, the proposed BTA measure could reflect the commuting trip demand elasticity, which is caused by travel distance and transfer tolerance. In the meantime, this BTA measure can provide an important basis for transit timetable adjustment in the study area during different time periods. The proposed measure is tested on a small transit network to display its function, and finally, it is applied to an empirical case to draw practical findings.

1. Introduction

Recently, it is necessary for many countries to introduce a series of policies to emphasize the dominant position of public transit. During the last two decades, transit accessibility measures have drawn major concerns of researchers who aimed to enhance the priority of the public transit system. Transit accessibility is also a key indicator which reflects the coordinated relationships between the transit system, land use, and other urban infrastructures (Mamun and Lownes, 2011).

In this paper, the measure of "by transit accessibility (BTA)" for commuters is proposed. Aiming at creating a new BTA measure for evaluating the convenience of going work by transit for commuters, two parameters are added into the existing BTA index. These two parameters are used to reflect the demand elasticity of travel distance and transfer tolerance. Moreover, for examining the BTA in the spatiotemporal dimension, a time-dependent zonal BTA index for the evaluating the transit accessibility level of the traffic analysis zone (TAZ) is designed. With the proposed regional BTA measures, a model for real-time transit timetable adjustment over all the study area is presented correspondingly. The significant difference between the proposed methodology and the existing one is that, it considers the demand elasticity of travel distance and transfer in the BTA measure, and that, time-dependent factors embedded in the proposed BTA measures could be used to evaluate the zonal BTA level for the TAZ, and to adjust the transit timetable at any time if necessary. Finally, the proposed timetable adjustment method ensures the time-varying balance between the supply and the demand of transit services for commuters.

The rest of this paper has been organized as follows. Relevant literatures are reviewed in Section 2. In Section 3, the proposed methodology is demonstrated. Section 4 offers an example to display the detailed implemental processes of the proposed models. An empirical study is given out in Section 5. The conclusions and future research issues are summarized in Section 6.

2. Literature review

2.1. Accessibility

Numerous methods have been used for evaluating the accessibility of infrastructure and public services (Gulliford et al., 2001). Although there has not been a unified definition for "accessibility" in the existing literature, most researchers agree that accessibility refers to the relative ease to access a location (or an infrastructure), to obtain a required service, or to participate in an activity. Following Khan (1992), Luo and Qi (2009), Luo and Wang (2003), Wang and Luo (2005) and Wang and Tang (2013), the definitions of accessibility were categorized into four types versus dichotomous dimensions (the potential and revealed versus the spatial and aspatial), which are the potential spatial (geographic access), the potential aspatial (social access), the revealed spatial (geographic access) and the revealed aspatial (social access) accessibility. Revealed spatial accessibility focuses on the actual utilization of facilities or services, while potential spatial accessibility evaluates the possible aggregate utilization or possible availability of facilities or services in a

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subject region. On the other hand, the revealed aspatial accessibility cares about the non-spatial related welfare, profit or bonus which could be accessed or obtained by the specific group of people, e.g., the pension that the aged people could get. Conversely, the potential aspatial accessibility refers to the possible immaterial profits could be obtained in the given region or for the specific human group.

Table 1 shows the representative measures of accessibility according to the categories explained above.

It is not necessary to introduce all methods for accessibility measurement in detail. However, the gravity method, which is the most representative method in the potential spatial dimension, and the basis of general accessibility measurement, should be emphasized when reviewing the accessibility literature.

The gravity method for accessibility measurement is commonly based on Hansen's (1959) potential equation:

$$A_i = \sum_j a_j f(c_{ij}) \quad (1)$$

where, A_i refers to the accessibility of zone i. a_j denotes the attractiveness of zone j, and is reflected by the resource at zone j, such as employment positions. $f(c_{ij})$ is the decay function of the generalized cost c_{ij} (e.g. distance, travel time, monetary cost, etc.) between zone i and j, and commonly with a family of forms in the scientific literature (Mamun et al., 2013):

Power: $f(c_{ij}) = c_{ij}^{-\gamma}$;

Exponential: $f(c_{ij}) = \exp(c_{ij}^{-\gamma})$, and

Combined: $f(c_{ij}) = k \cdot c_{ij}^{-\gamma} \cdot \exp(c_{ij}^{-\gamma})$.where, k and γ are user-defined parameters.

The limitation of Eq. (1) is that it takes only the "supply side", without accounting for the "demand side" for accessibility measures. Several researchers such as Khan (1992), Kwan (1998), Luo and Qi (2009), Luo and Wang (2003), Wang and Luo (2005) and Wang and Tang (2013) improved the gravity method by adding to the effect of the "demand". Particularly worth mentioning is the primary models of the floating catchment area (FCA) method used by Peng (1997), Shen (1998) and Wang and Minor (2002). Most of the previous accessibility measures of the FCA were based on pre-defined and arbitrary administrative boundaries and had different values in neighbouring areas. The FCA method overcomes these drawbacks using a dynamic buffering technique to measure the accessibility of the buffered zones (Peng, 1997).

Table 1
Summarization of representative publishes involved in accessibility measures.

	Spatial	Aspatial
Revealed	● Statistical analysis: Páez et al. (2012); ● Space–time measures: Hägerstrand (1970), Kwan (1998), Tribby and Zandbergen (2012), Welch and Mishra (2013), Fransen et al. (2015), Tong et al. (2015); ● Mathematical formulation based approach: Tuzun Aksu and Ozdamar (2014), Wang et al. (2015), Yang et al. (2015).	● RP/SP survey based statistical analysis: Ben-Akiva and Lerman (1985), Cherchi and Ortúzar (2002), Geurs et al. (2010), Leitham et al. (2000), Marcucci and Gatta (2011) ● Sociological approach: Bocarejo and Oviedo (2012)
Potential	● Gravity-based method: Hägerstrand (1970), Hansen (1959), Wang and Tang (2013); ● Trip destination based methods: Mavoa et al. (2012), Shi and Ying (2008); ● Trip origin based methods:Curl et al. (2015), Luo and Wang (2003); ● Origin–destination based measures Curl et al. (2015), Handy and Niemeier (1997).	● Activity based analysis: Ben--Akiva and Lerman (1985), Cascetta et al. (2013), Dong et al. (2006); ● Social and economic analysis: Burchardt (1999), Witter (2010), Lucas et al. (2001).

The FCA method is undoubtedly representative and practical, however, the searching distance threshold setting causes an inherent drawback. That is, the actual supply-demand distance might exceed the threshold value. For this sake, Radke and Mu (2000) proposed a two-step floating catchment area method (2SFCA), in which the limitation of the FCA was effectively overcome. Later, the 2SFCA method has attracted widespread attention among researchers, such as Luo and Qi (2009), Luo and Wang (2003), Mamun et al. (2013) and Wang and Luo (2005). The 2SFCA method was advanced and transformed according to changes of the environmental inputs. Moreover, it has been widely used and embedded in many GIS software programs, such as ESRI ArcGIS and CALIPER TransCAD.

Some scholars provided different approaches for measuring accessibility in the framework of a survey-statistics-analysis. The evaluated accessibility was more or less in the aspatial dimension. Occasionally, the utility theory, which displays the relationship between accessibility and social-economical characteristics (e.g., social class, job type, income level, sex, age, etc.), was applied in the literature related to accessibility measures (Cascetta et al., 2013; Cherchi and Ortúzar, 2002; Marrocu and Paci, 2013). A wider generalization of the measuring methods for the accessibility was presented by Wang and Tang (2013), Geurs et al. (2015) and Neutens (2015).

2.2. Transit accessibility measures

2.2.1. General research on transit accessibility

Measures of transit accessibility have been widely proposed in transport literature and could be divided into "to transit accessibility (TTA)" and "by transit accessibility (BTA)" (Moniruzzaman and Páez, 2012). TTA measures were derived from Hansen's (1959) gravity model presented in Eq. (1), which is used to evaluate the ease of getting to a transit station (Lin et al., 2014). With those measures, the service levels of the transit facilities were evaluated based on physical factors, such as walking time (distance), on-board time (or distance), obstacles or built environmental factors. In contrast, BTA measures concern the convenience of finishing a specific activity (e.g., shopping, entertainment, commuting) by transit. Geurs and van Wee (2004) stated the difference between TTA and BTA. They defined TTA as "access" and BTA as "locational accessibility (LA)" in their work. There are mainly two differences between the TTA and the BTA measures: (a) their evaluated objects are different — TTA measures generally examine the physical feature of transit facilities (such as the location, size, coverage, etc.), but BTA measures are commonly used for evaluating the convenience of taking the transit vehicle to travel or finish an activity for a specific human group; (b) they adopt different types of evaluating indexes — TTA is calculated based on built environment factors (Moniruzzaman and Páez, 2012), such as the walking distance (or time) to the nearest transit station, the number of intersections which should be passed through to get to the transit station, etc.; on the other hand, the evaluating index of BTA always considers the time or cost spent on the round trip by transit to accomplish the specific activity, or to reach the designated place to obtain the necessary service (Graham et al., 2015). As a matter of fact, the terms TTA and BTA are often used interchangeably as "transit accessibility" or "the accessibility of a transit system" in various circumstances. However, they are not the same, but were not clearly distinguished in many empirical analyses, such as Delmelle and Casas (2012), Foth et al. (2013), etc.

2.2.2. TTA measures

Measures of TTA are commonly combined with built environmental factors as well as social and socioeconomic factors of transit facility users. Murray et al. (1998) and Vandenbulcke et al. (2009) respectively studied the time to reach a transit station from a given location.