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Dynamic transit accessibility and transit gap causality analysis

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ABSTRACT

Public Transit Accessibility (PTA) analysis helps transit agencies and planners identify areas in need of transit service improvements and prioritize transit investments. To evaluate the accessibility of existing transit services and identify access gaps, it is critical to accurately estimate travel times between transit stops, which change throughout the day due to transit schedule variations. Commonly used methods in PTA ignore such temporal fluctuation. Moreover, these methods are unable to elucidate the causes of poor PTA. To address these issues, we first implemented an algorithm to effectively compute travel times at multiple departure times throughout the day in order to enable spatiotemporal PTA analysis. A series of indicators that are intuitive to interpret were developed to determine the varying causes of poor PTA and identify areas with immediate needs for improvements. We showcase the analytical framework using a transit network in the State of Utah operated by the Utah Transit Authority. The analysis is based solely on publicly-available open datasets, which makes it generally adaptable to other transit networks. Results can assist transit agencies with identifying areas in need of service improvement and prioritizing future investments.

1. Introduction

Public Transit Accessibility (PTA), a key indicator of transit service quality, plays an important role in users' mode choices (Moniruzzaman and Paez, 2012). PTA directly affects transit ridership and, consequently, influences active transportation mode use, public health, and other characteristics of the urban environment (Farber and Páez, 2011; Litman, 2003). The social functions of urbanized areas are highly dependent on and supported by convenient access to public transportation systems, particularly for the less privileged populations with limited auto ownership. Poor PTA can cause social exclusion for disadvantaged populations (SEU, 2003). An effective understanding and evaluation of PTA is therefore necessary to help transit agencies identify areas in most need of improvement and guide investment decisions and land use development (Coffel, 2012).

PTA refers to the ability to reach goods, services and activities via public transit. By definition, PTA has two main components: activity and transportation (Burns, 1980; Koenig, 1980). The activity component describes the attractiveness of destinations and is usually measured by population density, job density, and/or facilities available at destinations. The transportation component measures the ability to reach destinations and is influenced by spatiotemporal coverage of services, travel cost (e.g. travel time), and the comfort of service as experienced by users. It is difficult for any single PTA analysis to consider all factors that potentially affect the ease of travel. Ignoring critical factors, however, will result in the over- or underestimation of PTA. Travel time is one of the critical factors reflecting the feasibility of transit use. Overlooking travel time tends to overestimate the portion of population with transit access (Polzin et al., 2002). As a result, *travel time dependent* PTA measures, such as cumulative and gravity-based accessibility measures, have been widely used in recent years (El-Geneidy et al., 2016; Foth et al., 2013; Lei and Church, 2010; O'Sullivan et al., 2000; Widener et al., 2015).

Most relevant studies (Benenson et al., 2010; Krizek et al., 2009; Mavoa et al., 2012; Owen and Levinson, 2012) on transit performance have focused on transit travel time for a specific time-of-day (e.g. peak hour). This leads to an overly optimistic evaluation, as the optimum transit services (e.g. highest frequency and largest geographic coverage) are usually provided in peak periods. PTA could be measured for several times-of-day to unveil the temporal fluctuation in transit services (Farber and Fu, 2016; Farber et al., 2016), but analyzing and interpreting the results can be challenging due to the complexity of the added temporal dimension. Past studies in PTA have concentrated on identifying areas with poor accessibility (Benenson et al., 2010; Krizek et al., 2009; Mavoa et al., 2012; Owen and Levinson, 2012; Owen and Levinson, 2015) or mismatches between transit services (supply) and the Need for Public Transit Services (NPTS) (demand) (Farber et al., 2016; Fransen et al., 2015). However, little has been done with regard to identifying the causes of poor PTA in order to inform transit investment decisions. There are two main causes leading to poor PTA:

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inefficient transit services (e.g. inadequate spatial/temporal coverage), and geographical disadvantage (e.g. long distances between the study area of interest and desired destinations). Poor PTA due to inadequate transit services can be remedied by a transit agency via transit investment. However, a remote area with good transit services may still experience poor PTA. There is not much a transit agency can do in this latter case other than play one part of much broader land development efforts. There is therefore a critical need for PTA analysis to reflect both causes and distinguish between the two to avoid making poor investments in the wrong sets of solutions. To address this issue the transit gap causality analysis is required. Transit gap causality analysis measures how large the gap between PTA and NPTS is, and whether the gap is fixable by transit agencies. Dynamic PTA analysis, considering spatiotemporal dimensions with finer resolution, offers greater insights into the various causes of poor accessibility. This study complements the existing literature by developing effective indicators that provide a fuller exploration of PTA variation and transit gap causes in order to guide future transit investments.

The contribution of this paper is fourfold. First, this study captures the temporal fluctuations of PTA by measuring travel time at multiple departure times throughout the day. The time resolution is selected in such a way to reflect all possible waiting times and schedule variations. Weighted Average Travel Time (WATT) is utilized as a gravity-based PTA measure to showcase the spatiotemporal PTA analysis in high resolution at the transit stop-level. Second, we introduce a unified ratio that can fully capture the spatiotemporal variability and quality of transit services throughout the day and is robust to parameter or scale selection. Third, the concept of Public Transit Accessibility Gap (PTAG) is developed to identify regions with transit mismatches by comparing WATT to the Need for Public Transit Services (NPTS). Finally, PTAG and the unified ratio are jointly used to identify the causes of transit mismatches and poor PTA. The results rank areas based on their need for transit improvement to further inform transit investment decisions.

Previous studies on PTA are discussed at length in Section 2. We demonstrate that these previous studies lacked the ability to accurately analyze the temporal aspect of PTA and fully reveal the causes of accessibility gaps due to the lack of computational methods that enable the spatiotemporal analytics to uncover transit supply and demand interaction. Then, the analytical framework for measuring PTA and identifying accessibility gaps is presented via the development of indicators that reflect transit gap causes while ensuring effective geographic standardization. The analytical framework is applied to the Utah Transit Authority (UTA) transit network in the State of Utah. The paper concludes with a discussion of results and implications of study findings.

2. Literature review

Accessibility analysis links land-use with transportation (Horner, 2004). The land-use part of the analysis seeks to quantify the activity component of accessibility based on desired urban/rural services that are available. The transportation part of the analysis characterizes the ease of travel, and is usually described with a cost function. Several measures have been developed to date for PTA. The cost function is an important factor that distinguishes these measures (Lei and Church, 2010). Some of them, such as local index of accessibility (Rood and Sprowls, 1998), percentage of service coverage (Kittelson et al., 2003), and transit level-of-service (Ryus et al., 2000; Tumlin et al., 2005), do not consider travel time and emphasize the assessment of spatial coverage, service frequency, vehicle capacity, and comfort of service. Polzin et al. (2002) proposed a “time-of-day” PTA evaluation, and discussed the fact that ignoring travel time could induce bias in PTA results. Gradually, PTA measures that consider travel time gained popularity. Among them, cumulative and gravity-based measures are the most widely used. The former gauges the number of opportunities reachable within a fixed cost threshold (e.g. travel time window) (Bhat et al., 2000; El-Geneidy et al., 2016; Geurs and Ritsema van Eck, 2001; Vickerman, 1974; Wachs and Kumagai, 1973). Thus, the selection of the threshold for cumulative measures greatly influences the accessibility results. The gravity-based accessibility measures count the number of opportunities reachable, normalized by a weighting cost function (Bhat et al., 2000, Bhat et al., 2006, Geurs and Ritsema van Eck, Hansen, 1959). It addresses the single-threshold limitation of the cumulative methods, yet its result is dependent on the weighting function specification. Our discussion of PTA will primarily be focused on these two measures for the rest of paper.

Prior to mid-2000s, the calculation of public transit travel time was challenging due to the unavailability or inconsistent format of transit schedule data. Simplified forms of public transit networks were used for calculating travel times (Beimborn et al., 2003; Kawabata and Shen, 2006; Kawabata, 2009; Polzin et al., 2002; Wu and Hine, 2003). Travel time was estimated based on service availability at a specific time-of-day, distance to and from transit stops, or a combination of both. Service frequency and reliability were used to measure the waiting time. In-vehicle travel time was estimated based on survey data or incomplete transit operation times. Yet, since travel time was estimated rather than measured with these approaches, there were estimation errors and losses of fidelity (Owen and Levinson, 2015). The recent advent in automatic data collection methods and uniformity of available data format has enabled and facilitated the measurement of travel time in public transit (Ma and Wang, 2014).

The creation of General Transit Feed Specification (GTFS) sparked a stream of research and applications on travel time dependent PTA. GTFS was developed in 2005 by Google and TriMet for transit agencies to publish their schedules, trips, routes, and stops data in an open-source format that is usable for Google Transit Web-based Trip Planner (Google, Inc., 2016). GTFS provides a detailed public transit schedule in plain text format that greatly facilitates travel time measurement. Most studies in PTA have focused on using GTFS data to measure travel times between origin-destination (O-D) pairs for specific times-of-day (Benenson et al., 2010; Krizek et al., 2009; Mavoa et al., 2012; Owen and Levinson, 2012). Yet ignoring the temporal fluctuation due to schedule variation leads to biased results (Farber and Fu, 2016). For example, stops that are served by bus routes operating only during peak periods might have an overestimated level of accessibility.

To address such limitations, Mavoa et al. (2012) jointly considered a PTA index and transit frequency measure. They argued that transit frequency measures represent the transit level of service. However, transit frequency is not necessarily constant throughout the day and the PTA index is measured based on specific time-of-day travel times. The value of the PTA index can vary significantly, depending on the specific departure time that the index is measured. For example, when measured at the moment where a bus is approaching the transit stop, the PTA index is close to its maximum value. Similarly, when measured at the time point when the bus has just departed from a stop, the value is approximate to its minimum. Thus, a single departure time method might lead to over- or underestimating PTA for different stops. Studies that use the minimum travel time throughout the day to measure PTA also suffer from similar issues of accessibility overestimation (Lei and Church, 2010; Owen and Levinson, 2012).

Fan et al. (2010) measured PTA for each hour-of-the-day, and averaged the values for analysis. Hourly measures can still be coarse in terms of resolution, as PTA can vary greatly from minute to minute (e.g., when bus arrives and waiting time is minimum versus when the bus leaves and waiting time is maximum). Fransen et al. (2015) and Owen and Levinson (2015) measured the PTA for each minute of specific peak periods of the day. They did not consider the service variability for other times-of-day in their calculation. Farber et al. (2016) addressed all the aforementioned issues by measuring travel times between all O-D pairs for each minute-of-the-day using GTFS. They developed a travel time ratio to represent its temporal fluctuation. The ratio was calculated based on the local average travel time (e.g. within 1 h of the selected trip) and global average travel time (all times-of-day). The proposed