Travel Behaviour and Society 4 (2016) 40–48

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Space–time mismatch between transit service and observed travel patterns in the Wasatch Front, Utah: A social equity perspective

Steven Farber [a,*], Benjamin Ritter [b], Liwei Fu [b]

[a] Department of Human Geography, University of Toronto Scarborough, Canada
[b] Department of Geography, University of Utah, United States

ARTICLE INFO

Article history:
Received 29 May 2015
Received in revised form 5 January 2016
Accepted 15 January 2016
Available online 10 February 2016

Keywords:
Public transit
Social equity
Travel time cubes
Transit mismatch
Temporal mismatch

ABSTRACT

In the absence of other alternatives, people who rely on public transportation to conduct their daily activities have travel patterns that differ from discretionary transit users, especially those who choose to use transit for work trips. At the same time, in many regions around the world, public transportation is primarily designed to accommodate peak-hour travel demands in order to reduce congestion and its impacts. It is theorized that this results in a mismatch between the demand and supply of public transportation among populations at risk of social exclusion. In this research, we characterize and compare the spatiotemporal patterns of travel demand and transit supply. Our analysis consists of a comparison between observed travel patterns and a new temporal measure of transit supply based on travel times. We measure travel demand with the observed trip-making characteristics (i.e. origin, destination, time-of-day) of the respondents to two transportation surveys conducted in Utah. Transit supply is characterized using a transit travel time cube, a three-dimensional array of origin–destination transit travel times computed for all origins, destinations and times of day. Mismatch is examined by descriptive and multivariate comparisons of observed trips and computed levels of transit provision. Our results confirm theory: more marginalized groups demand travel between locations at times of the day that are poorly served by transit. However, when controlling for all variables simultaneously in a multivariate regression, few socioeconomic factors remain significant, indicating the overall importance of employment status, making work trips, and traveling during peak times, in explaining mismatch.

1. Introduction

In an urban context, a just society includes equitable access to public transportation (Golub and Martens, 2014; Martens, 2009; Martens et al., 2012). One way to achieve equity, vertical equity in particular, is to provide transit service to those people who need it most, where need is most often assessed using considerations of socioeconomic status (Bullard et al., 2004; Litman, 2002; Litman and Brenman, 2011). Of course, transportation planning incorporates a complex set of technical and political processes, and social equity is but one consideration in a multi-objective agenda that has often favoured more readily measurable, predictable, and pecuniarily expressible outcomes of transport models like travel-time savings, congestion and throughput (Deka, 2004). As according to the adage, “we build what we measure”, transport planning has focussed on achieving increased mobility rather than explicitly increasing accessibility or the equitable distribution of the accessibility benefit between modes (Benenson et al., 2011; Golub and Martens, 2014; Kaplan et al., 2014; Martens et al., 2012), across space (Martens et al., 2012; Welch and Mishra, 2013), and between population groups (Delbosc and Currie, 2011; Welch, 2013). As a result, some public transportation systems fall short of meeting the needs of those who depend on transit to participate in daily activities, putting people at risk of transport related social exclusion (Church et al., 2000; Hine, 2003; Kenyon, 2003, 2006; Lucas, 2012; Lucas et al., 2001; Páez et al., 2009; Preston and Rajé, 2007; Raje, 2004).

Most studies of social equity and public transit accessibility entail an aggregate comparison between transit need and transit supply. In these studies, transit need is often established over space as a measure of socioeconomic status in neighborhood units while transit supply is typically measured at the neighborhood level as the ease of reaching transit facilities (Moniruzzaman and Páez, 2012; Murray et al., 1998; O’Neill et al., 1992), reaching transit facilities weighted by level of service (LOS) (Al Mamun and Lownes, 2011; Currie, 2010; Drew and Rowe, 2010; Henk and Hubbard, 1996; Kittelson et al., 2003; Rood and Sprowls, 1998;

---

* Corresponding author.
E-mail address: steven.farber@utoronto.ca (S. Farber).

http://dx.doi.org/10.1016/j.tbs.2016.01.001
2214-367X/

Ryus et al., 2000), or reaching actual destinations with transit (Farber et al., 2014b; Foth et al., 2013; Lei and Church, 2010; O'Sullivan et al., 2000). One drawback of these studies is that transit need is poorly characterized by zonal population characteristics since different population groups demand travel to different types of destinations at different times of the day. Similarly, accessibility is poorly characterized by generalized measures of station access or destination access since travel times to destinations can be highly variable depending on time of day variations in schedules. Ignoring the temporal fluctuations in activity patterns and travel times makes it difficult to know whether the transit services that are "provided" are actually what is "needed" by different population groups at different times of day. In an effort to address temporal variations in transit access, Polzin et al. (2002) conduct a time-of-day mismatch study of aggregate travel demand by computing the percentage of origin–destination flows in a region that could be feasibly met by the current provision of public transit. They consider feasibility as a threshold of acceptable wait time at the origin, and frequency of service at the destination. Although their approach measures temporal mismatch in terms of total travel demand in a region, they make no attempt to further explore the distributional aspects of this mismatch between social groups. In fact, few equity studies have considered the unique spatiotemporal signatures of transit supply and travel demand for different population groups, yet, doing so greatly increases the validity of the analysis and could lead to policies that more effectively increase equity in transit provision (Farber et al., 2014b; Owen and Levinson, 2014; Ritter, 2014). The purpose of this study is to investigate how well public transit matches the spatiotemporal travel patterns for different population groups in the Wasatch Front, Utah. To accomplish this task, we: (a) characterize travel patterns using observed trips from household travel and onboard passenger survey data, (b) put forward a measure of spatiotemporal transit service based on origin-to-destination travel times, and (c) determine whether socioeconomic status is associated with travel demands that are spatiotemporally mismatched with transit supply in the region.

The rest of the paper is organized as follows. In the next section we describe the travel time cube and how we use it to create a temporally dynamic measure of transit service. We also put forward our empirical analysis plan, and provide a description of our study area and datasets. In the third section we present and discuss the results of our descriptive and multivariate analysis of transit mismatch. We conclude the paper in Section 4 with a brief summary of results, a discussion about policy implications, and we propose several avenues for future research.

2. Methods

2.1. The public transit travel time cube

We propose a new data object, the public transit travel time cube, which can be used to establish spatiotemporal signatures of transit service in a region. The travel time cube is a three dimensional array $T = [t_{i,j,m}]$ where $t_{i,j,m}$ is the shortest public transit travel time from location i to location j at time m. In this case, i and j index population weighted block group centroids in the region, and m[1] is used to index the minutes in a day. So, for example, $t_{4,10,480}$ is the travel time from block group 4, to block group 10 with a departure time of 8 am (the 480th minute in the day).

In practice, the cube is computed in a GIS making use of a pedestrian network file (to model ingress and egress times) and a transit network and schedule stored as a general transit feed specification (GTFS) package[2]. An *Esri ArcMap* plugin named *Add GTFS to Network Analyst* is used to create a routable multi-modal *Network Dataset* and custom travel time evaluators which enable the use of many Esri *ArcMap Network Analyst* functions. We use the *Esri OD Cost Matrix* tool to compute shortest path travel times from centroid to centroid in the region, and custom Python scripts are employed to process the computational workflow of iterating cost matrix computations over every start-time minute of the day. Similar data objects built with tools from Esri and other developers have been used elsewhere in the literature (Farber et al., 2014b; Lei et al., 2012; Owen and Levinson, 2014).

For our case study, we used the Utah Transit Authority (UTA) GTFS data to create travel time cubes for a typical weekday, Saturday and Sunday. The particular GTFS package used for this research consisted of service dates ranging from August 19th to December 7th, 2013 and included 122 transit routes, 6202 transit stops, and 7472 transit trips. Our study area contains 1326 block groups, resulting in $1326 \times 1326 \times 1440 \approx 2.5$ billion uniquely computed shortest path travel times per cube. Given the volume of computations and the ensuing data storage demands, we employed distributed processing in a windows ArcGIS environment to speed up the runtime of our computations. The study area, seen in Fig. 1, was trimmed by excluding some peripheral block groups that either had no transit service, or only very specialized services for accessing ski resorts and distant urban settlements. Also, the use of population weighted centroids ameliorates the effects of varying block group sizes, especially at the periphery of the study area.

2.2. Spatiotemporal measures of transit service

The individual trip records from the two surveys (see Section 2.4) were combined with the travel time cube in order to construct service measures for each observed trip. First, the origin and destination (OD) of each recorded trip was associated with an OD pair in the travel time cube based on a point-in-polygon assignment. Next, an average transit travel time for an hour-long period straddling the observed trip departure time was extracted from the travel time cube. The average travel time within a one-hour period is assumed to be representative of the transit service provided at the time of each recorded trip; this moving average is less sensitive to errors in trip time recording that may significantly impact the travel time extracted from the cube. The selection of a one hour buffer (30 min before and after the observed trip) smoothes the travel time quite substantially (as seen in Fig. 2). A sensitivity analysis found that a 15 min buffer on each side obtained nearly identical travel time results (RMSE = 1.13 min) and a 5 min buffer on each side obtained a RMSE of 4.90 min. The degree of "smoothing" error for a given buffer is associated with the frequency of service and how rapidly frequencies of service change over the course of the day. While the size of the smoothing window we choose may impact the results slightly, we are more comfortable with a higher degree of smoothing than the potential for gross over or under representation of travel times associated with a buffer too small. A full sensitivity analysis of the use of different window thresholds is recommended for future research.

Next, we compare the local average travel time (i.e. within 1 h) of the observed trip to the global average (i.e. across the entire day)

---

[1] The travel time recorded is the shortest path found in the multimodal network at a particular time of departure. It includes ingress, egress, waiting and transfer time associated with the fastest trip. If the shortest travel time is found by walking only, then the walking only trip time is recorded in the cube.

[2] Because of this, our transit travel time cube is based on scheduled travel times, and are not sensitive to real world service disruptions or congestion. Future work investigating real-time or historical vehicle location data is one possible extension of the travel time cube research thread.