



Measuring the impacts of new public transit services on space-time accessibility: An analysis of transit system redesign and new bus rapid transit in Columbus, Ohio, USA

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A B S T R A C T

The absence of effective access to opportunities and services is a key contributor to poor socio-economic and health outcomes in underserved neighborhoods in many cities. The city of Columbus, Ohio, USA is attempting to enhance residents' accessibility by providing new public transit services. These new services include a major Transit System Redesign (TSR) of the conventional bus network and the introduction of a new bus rapid transit, named CMAX. Using a high-resolution space-time accessibility measure, we analyze whether these new public transit services will change residents' accessibility to job and healthcare in an underserved neighborhood of Columbus. Also, we assess whether enhancing the CMAX service to reduce delays (e.g., reserved lane, off-board payment system) will improve accessibility. The high-resolution space-time accessibility measure in this study uses published public transit schedules via the General Transit Feed Specification (GTFS). We use multiple departure times during a day to account for the temporal fluctuations of accessibility based on the transit schedule changes. We also consider the operating hours of job opportunities and healthcare services. Results suggest that the TSR yields ambiguous benefits for accessibility to jobs and healthcare. However, the new CMAX service and its potential upgrades lead to a substantial increase in both job and healthcare accessibility. The results can be used for city officials and urban planners to evaluate the effectiveness of public transit innovations in improving accessibility.

1. Introduction

Accessibility provides opportunities for citizens to participate in vital activities and to reach necessary services (Handy & Niemeier, 1997; Hansen, 1959). Low levels of accessibility and accessibility inequalities can exacerbate socio-economic and health disadvantages. For example, the Linden neighborhood in Columbus, Ohio, USA faces many challenges because of the limited access to crucial resources such as job and health care services. The median household income of Linden is less than half of the broader city, and parts of the neighborhood's unemployment rate are over 15% (Bliss, 2016; Columbus, 2016a). Also, South Linden's infant mortality rate is close to 26 (per 1000 live birth) which is about four times higher than the national average (Bliss, 2016; CelebrateOne, 2015).

To improve accessibility to opportunities, the city of Columbus is providing new public transportation services in collaboration with Central Ohio Transit Authority (COTA), the main public transit agency in Columbus. The city's public transit innovation consists of two stages.

The first stage is a major Transit System Redesign (TSR) which revamps the existing COTA bus system. TSR simplifies complex routes and offers more frequent and consistent service, with the intent of providing a simpler, more reliable system with better access to destinations (Central Ohio Transit Authority, 2017a). The second phase is constructing a new bus rapid transit (BRT) service called CMAX through the Linden neighborhood. CMAX is designed to enhance Linden residents' accessibility to job and healthcare by connecting major employment centers and hospitals with relatively short headway (Columbus, 2016a, 2016b, 2016c; Bliss, 2016; Central Ohio Transit Authority, 2017b).

In this study, we investigate whether the TSR and new BRT services will improve Linden residents' access to job and healthcare. Furthermore, we simulate changes in the CMAX operating speed to assess whether potential upgrades that minimize delays (e.g., off-board payment system, reserved bus lane) will further improve accessibility. We use a high-resolution space-time accessibility measures based on published and proposed transit schedules available via the General Transit Feed Specification (GTFS) and detailed street network data. The

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space-time accessibility measures capture multimodal accessibility, namely, walking to access and egress the transit system. We also consider the time of day and day of the week since transit travel times fluctuate due to the changes in service provision parameters such as headways (Boisjoly & El-Geneidy, 2016; Farber & Fu, 2017; Farber, Morang, & Widener, 2014; Owen & Levinson, 2014; Widener, 2017). We consider four departure times representing peak/off-peak hours to capture dynamics in accessibility due to the transit schedule changes. We also account for temporal availability at the destinations such as working hours and healthcare service hours. Results suggest that the TSR by itself yields ambiguous benefits for accessibility to jobs and healthcare in this neighborhood. However, the new CMAX service and its potential upgrades lead to a substantial increase in both job and healthcare accessibility.

The next section of this paper provides background about space-time accessibility measures for public transit. Section 3 provides detail on the new public transit services implemented in Columbus, Ohio and describes Linden, an underserved neighborhood in the city. Section 4 describes data used in this analysis and Section 5 describes the methodology. Section 6 describes the study design and scenario analysis. Section 7 provides the results, and Section 8 concludes with some comments on the study's contributions, limitations, and future steps.

2. Background

Recently, there has been growing interest from transportation researchers and practitioners in understanding accessibility by public transit within urban areas. Among the four major accessibility measurement approaches, opportunity-based, gravity-type, utility-based and space-time measures (Benenson, Ben-Elia, Rofé, & Geyzersky, 2016; Geurs & van Wee, 2004; Kwan, 1998; Liu & Zhu, 2004), space-time measures based on the time geographic framework are increasingly popular since they capture heterogeneous social constraints (e.g., gender, socioeconomic status) on human activities in space and time (Hägerstrand, 1970; Kwan, 1998, 1999; Lenntorp, 1978; Miller, 2005, 2017; Neutens, Witlox, & Demaeyer, 2007), as well as integrate spatial and temporal constraints imposed by public transport as well as the location and timing of opportunities (Djurhuus, Sten Hansen, Aadahl, & Glümer, 2016; Tasic, Zhou, & Zlatkovic, 2014). Also, space-time accessibility measures allow the analyst to simulate the changes in public transit performance using speed, time budgets, travel origins/destinations, and activity locations as parameters. Finally, data required to measure space-time accessibility at a high temporal and spatial resolution are increasingly available; these include detailed road networks, transit routes, and schedules, including the widely used GTFS data format for publishing transit schedules to services such as Google Transit (Salonen & Toivonen, 2013).

O'Sullivan, Morrison, and Shearer (2000) is the first attempt to investigate transit-based space-time accessibility using the time geographic framework. The researchers reconcile two accessibility measures: opportunity-based measures and space-time measures. They use isochrones delineating accessible areas given specified time budgets to combine those two measures using a geographic information system (GIS). In computing accessibility, O'Sullivan et al. (2000) account for various temporal elements of a trip, including walking time, waiting time, and in-vehicle travel time. Horner and Mefford (2005) conduct a similar isochrone-based study evaluating the spatial and social variation in job accessibility by bus service in Austin, Texas, USA. However, due to the unavailability of detailed transit schedule and the limitation of the conventional GIS network model, both of these studies above simplified the travel environment. For instance, they assume that bus speeds are constant along the whole routes, ignoring the differences between downtown and suburban roads. Also, they assume every traveler waits the same amount of time (one-half of the headway) at the initial bus stop. These simplifying assumptions result in less accurate travel time calculations and consequently misrepresent accessibility

(Djurhuus et al., 2016; O'Sullivan et al., 2000; Salonen & Toivonen, 2013).

With the advent of GTFS data and techniques for combining the data with multimodal networks via GIS, more recent studies of space-time accessibility using transit account more fully for temporal elements of the transit-based trip, allowing more realistic calculations of transit-based accessibility (Benenson et al., 2016; Djurhuus et al., 2016; Farber et al., 2014; Ma & Jan-Knaap, 2014; Salonen & Toivonen, 2013; Tasic et al., 2014; Widener, 2017; Widener, Farber, Neutens, & Horner, 2015). A good example is the analysis of accessibility to healthy food options in Cincinnati, Ohio, USA by Widener et al. (2015). The authors construct a multimodal network capturing bus and walking using GTFS and sidewalk data. They apply a single departure time, 5 p.m. on Monday, to calculate and compare accessibility with different origins. However, using one departure time cannot reveal fluctuations in accessibility subject to transit schedule changes.

To fill this gap, researchers have developed dynamic accessibility analysis using multiple departure times (Boisjoly & El-Geneidy, 2016; Farber & Fu, 2017; Farber et al., 2014; Owen & Levinson, 2014; Widener, 2017). While these studies capture the temporal dynamics in accessibility in transit schedules, they fail to consider the temporal variations in the travel destinations such as working and operating hours. Assuming the opportunities such as jobs and healthcare are available at all times can lead to a serious over-estimation of accessibility (Boisjoly & El-Geneidy, 2016). To address this limitation, Legrain, Buliung, and El-Geneidy (2015) combines variations in both job availability and transit schedule for their accessibility computation. Further, researchers utilize a big spatio-temporal database including opening/closing hours as well as locations of various resources to model and simulate urban accessibility (Fosset et al., 2016).

3. New public transit services in Columbus

This section describes the new public transit services being deployed in Columbus, Ohio, USA. The first is a Transit System Redesign (TSR) that simplifies the existing bus network and offers more frequent and consistent service along the new routes. The TSR is a region-wide change. In contrast, a new bus rapid transit (BRT) service called CMAX explicitly targets northeast Columbus, in particular, the Linden neighborhood that is underserved by job opportunities and healthcare (Bliss, 2016). Fig. 1 provides a map of the study area, the Linden neighborhood, and the proposed CMAX route.

3.1. Transit System Redesign (TSR)

TSR is the first major rerouting of COTA bus network since its inception in 1974. During the past 40 years, the urban form has changed, and new employment clusters have emerged in suburban areas. However, COTA had maintained its routes the same as designed by the former transit agency, Columbus Transit Company (CTC), when jobs were centralized in downtown. As a result, the old bus network increasingly failed to satisfy customers' needs to access their destinations.

To meet new ridership needs, COTA developed a new bus network and implemented this system overnight on May 1, 2017. Fig. 2 shows the maps of former (Fig. 2a) and TSR (Fig. 2b) bus systems. The TSR bus network is more straightforward compared to the traditional bus network. TSR has three major advantages compared to the conventional bus operation. First, TSR saves travel time by simplifying bus routes and making services more direct. Second, TSR provides more frequent service (maximum 15 min headway) by reducing the number of bus lines (from 74 to 48) and allocating 70% of service to high-ridership routes. The total sum of bus routes' lengths decreases from 2297.44 km to 1640.81 km, accordingly. Third, TSR operates with the consistent schedule regardless of weekdays or weekends. COTA expects TSR will connect customers to more jobs and other opportunities (Central Ohio Transit Authority, 2017a).

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